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HEALTHY CATCHMENTS HEALTHY HARBOUR

Sydney Harbour Water Quality Improvement Plan

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This project was only possible because of the collaborative funding partnerships that Greater Sydney Local Land Services (GS LLS) established with the NSW Office of Environment and Heritage (OEH); Sydney Water; NSW Roads and Maritime Services; and 16 local government authorities (i.e. Auburn, Ashfield, City of Sydney, Blacktown, Parramatta, Holroyd, Strathfield, Canada Bay, Ryde, Ku-ring-gai, Manly, Lane Cove, Woollahra, Leichhardt, Marrickville and Burwood). GS LLS also acknowledge the expert guidance provided by members of the Advisory Panel, which included: Prof Emma Johnston from the Sydney Institute of Marine Sciences (SIMS); Dr Peter Scanes (OEH); Dr Geoff Coade (OEH); Gus Pelosi (OEH); Dr Karen Astles from the Department of Primary Industries (DPI); Dr Bob Creese (DPI); Lesley Diver, formerly with the Sydney Metropolitan Catchment Management Authority (SMCMA); Stephen Lynch, formerly with the SMCMA; and Stephen Blockwell, formerly with Sydney Water. GS LLS also acknowledge contributions from Rod Kerr, Sydney Water, as well as considerable support from Matt Savage, Harbour City Ferries. All photographs of Sydney Harbour marine-life have been provided by David Harasti.

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EXECUTIVE SUMMARY

Sydney Harbour, together with its foreshores, headlands and tributaries is the city's largest and most accessible open space and natural area. It is Sydney's best loved urban space; a national icon; a busy transport corridor; an economic powerhouse for industry, commerce, trade and tourism; and much more. The Harbour embodies the nature of Australia. It remains a place of unmatched Aboriginal significance. It is a direct and accessible symbol of Eora cultures. It contains the most significant surviving evidence of colonial settlement and is now a powerful symbol of a multicultural Australia.

Sydney Harbour and its catchment have natural resource assets of national significance and, as identified within the Environment Protection and Biodiversity Conservation Act (1999), these assets include: 3 threatened ecological communities; 62 threatened species; 29 migratory species; and 48 marine protected species. There are more fish species in Sydney Harbour (586) than for the entire coast of the United Kingdom (Hedge *et al.* 2014).

However, all is not right with Sydney Harbour. The sediments still carry the toxic legacy of years of industrial discharges. Testing of fish and crustaceans revealed high levels of dioxins that resulted in a complete ban on all commercial fishing in Sydney Harbour in January 2006 (DPI 2012). Whilst recreational fishing has not been banned, fishers have been advised that no fish or crustaceans caught west of the Sydney Harbour Bridge should be eaten and, for fish caught east of the bridge, generally no more than 150 grams per month should be consumed (DPI 2012). Whilst changes in legislation have made it illegal to purposely dump toxic waste in Sydney Harbour, **thousands of tons of toxic pollutants still enter the Harbour each year through the stormwater system and sewage overflows**.

Stormwater is a toxic cocktail that contains everything from heavy metals (such as copper, zinc and lead) to viral pathogens (Freewater, 2004). Many of these chemicals will never break down or take decades to do so. Birch *et al.* (2010) estimate that stormwater contributes an average of 475 t total nitrogen (TN), 63.5 t total phosphorus (TP) and 343,000 t total suspended solids (TSS) to Sydney Harbour each year. These volumes may triple in a very wet year. **Stormwater pollution is now the major threat to the ecological integrity of Sydney Harbour and threatens the multiple social, environmental and economic benefits that this iconic waterway provides.**

The Sydney Harbour Catchment Water Quality Improvement Plan is the first environmental management plan to encompass the whole of Sydney Harbour's catchment as well as the waterways and will provide the first coordinated management framework for the 25 local councils, 11 state government agencies and 2 federal government agencies, who have a stake in improving the future health of Sydney Harbour and its catchments. The Plan is divided into five sections.

Section 1 introduces the Plan and its objectives, of which the primary objective is to identify threats to water quality in the Harbour and its tributaries and to set targets for pollutant load reductions required to protect the condition and values of the Harbour. It includes a summary of the key catchment characteristics, such as area and land use for each of the four major catchments draining to Sydney Harbour. Sewer overflows are also a substantial issue in the catchment and the major source of pathogens to the Harbour. This section provides an historical overview of pollutant input and structural changes to the Harbour. It then quantifies pollutant loads entering the Harbour through the stormwater and through sewage overflow events.

Section 2 discusses the many environmental, social and economic benefits to the Sydney region and its people that the Harbour and its tributaries provide. These benefits were identified through the stakeholder feedback at workshops held as part of the development of this Plan, surveys conducted by the Marine Estate Management Authority (MEMA, 2013) and other literature. The benefits discussed are environmental (Biodiversity and Ecosystem services), social (recreational fishing, swimming, boating and aesthetics), and economic (fishing and tourism).

Section 3 identifies potential threats to these benefits, including the sources of pollution entering the Harbour, as well as the level of risk associated with each of these threats. In doing so the Plan is consistent with the NSW

government's new Marine Estate Management Act, which indicates that management of the marine estate should be based on an assessment of threat and risk to community benefits. It evaluates six potential options to address the future growth of Sydney as forecast by the NSW Department of Planning & Environment. These options include various levels of Water Sensitive Urban Design (WSUD) incorporated in the redevelopment and retrofitting of the urban landscape.

Section 4 proposes load and condition targets for Sydney Harbour and its catchment. Management actions to achieve these targets and address other threats raised in *Section 3* are proposed and rated for their relative importance based on the risk level of the threat they address as well as their relative contribution to resolving the threat. Among the recommendations is the need for a whole of government approach to set up and adequately fund a program or initiative to coordinate management actions in the Sydney Harbour catchment and assist MEMA in the management of threats to the Harbour. This high priority action should facilitate collaboration between Local Government, State Government, Sydney Water and key business interests. Such an Urban Water Management Program (UWMP) should be funded through a collaborative partnership between local government, state agencies and nongovernment organisations for this purpose. The activities of the UWMP could be coordinated by a Steering Committee with representation from each partner and facilitated by a project officer hosted by the GS LLS or other appropriate agency. A priority for the UWMP should be the development of whole of catchment, whole of government Management Plan for Sydney Harbour.

Section 5 outlines a monitoring and modelling strategy to address knowledge gaps identified during the development of the plan. It is proposed that the collaborative UWMP recommended in this Plan be used to facilitate future monitoring and modelling activities to fill these gaps. An evaluation of the Plan is an essential part of ensuring actions are implemented and are achieving their desired objectives. A framework to underpin this evaluation is presented together with a table of measures for each of the key recommendations.

The appendices include a summary of the results of stakeholder workshops and community forums undertaken to inform the Plan; a list of estimated pollutant loads (modelled) currently entering the Harbour from the various land uses; a list of the pollutant targets for each subcatchment of the Harbour based on 70% WSUD to infill redevelopment, 10% retrofit to existing urban areas and capping sewer overflows to no more than 40 in 10 years; a list of load targets by LGA based on the same scenarios; and an overview of the Sydney Harbour CAPER DSS constructed to support the development of this Sydney Harbour Water Quality Improvement Plan.

Sydney Harbour is one of Australia's greatest assets and is worth billions of dollars to the NSW economy annually (Hedge *et al.,* 2014). Sydney's population is expected to grow by 1.6 million over the next 20 years. If nothing is done to address stormwater pollution, then the pollution input will continue to rise in proportion to population growth and the value of the Harbour will diminish accordingly.

Sydney Harbour receives more than 10 million visitors a year and visitor direct expenditure contributes over $5 billion to the city's economy.

Glossary of Acronyms

CAPER DSS	Catchment Planning and Estuary Response Decision Support System
EPA	Environmental Protection Authority
GS LLS	Greater Sydney Local Land Services
LGA	Local Government Authority
MEMA	Marine Estate Management Authority
OEH	NSW Office of Environment and Heritage
PEM	Pollutant Export Model
RMS	NSW Roads and Maritime Services
SHERM	Sydney Harbour Ecological Response Model
SHWQIP	Sydney Harbour Water Quality Improvement Plan
SIMS	Sydney Institute of Marine Science
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorous
TSS	Total Suspended Solids
WSUD	Water Sensitive Urban Design

Diver and Eastern Shovel Nose Shark (*Aptychotrema rostrata*)

Forward

Sydney Harbour Catchment Water Quality Improvement Plan (SHCWQIP) was developed using an integrated hydrological and ecological modelling approach. The objectives of the project are to achieve an improvement in the water quality and ecological integrity of Sydney Harbour and its catchment; to engage key land managers and other stakeholders in the project design and process; and encourage ownership of the outcomes. The development of a catchment-wide Water Quality Improvement Plan with the key stakeholders has allowed a collaborative approach as well as a transparent and open discussion of the water quality improvements needed to protect the environmental, social and economic values of Sydney Harbour and tributaries. The process included the characterisation of land and its use within the catchment draining to Sydney Harbour. Intensive water quality monitoring was undertaken to assist the development and validation of catchment pollutant export models (CPEMs) to simulate and quantify the mobilisation and transport of stormwater. A high resolution 3-dimensional hydrodynamic model of the Harbour and its tributaries was developed and integrated with the CPEMs for the development of water quality models that simulate and predict the transport and fate of pollutants and phytoplankton under varying climate and land use management scenarios. Probabilistic higher order ecological response models were developed to predict the influence of management strategies on the ecology of the Harbour.

All models were integrated into the CAPER DSS to support the development of this Plan. The DSS integrates management actions, land use and climate, catchment water quality, receiving water quality and management costs to:

- Allow the examination and prioritization of catchment management scenarios that could be implemented to protect water quality in Sydney Harbour and its tributaries;
- Provide a tool that can be used by local councils and catchment managers to facilitate the testing of local scale catchment management scenarios and prioritise local water quality improvement interventions; and
- Evaluate costs.

This project was only possible because of the collaborative funding partnerships that Greater Sydney Local Land Services (GS LLS) established with 16 of the local government authorities that lie within the Sydney Harbour catchment (i.e. Auburn, Ashfield, City of Sydney, Blacktown, Parramatta, Holroyd, Strathfield, Canada Bay, Ryde, Ku-ring-gai, Manly, Lane Cove, Woollahra, Leichhardt, Marrickville and Burwood); the NSW Office of Environment and Heritage (OEH); Sydney Water; and NSW Roads and Maritime Services.

Sydney Pygmy Pipehorse (*Idiotropiscis lumnitzeri*)

CONTENTS

SECTION 1: INTRODUCTION

Purpose and scope of the Plan

The Sydney Harbour Water Quality Improvement Plan (WQIP) is the result of a concerted effort by the Greater Sydney Local Land Services (GSLLS), NSW Office of Environment and Heritage (OEH), Local Government, regional NRM groups, community environmental groups, consultants, local indigenous groups and the general community.

The main objective of the Plan is to identify threats to water quality in the Harbour and its tributaries and to set targets for pollutant load reductions (in terms of total nitrogen, total phosphorus, suspended sediment and pathogens) required to protect the condition and values of the Sydney Harbour, its tributaries, estuaries and waterways. In addition, it is expected that the Plan will be a tool for raising awareness and promoting behaviour changes amongst individuals and organisations. It is anticipated that the Plan will find an audience amongst Local, State and Federal Government agencies as well as with interested individuals, community groups and organisations.

The WQIP is designed to give focus and direction to water quality policy development and on-ground implementation throughout the Sydney Harbour catchment. It will help guide more localised or sub-catchment planning and policy development by local councils and regional groups of councils. It should also help guide regional planning policies such as the Sydney Metro Strategy and its sub-regional strategies and the Marine Estate Management Strategy being developed and implemented by the NSW Government.

Everyone's actions have the potential to contribute to water quality issues. Choices that households, businesses, developers, Local and State governments make will all have an effect on the levels of nutrients, sediments and pathogens exported from the catchment into the tributaries, estuaries and Harbour. To be effective, the Plan needs to be owned and implemented by all levels of government as well as by individuals and organisations. The Plan provides direction on how each of these groups could act to implement its recommendations.

The Plan has been written to reduce future pollutant loads to the Harbour, its tributaries and estuaries. It also provides some future direction into how to manage specific pollution problems arising from past activities, for example issues with toxic sediments derived from past industrial activities in the catchment. It has been developed to be consistent with the risk framework being designed and implemented for management of the Marine Estate by the Marine Estate Management Authority (MEMA).

Catchment description

This section of the Plan summarises the key catchment characteristics, such as area and land use for each of the four major catchments draining to Sydney Harbour.

Sydney Harbour catchment covers an area of 484 km^2 and has been divided into 4 catchment areas for this plan:

- the Parramatta River catchment
- the Lane Cove River catchment
- the Middle Harbour catchment, and
- the remaining foreshore areas draining into Port Jackson.

FIGURE 1. SYDNEY HARBOUR CATCHMENT SHOWING MAJOR SUBCATCHMENT BOUNDARIES AND LOCAL GOVERNMENT AREAS

The Parramatta River catchment

The Parramatta River catchment covers approximately 250 km^2. The river is the main tributary to Sydney Harbour and is tidal to the Charles St weir. The catchment has been heavily developed and has a long history of industrialization. Relatively little vegetation is left in the catchment with small isolated patches scattered throughout the catchment but predominantly in the northern part and along creek lines.

The Lane Cove River Catchment

The Lane Cove River catchment covers approximately 95 km^2. The river is a northern tributary to the Sydney Harbour located on the northern side of Parramatta River joining between Clarkes Point, Woolwich and Greenwich Point, Greenwich and is tidal downstream from the weir near Fullers Bridge. 'The estuary is characterised by an open mouth with semi-enclosed bays with shallow or submerged deltas and on-going sediment infilling in some areas' (Gondwana Consulting, 2011).

The Middle Harbour Catchment

The Middle Harbour catchment covers approximately 100 km^2. The river is a northern tributary arm to Sydney Harbour and an inlet of the Tasman Sea located north of the Sydney central business district between Grotto Point near Clontarf and Middle Head. There are many small creeks that drain into Middle Harbour from surrounding hills but no significant rivers that flow into it. Middle Harbour has its main source in the upper reaches of Garigal National Park where it forms Middle Harbour Creek and flows southeast to become Middle Harbour at Bungaroo. Bushland covers one-quarter of the catchment mostly in Garigal National Park (22 km^2).

The shore of Middle Harbour is mostly rugged, forested or barren with few flat land areas so the area was almost entirely neglected for the first two centuries of European settlement in Sydney. Land use in the catchment is mainly residential with a population of approximately 200,000 people. There is also some industrial and commercial land use.

Foreshore areas draining to Port Jackson

Port Jackson is a Harbour that 'comprises of all the waters within an imaginary line joining North Head and South Head. Within this Harbour lie North Harbour, Middle Harbour and Sydney Harbour' (Geographical names board of New South Wales, Reference no. 47142). For the purposes of this study the 'rest of Port Jackson' refers to the Harbour components described above but excludes Middle Harbour.

These foreshore catchment areas flowing to Port Jackson cover approximately 39 km^2. The Harbour is semi diurnal tide dominated and stretches 19 km from the most easterly point at the Tasman Sea at the entrance at North and South Heads to the most westerly point where Lane Cove and Parramatta Rivers enter the port (Harris and O'Brien, 1998).

The Harbour is heavily embayed. The bays on the southern side of the Harbour tend to be wide and rounded, whereas bays on the south side are generally narrow inlets. There are a number of recreational and bushland areas including the Sydney Harbour National Park scattered throughout the mainland and many of the bays have beaches. The major central business district of Sydney (1,687 m^2) begins at Circular Quay, which started as a small bay on the south side that overtime has become a rectangular quay due to the reclaiming of land. The northern side of the Harbour is mainly used for residential purposes.

Catchment land use

Table 1 and Figure 2 summarises the relative land use areas of the major subcatchments in the Sydney Harbour catchment. Figure 2 shows that the catchment is heavily urbanized with 80% of the catchment covered by urban land use types. The majority of the catchment is residential, with roads (19%) and parklands (14%) the next largest land uses. Rural land use (0%) and Rail (1%) are the smallest areas of land use type.

TABLE 1. RELATIVE LAND USE AREAS OF THE SYDNEY HARBOUR SUBCATCHMENTS

Subcatchment	Bushland	Commercial	Industrial	Parkland	Rail	Residential	Roads	Rural
Parramatta	3%	8%	6%	12%	1%	49%	20%	1%
Lane Cove	7%	9%	1%	17%	0%	49%	17%	0%
Middle Harbour	16%	3%	1%	20%	1%	44%	15%	0%
Port Jackson	6%	17%	3%	11%	1%	40%	22%	0%
Total	6%	9%	4%	14%	1%	47%	19%	0%

Sewer overflows are also a substantial issue in the catchment. Figure 3 shows the sewer overflow points in the catchment. Sewer overflows can be caused by illegal connections of stormwater into the sewer system and incursion of stormwater and rainfall into sewer pipes due to cracks in the pipe network. These overflows generally operate during high flow events and discharge a mix of stormwater and untreated sewage.

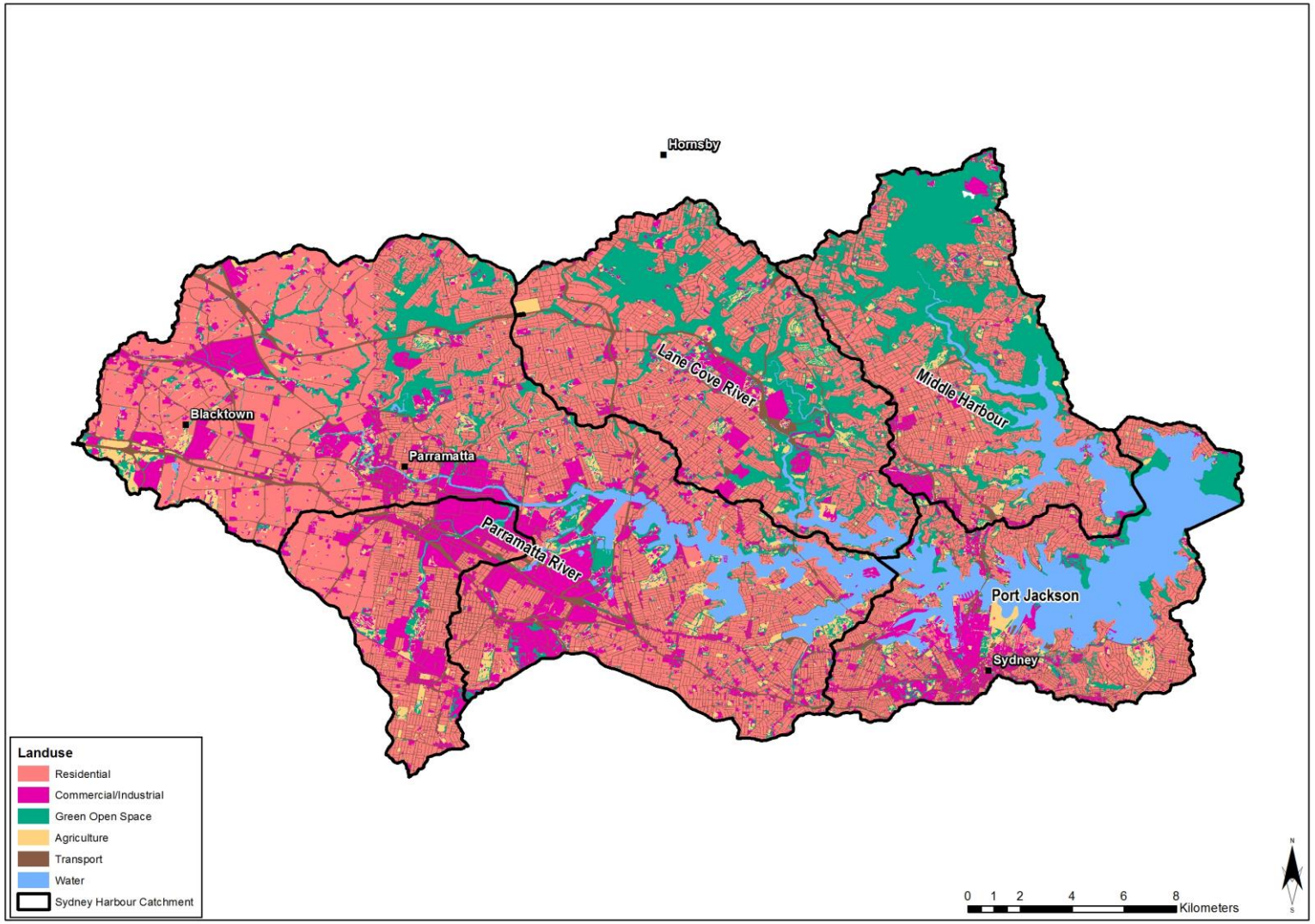


FIGURE 2. LAND USE IN THE SYDNEY HARBOUR CATCHMENT

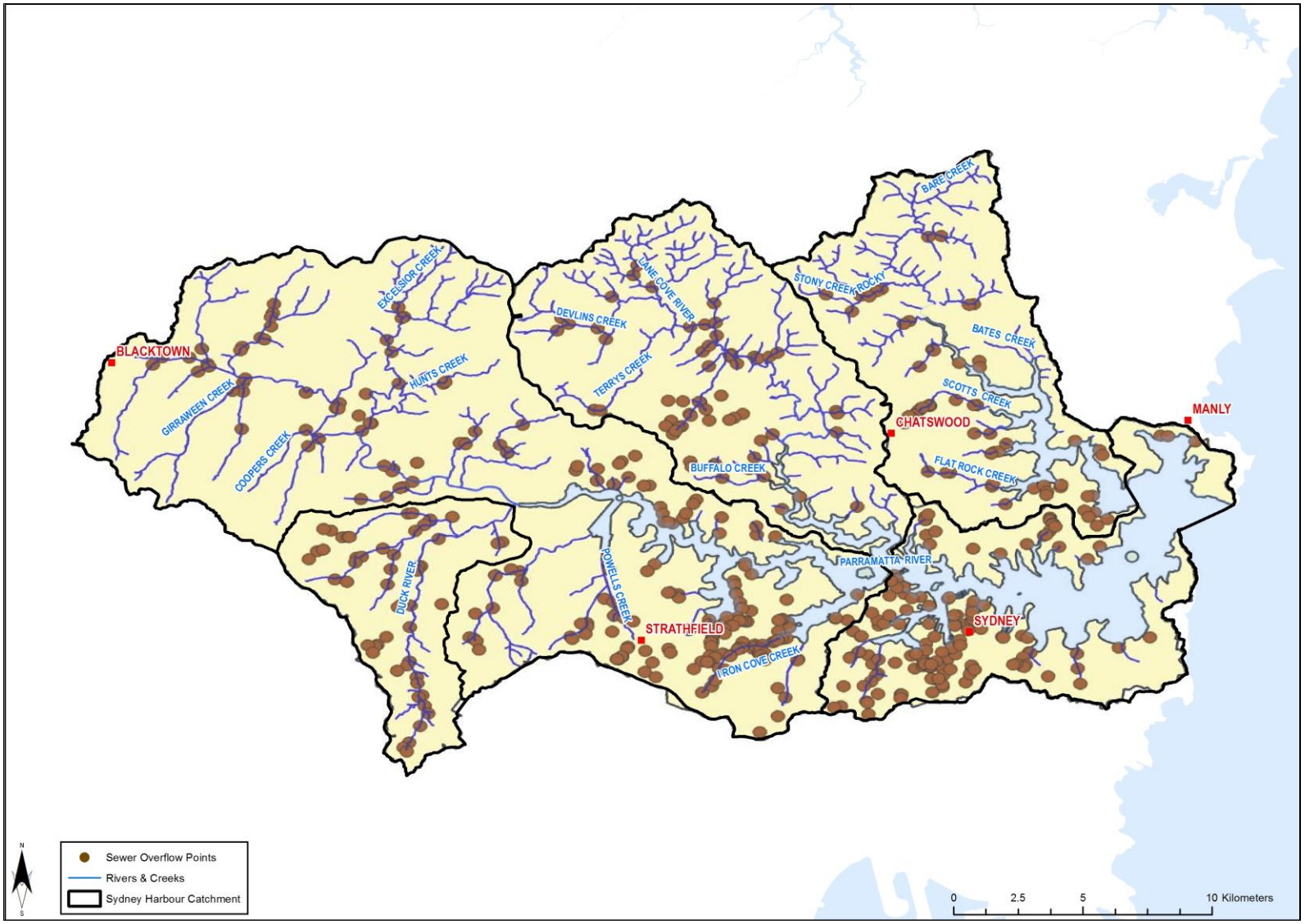


FIGURE 3. SEWER OVERFLOW POINTS IN THE SYDNEY HARBOUR CATCHMENT

Past and current actions

This section of the Plan provides an historical overview of pollutant input and structural changes to the Harbour.

Past actions in and around the Harbour have played a significant role in the condition of the estuaries and waterways today, particularly with regard to industrial pollution and toxic sediments, and the constructions of barriers including seawalls and weirs.

Up until the 1970's industrial waste was dumped into the Parramatta River. This has resulted in the southern central embayments being heavily contaminated with a range of heavy metals and chemicals. The northern embayments are not as affected because lack of access to the northern shore delayed industrialisation and development of these areas. Homebush Bay, Iron Cove and the area around Breakfast Point are the most contaminated areas. There are numerous fishing bans in the Parramatta River due to contamination particularly around Homebush Bay where there is a complete fishing ban. Stakeholders acknowledged that heavy industry in the past around Darling Harbour had also contaminated sediments and suggested that they would value sediments being cleaned up enough so fish could be eaten.

In tidal sections below Fullers Bridge (Lane Cove catchment), industrial waste was released into the Lane Cove estuary up until the early 1990's. Toxic chemicals from tanneries were released into the Burns Bay catchment from the 1880's to 1970 and effluent from the corn starch factory near Epping Road was disposed directly into the estuary until 1991. There is also potential for leachate to enter the estuary from landfills at Buffalo Creek (operated 1950's – 1972), Magdala Road (operated 1959-1972) and Stony Creek (operated 1954-1980). Dredging of the middle section of the Lane Cove River estuary took place in the late 1950's to 1974; however, there has been concern that this inhibited tidal flushing of the estuary.

In Middle Harbour, sedimentation is present in the north and south arms of Sandy Loaf Bay where Flat Rock Creek discharges into Long Bay and Sandy Bay, Clontarf. This area was last dredged in 1988. Since this time the sediment is visible at low tide for 50 metres from the rock walls which has restricted boating and recreational fishing in the area (Reocities, accessed 2014).

Since European settlement there has been significant alteration to the Harbour shore line. In 1978 Pitblado (1978; in Hedge *et al.*, 2013) estimated that about 24% (or 77km) of shoreline had been removed due to reclamation, while more recently Hedge *et al.* (2013) suggest that more than 50% of the intertidal shoreline is made up of artificial breakwalls. Others reported that about 22% of the estuary (50km^2) had been reclaimed for industry, residential and recreational purposes (Birch, 2007; Birch *et al.*, 2009 in Hedge *et al.*, 2013).

In the 1930's a weir was constructed above the tidal range across the river at Fullers Bridge in the Lane Cove catchment. This prevented tidal ingress upstream of the weir and caused significant changes to the physical processes and natural ecosystems by creating a low energy freshwater sedimentary environment behind the weir. Although the Lane Cove estuary has undergone significant environmental change since European settlement, extensive rocky shoreline sections remain as open space or narrow areas of natural (or modified) bushland between low to moderate density urban development. Larger areas of bushland surrounding the river's edge are near Riverview and Lane Cove West. In the middle to northern reaches (Fig Tree Bridge to Fullers Weir) approximately 80% of the main arm of both sides of the river is covered with bands of riparian vegetation that extends greater than 20 metres from the shoreline.

The hydrodynamics of Sydney Harbour play an important role in the state of its water quality. Rainfall in Sydney is characterised by dry conditions with infrequent high rainfall events (>50mm rainfall) (Hedge *et al.*, 2013). Stormwater is therefore mainly generated under high rainfall events with the volume of stormwater under dry, intermediate and high rainfall conditions 10, 30 and 60% respectively (Birch and Rochford, 2010; Lee *et al.*, 2011 in Hedge *et al.*, 2013). The Harbour is well flushed near the entrance but poorly flushed in the upper reaches. Water residence time varies from 0-20 days in the main body of water, to up to 130 days in the top of Parramatta River (Roughan *et al.,* unpublished in Hedge *et al.*, 2013). Therefore during high rainfall and consequential stormwater events, pollutants that are discharged near to the outlet can be flushed to the ocean, but otherwise they will linger within the estuaries.

While many swimming baths in Middle Harbour often comply with water quality guidelines, *faecal coliform* and *Enterococci* compliances are considerably varied (NSW Environment and Heritage, 2013; NSW Government, 2008). There are also several stormwater overflows throughout the catchment that contribute pollution to Middle Harbour. Contaminants include suspended solids, nutrients (phosphorus and nitrogen), hydrocarbons, herbicides and pesticides from houses, gardens, roads and industrial areas.

In Port Jackson, industrialisation in the Sydney area has caused marine pollution and anthropogenic sediment to be deposited into the Harbour. There are several sewer overflow points and stormwater drain discharges throughout the region, thus water quality compliance is varied across the Port Jackson region. *Faecal coliform* and *Enterococci* densities tend to increase with increasing rainfall (NSW Environment and Heritage, 2013).

Major sources of pollutant loads

This section of the Plan quantifies pollutant loads entering the Harbour through the stormwater and through sewage overflow events. It provides a comparative analysis of the different land uses and sources of the different pollutants, identifying the issues of concern.

Diffuse loads versus sewer overflows

Figure 4 shows the proportion of loads derived from diffuse sources versus sewer overflows. This Figure shows that the vast majority of pathogens (93% *Enterococci* and 80% faecal coliforms) are contributed from sewer overflows. Conversely, TN, TP and TSS are clearly dominated by diffuse sources, which account for 90% of nutrient and 98% of sediment loads. The total annual average loads of these pollutants from various land uses and sewer overflows for each of the 4 subcatchment areas to Sydney Harbour are given in Appendix 2.

Figure 5 shows the split of contributions of each pollutant from diffuse versus sewer overflows for each of the 4 main subcatchments making up the Harbour. This Figure shows that the dominant sources of nutrients and sediments are diffuse for each of the four major subcatchments, being at least 86%, but more commonly over 90% of the pollutant source. A greater proportion of nutrients are derived from sewer overflows than diffuse sources when compared to sediments for Parramatta, Lane Cove and Middle Harbour. Sewer overflow data provided for Port Jackson foreshore areas had zero flows and so no sewer overflow contribution for any pollutant.

Sydney's sewerage system is implicated as the source of most of the pathogen concentration within the Sydney Harbour, with reports that sewerage overflows occurred more than 3000 times a year (Bickford *et al.*, 1999 in Hedge *et al.*, 2013), although it is expected that this number would have decreased since the north-side tunnel was completed. Stakeholders are particularly worried about the *E.coli* and *Enterococci* values being too high for Harbour pools to be used with the one at Manly being given as an example. This concern is echoed by results from the Sydney Harbour CAPER DSS which

show that the primary source of pathogens to the Harbour is sewer overflows. Contributions from sewer overflows ranged from 67% for Middle Harbour *E.Coli*, to 95% pollution of *Enterococci* for Parramatta. The Parramatta subcatchment has the highest percentage of sewer overflow pollution of each type of pathogen, compared to the other catchments.

FIGURE 4. THE PERCENTAGE OF EACH WATER POLLUTANT THAT IS CONTRIBUTED FROM SEWER OVERFLOWS (SOF) VERSUS DIFFUSE SOURCES, FOR THE WHOLE OF THE SYDNEY HARBOUR

In Lane Cove an extensive sewer system (The Northern Suburbs Ocean Outfall Sewer (NSOOS) services) runs through the catchment, with about 120 overflow points discharging directly into the Lane Cove River and its tributaries (Rawling and Stricker, 1992 cited in Sinclair Knight Merz, 1997). As the tidal section of Lane Cove Estuary has limited exchange of riverine water, with each tide poor quality water remains in the estuary for long periods of time compared to elsewhere in Port Jackson. Thus, the export and dilution of pollutants and salinity of the water column which affects the rates of die-off of pathogens has health implications for marine life and users (EPA, 1995 cited in Sinclair Knight Merz, 1997).

The Northern Suburbs Ocean Outfall Sewer (NSOOS) crosses Middle Harbour at The Spit, between Parriwi Point and Clontarf Flat. There are main sewer overflows located at Quakers Hat Bay, near Mosman; Scotts Creek, near Castle Cove and Tunks Park, Cammeray. In high rainfall events diluted sewage is also discharged into Middle Harbour from near Roseville Bridge.

Hightail Shrimp (*Thor amboinensis*) in Sand Anemone at Clifton Gardens

FIGURE 5. THE PROPORTION OF POLLUTANTS THAT IS CONTRIBUTED FROM SEWER OVERFLOWS (SOF) VERSUS DIFFUSE SOURCES FOR THE FOUR MAJOR SUBCATCHMENTS IN THE SYDNEY HARBOUR CATCHMENT

Figure 6 shows the percentage of the diffuse loads of each pollutant that come from various land uses in the catchment. It also shows the percentage of the catchment area under each land use. It shows clearly that the majority of the diffuse pollutant load to the Harbour is coming from residential areas. These areas correspond to 47% of the area and contribute 81% of the diffuse *E.coli, Enterococci,* and *faecal coliform* loads, and 51- 52% of the TN, TP and TSS. Roads contribute more substantially to nutrients and sediment but less to pathogens relative to their area compared to residential areas.

The land use that contributes the least pollutant loads to the Harbour is rural. Rural land contributes less than 1% of all pollutants, but it also covers less than 1% of the area. Rail areas are also very small contributors of pollutants to the Harbour, covering 1% of the catchment and contributing 0-1% of the load of any pollutant.

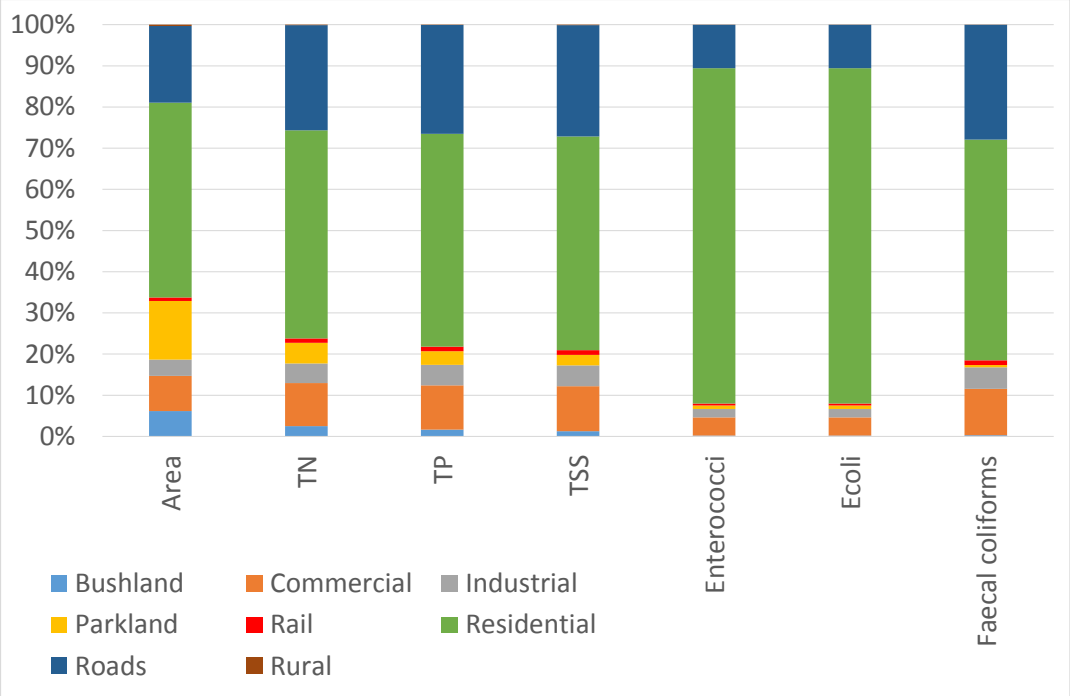


FIGURE 6. RELATIVE PROPORTION OF POLLUTANT LOAD THAT IS COMING FROM EACH LAND USE FOR THE WHOLE SYDNEY HARBOUR CATCHMENT

Figure 7 shows that Roads, Rail, Industrial and Commercial land uses are the worst contributors to TN, TP, TSS and *faecal coliform* pollutant loads by unit area. So whilst railways contribute the second lowest absolute pollutant load to the catchment, by unit area, they are the largest contributor of 4 of the 6 pollutants shown here. Given this, it can be expected that rail areas are substantial contributors to local water quality issues. Although residential land is not the greatest contributor of TN, TP, TSS and *faecal coliforms* by unit area, it is still by far the greatest contributor of *Enterococci* and *E.coli*., which emphases the need to manage the impacts of runoff from residential areas on the Harbour water quality.

Port Jackson Shark (*Heterodontus portusjacksoni*) at Bluefish Point - North Head

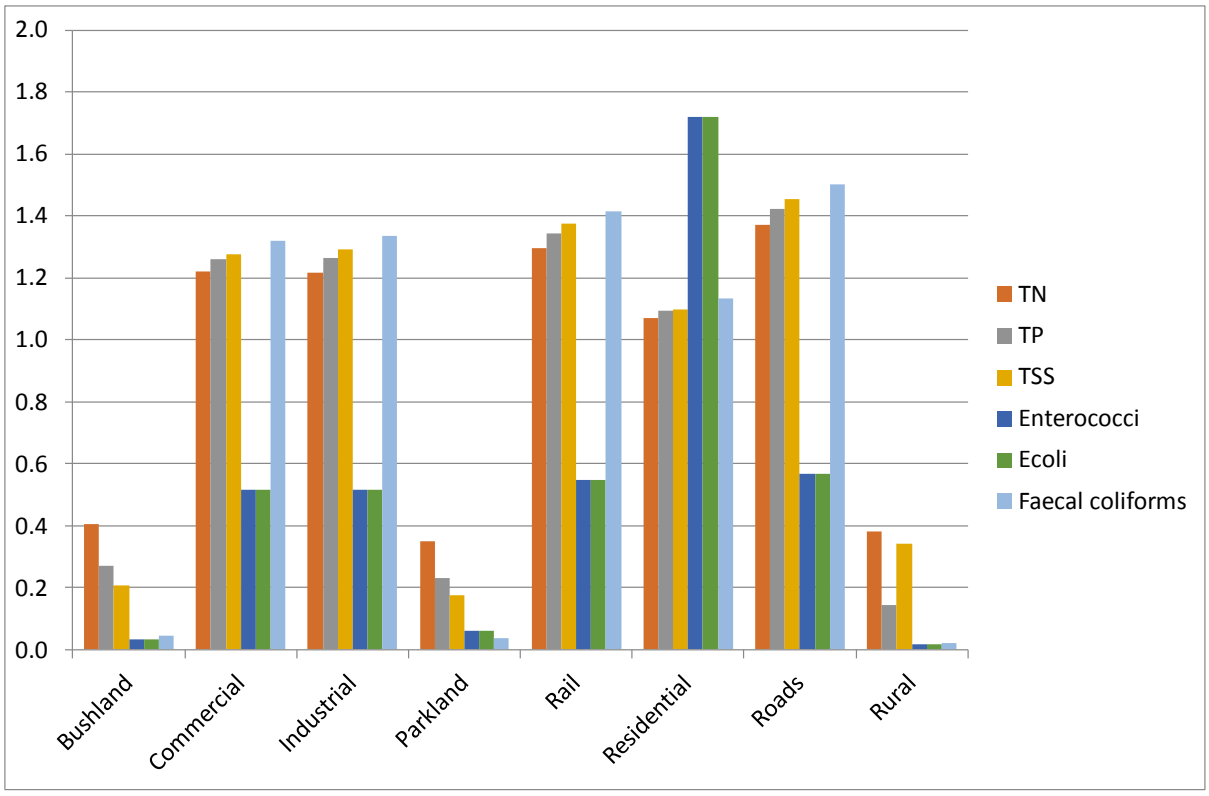


FIGURE 7. DIFFUSE POLLUTANT LOAD PER UNIT AREA THAT IS COMING FROM EACH LAND USE FOR THE WHOLE SYDNEY HARBOUR CATCHMENT

Figure 8 shows that the dominant land use which is polluting the water ways is residential, for all subcatchments, and all pollutants. About 80% of the *E.coli* and *Enterococci* are contributed by the residential land use and about 45-60% of the *faecal coliforms* across all subcatchments. Roughly half off diffuse sediments and nutrients are produced by residential areas although this is only slightly greater than the proportion of area dedicated to residential areas in each catchment.

Roads are the next greatest contributor of pathogen pollution for all subcatchments. Commercial property also contributes a substantial proportion (10-20%) of the pathogen pollution for Port Jackson, and to a lesser extent for Lane Cove and Parramatta subcatchments, although these land uses produce *Enterococci* and *E.coli* to a smaller extent compared to their relative area. The impact from industrial land use is also notable for the Parramatta catchment. Industrial and commercial areas produce above the average amount in terms of nutrients, sediments and faecal coliforms, but relatively less for *Enterococci.*

Pot Belly Seahorse (*Hippocampus abdominalis*) Manly

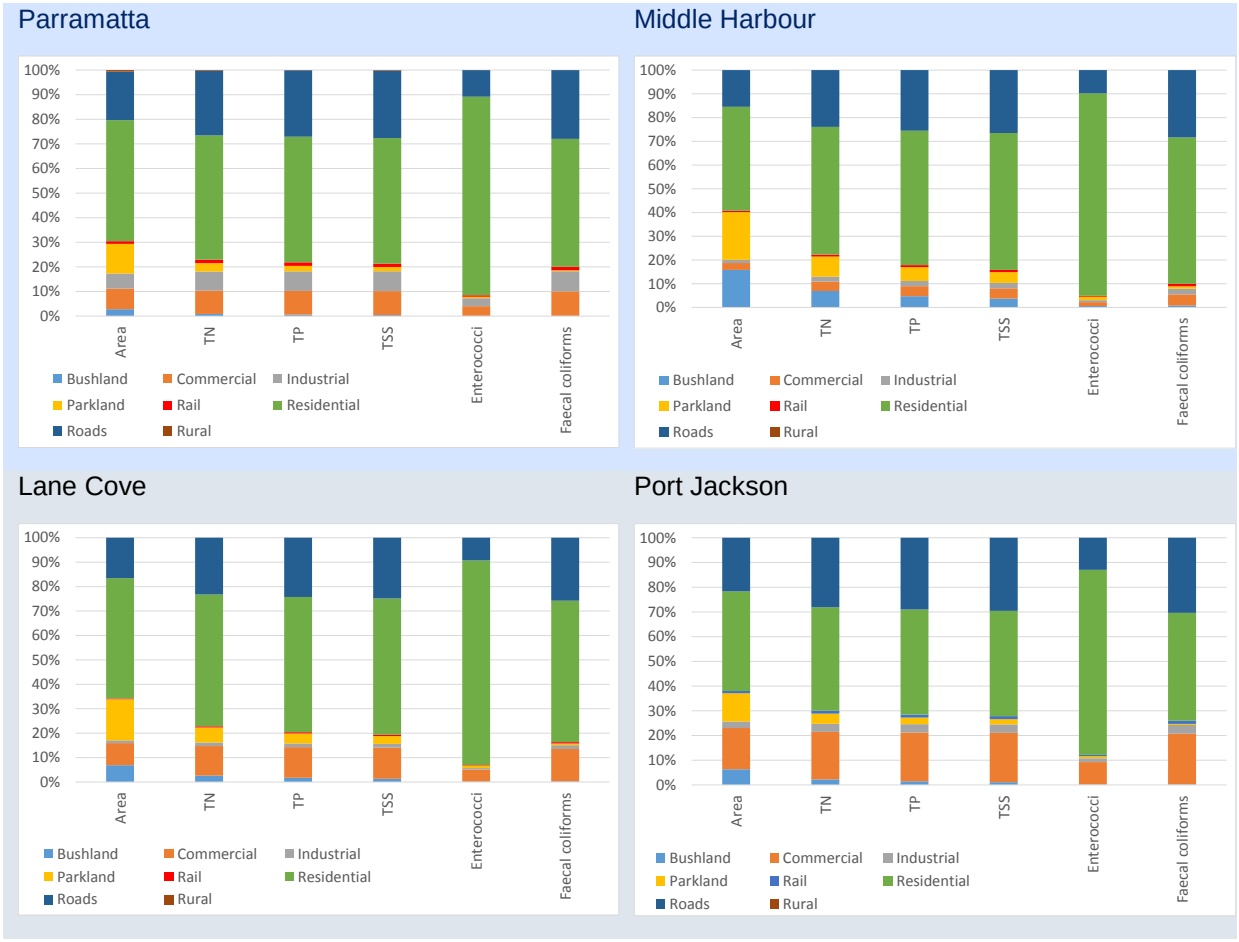


FIGURE 8. PERCENTAGE OF POLLUTANT LOAD COMING FROM EACH LAND USE FOR THE FOUR MAJOR SUBCATCHMENTS IN THE SYDNEY HARBOUR CATCHMENT

Change in pollutant loads and estuary condition since European settlement

This section of the Plan quantifies the increase in load concentrations since European settlement. It illustrates that whilst pollutants such as TN, TP and TSS have generally undergone and increase of up to 7-fold, some pathogens have increased by as much as 470-fold.

The current pollutant loads and their sources illustrate the impact of development on Sydney Harbour. This point is made even clearer when comparing the current loads with those estimated from pre-European settlement (modelled assuming bushland is the only land use in the catchment). Figure 9 shows that for the whole of Sydney Harbour the TN, TP and TSS loads are likely to have increased about 3, 5 and 6-fold, respectively compared to pre-European values. The results are very similar for each of the subcatchments, with the Parramatta subcatchment having the greatest increase in loads being about 4, 6 and 7–fold increases in TN, TP and TSS, respectively. This highlights the impact of urbanization on water quality.

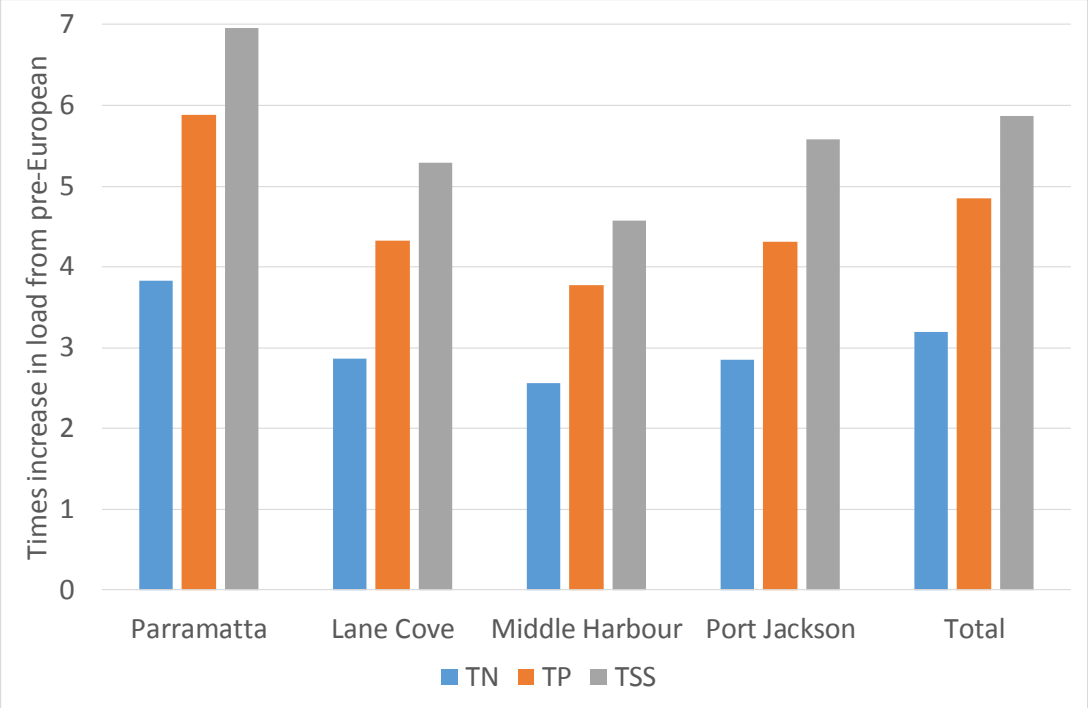


FIGURE 9. CURRENT NUTRIENT AND SEDIMENT LOADS VERSUS ESTIMATED PRE-EUROPEAN LOADS FOR THE FOUR MAJOR SUBCATCHMENTS

The change is even more dramatic when considering pathogen loads (see Figure 10). Increase in the *Enterococci* loads and *faecal coliform* loads are estimated at roughly 470 and 130-fold respectively. Obviously, with the influx of a very large population and a loss of natural groundcover to filter pollutants, came the influx in pathogens which have ultimately ended up in the waterways. Again the largest increase is in the Parramatta subcatchment where the increase in *Enterococci* and *faecal coliform* loads are more than double that of any other subcatchment, roughly 770 and 220-fold respectively. Relative increases in Port Jackson pathogens are less than elsewhere in the catchment (although still very substantial at roughly 30-fold increases) because of the lack of sewer overflows in this area, which are a large source of pathogen loads as discussed above.

Weedy Seadragon (*Phyllopteryx taeniolatus*)

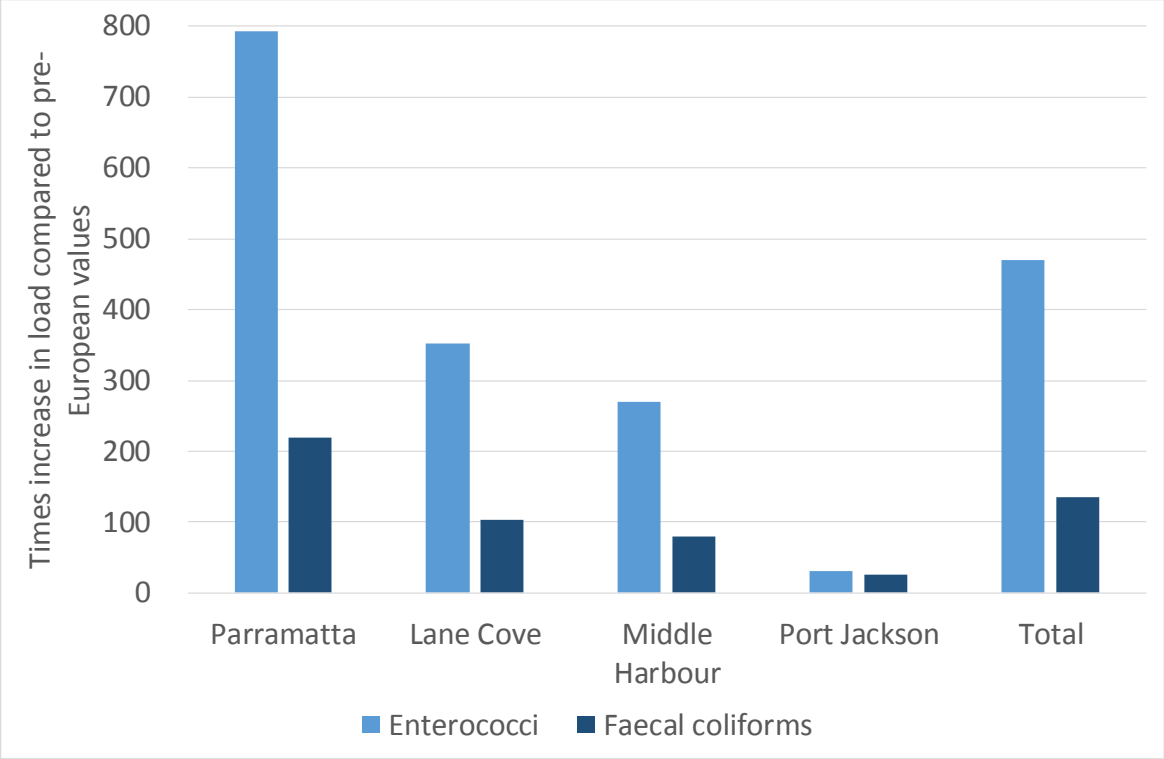


FIGURE 10. COMPARISON OF THE CURRENT *ENTEROCOCCI AND FAECAL COLIFORM* LOADS AND THE PRE-EUROPEAN VALUES FOR THE FOUR MAJOR SUBCATCHMENTS

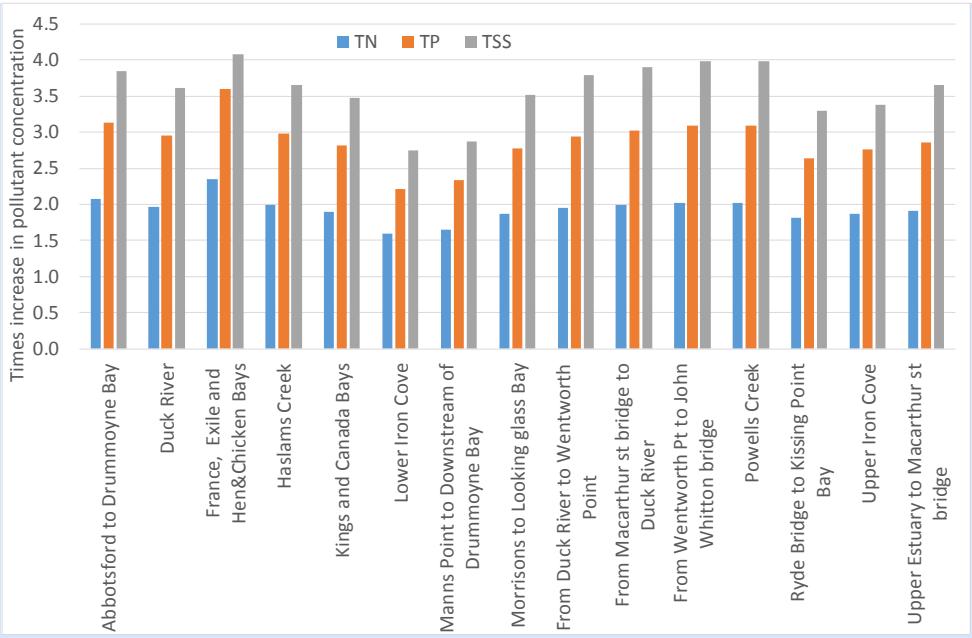
Focusing on the change in the concentration of pollutants (TN, TP TSS, *Enterococci* and *faecal coliforms*) on the subcatchment estuaries compared to pre-European values shows a similar story as the change in the loads discussed above. Figures 11 and 12 shows estimates of impact on the pollutant concentrations (TN, TP and TSS; and *Enterococci* and *faecal coliforms*) in the major estuary zones associated with the various major subcatchments since European settlement, due to the changes in loads given in Figures 9 and 10. In the Parramatta region, and for the whole of Sydney Harbour, the greatest impact on estuary condition for all pollutants were France Bay, Exile Bay and Hen and Chicken Bay with a 2.3, 3.6, 4.1, 767, and 203-fold estimated change in TN, TP, TSS, *Enterococci* and faecal coliforms. The Lower Iron Cove zone had the least change in pollutant concentration in the Parramatta Region, but it still corresponds to 1.6, 2.2, 2.7, 25 and 13-fold increases in TN, TP, TSS, *Enterococci* and *faecal coliforms*, respectively.

In the Lane Cove region there was not a lot of difference between the change in TN, TP and TSS concentrations between the major estuaries, except for change the *Enterococci* concentrations from Millwood avenue to Epping Bridge, which were over double that of any other major estuary zone in that area. These values were comparable to the Haslams Creek estuary, which had the third greatest increase in pathogen concentration of the Parramatta region estuary zones. In the Middle Harbour region, 3 of the 4 estuary zones had TN, TP and TSS values similar to that of the estuaries in Lane Cove, while the change in these pollutants for the Bantry Bay to Echo Point estuary zone more closely matched the worst estuary zone in the Parramatta region (France Exile and Han & Chicken Bays).For pathogens, Bantry Bay to Echo Point had the greatest increase in *Enterococci* of the estuary zones in the Middle Harbour, and it was the third highest increase of any estuary in the whole of Sydney Harbour. Sugar Loaf Bay to the Spit had one of the lowest changes in pathogen concentrations of any estuary in the whole of Sydney Harbour. In the remaining estuary zones of the Harbour, Rose and Double Bays had the greatest change in TN, TP and TSS from the pre-European concentrations with similar changes to three of Parramatta's top 5 estuary zones (From Macathur St bridge to Duck River, From Wentworth Point to John Whitton bridge and Powells Creek), Upper

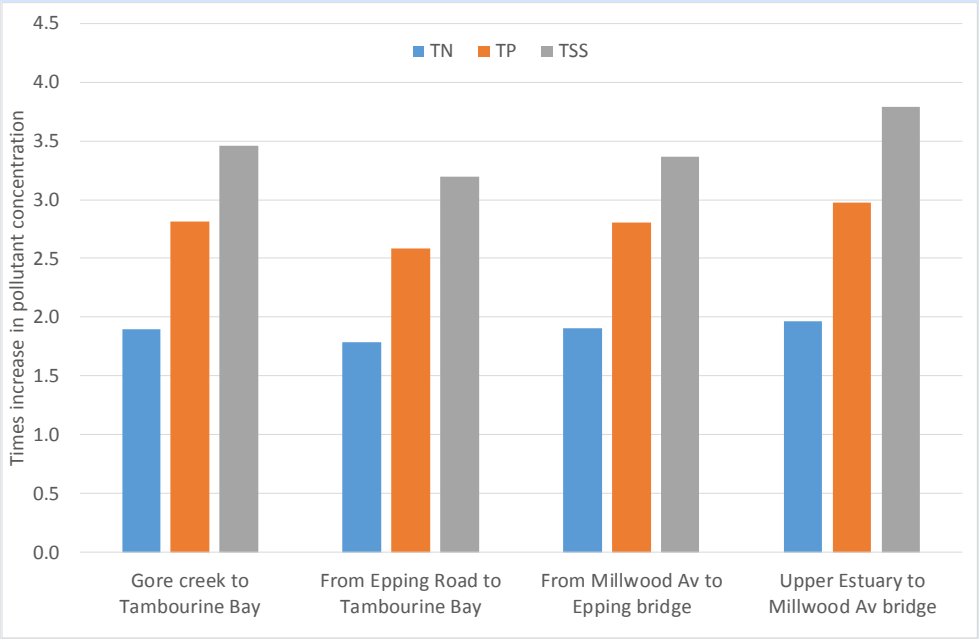
Estuary to Millwood in the Lane Cove Region, and Bantry Bay to Echo Point in the Middle Harbour Region. Farm Cove, Sydney Cove and Neutral Bay had an extreme increase in *Enterococci* (about 400 times), with Blackwattle, Johnstons and Rozelle Bays also being high (238 times). Note that the Blackwattle Bay was noted by the stakeholders as being very dirty following rainfall events. Rose and Double Bays are estimated to have had the lowest change in pathogen concentration since European settlement, being 24 times for *Enterococci* and 19 times for faecal coliforms.

Giant Australian Cuttlefish *(Sepia apama)*

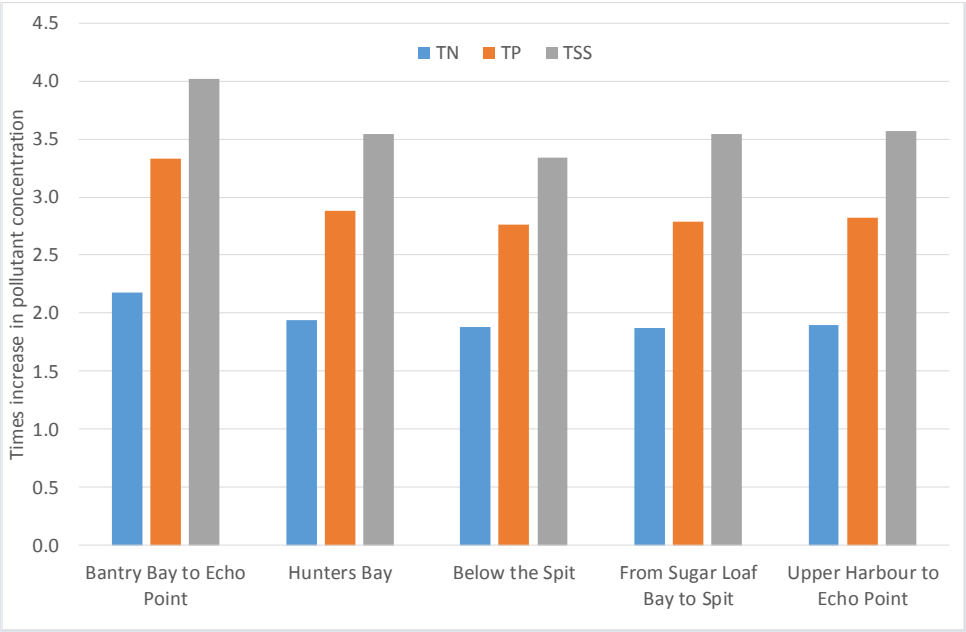
Parramatta



Lane Cove



Middle Harbour



Sydney Harbour

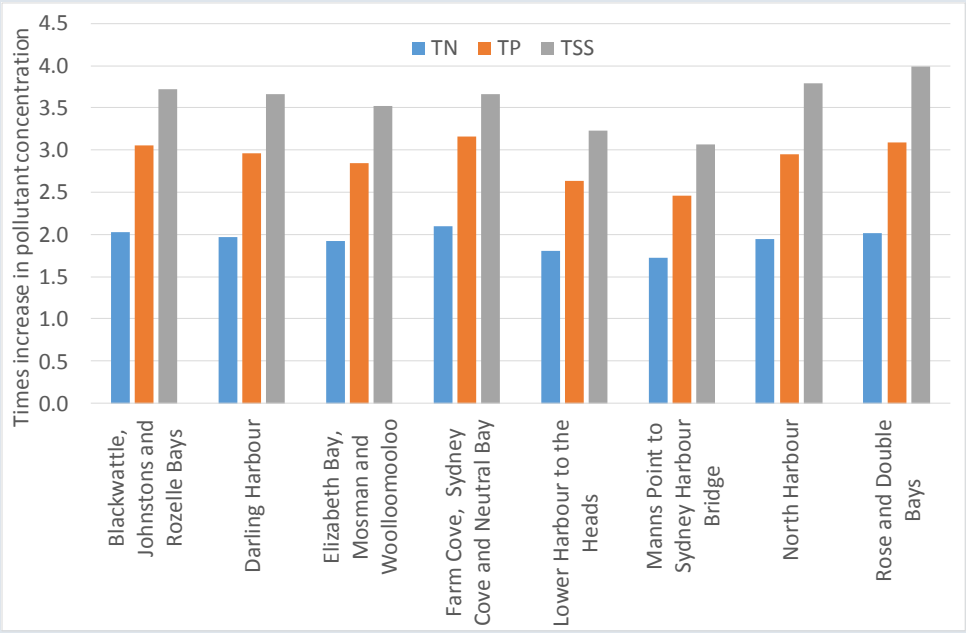
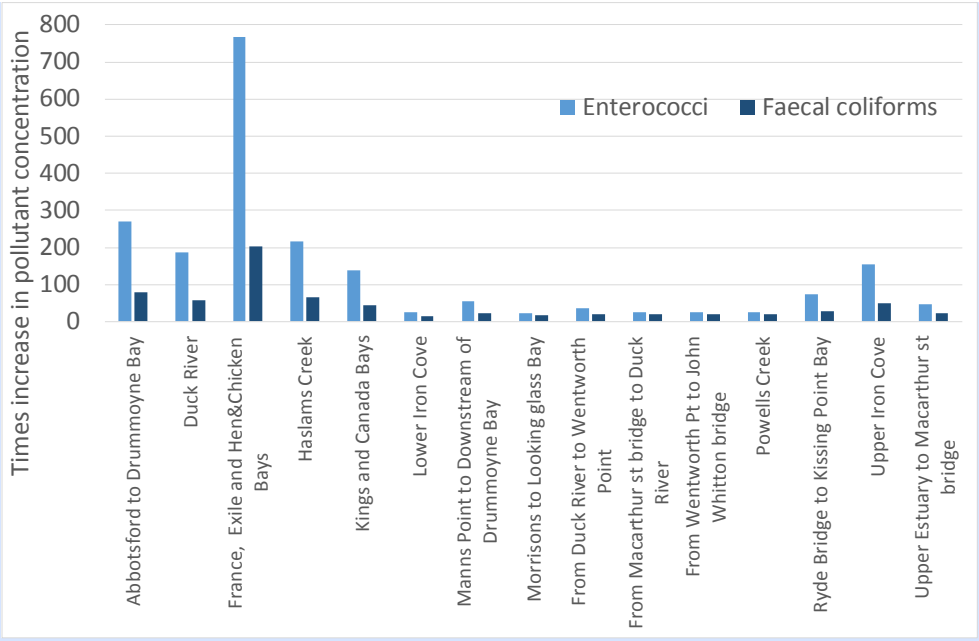
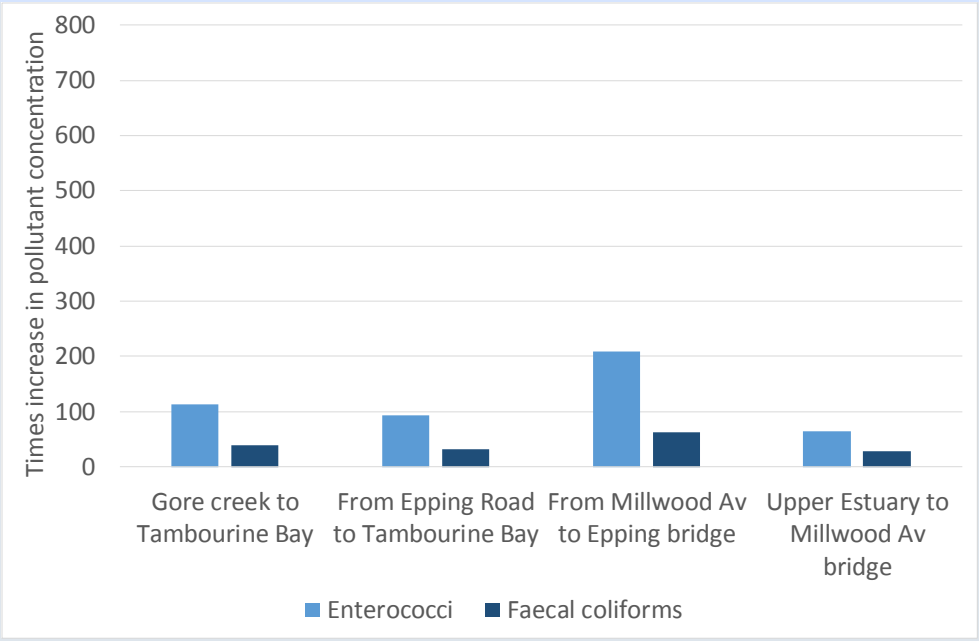


FIGURE 11. COMPARISON OF THE CURRENT NUTRIENT AND SEDIMENT CONCENTRATIONS AND THE PRE-EUROPEAN VALUES FOR THE MAJOR ESTUARIES IN THE FOUR MAJOR SUBCATCHMENTS.

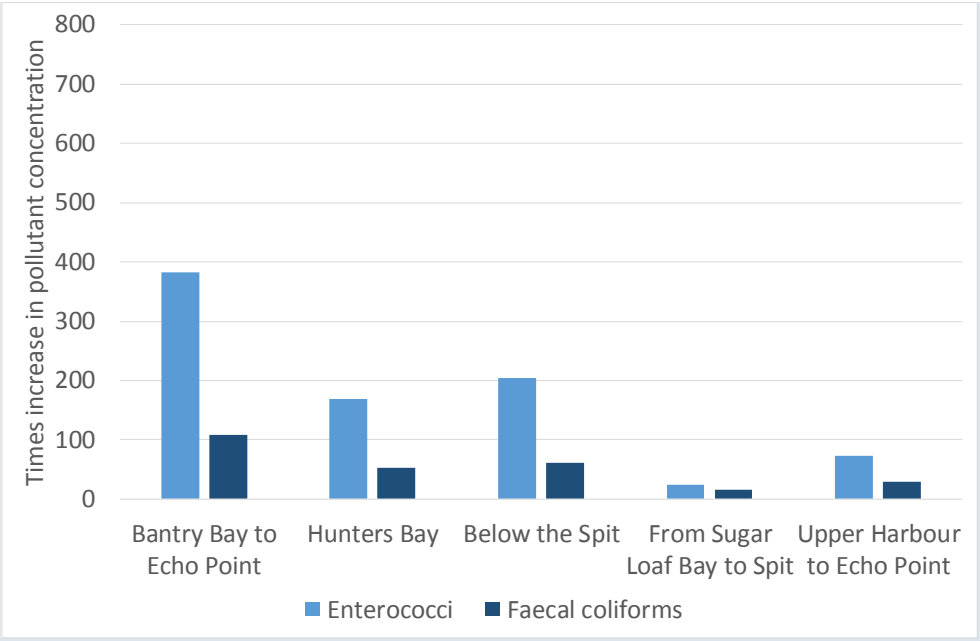
Parramatta



Lane Cove



Middle Harbour



Sydney Harbour

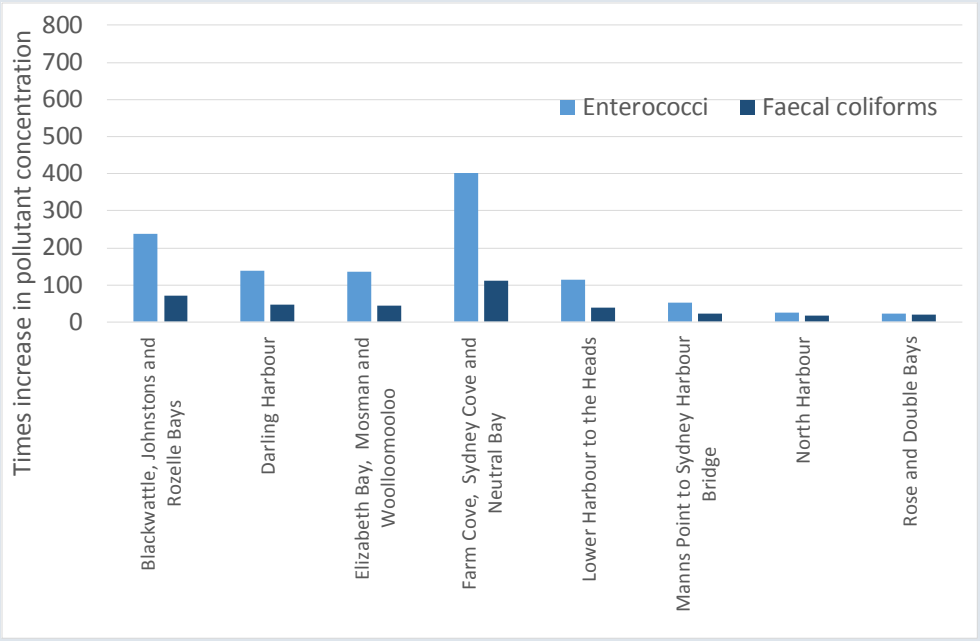


FIGURE 12. COMPARISON OF THE CURRENT NUTRIENT AND SEDIMENT CONCENTRATIONS AND THE PRE-EUROPEAN VALUES FOR THE MAJOR ESTUARIES IN THE FOUR MAJOR SUBCATCHMENTS.

SECTION 2. BENEFITS OF SYDNEY HARBOUR AND ITS TRIBUTARIES

The Sydney Harbour and its tributaries provide many environmental, social and economic benefits to the Sydney region and its people. This section discusses these benefits as identified through the stakeholder feedback at workshops held as part of the development of this Plan (see Appendix 1), surveys conducted by the Marine Estate Management Authority (MEMA, 2013) and other literature. The benefits discussed are environmental (Biodiversity and Ecosystem services), social (recreational fishing, swimming, boating and aesthetics), and economic (fishing and tourism).

Environmental benefits

According to MEMA (2013), Sydney-siders perceive that the highest priority environmental benefit was the clean water of the marine estate, supporting a variety of habitats and marine life. The Harbour and the freshwater systems that feed it provide a habitat, sanctuary and breeding grounds for over 3000 species of fish, crustaceans, molluscs, worms and echinoderms (Reid *et al*., 2013) with at least double the number of polychaete, crustacean and mollusc species (2355) than Botany Bay (1636), Hawkesbury River (1335) and Port Hacking (981) (Hutchings *et al.*, 2013). There are more species of fishes and invertebrates in Sydney Harbour than can be found around the entire coast of Britain. The Harbour supports threatened species such as the Little Penguin (*Euduptor minor*) which are highly valued by the locals. Other vulnerable species include the Weedy Seadragon (*Phylloptery Taeniolatus*), the Eastern Blue Groper (*Archoerodus viridis*) and the Australian Giant Cuttle Fish (*Sepia apama*). The Harbour also provides a haven for hump back whales that use it when travelling to and from the Antarctic. The importance of the Harbour has been recognised by the State Government with the North Harbour Aquatic Reserve (NSW Department of Primary Industries, 2015).

As the Lane Cove Estuary is located downstream from the Lane Cove National Park, an area of 598 hectares, it provides a valuable environmental resource. Lane Cove bushland has a diverse range of flora and fauna with around 625 species of indigenous plants in a number of vegetation types such as wet and dry schlerophyll forest and heath land with mangroves and tidal flats in the lower estuary. The Lane Cove Bushland Park is home to an endangered species of fungus, *Hygrocybe lanecovensis* that is not found anywhere else. Although there are National Parks within the Sydney Region there is no official protection for the Harbour. The National Parks Association is pushing for it to be made a marine park (National Parks Association of NSW, 2015)

The state of the biodiversity in the Harbour and its tributaries depends on many factors including the tidal flushing, high diversity of habitats (Hutchings *et al.,* 2013) and quality of the water in the estuaries. The tributaries provide vital nutrients into the marine environment. Johnson (2012) states that “up to a point, the input of nutrients will increase productivity, but too many nutrients lead to algal blooms and fish kills. Determining when we might breach the threshold nutrient concentration is an important research question for Sydney Harbour.” If the input water quality is poor, then the negative consequences upon the biodiversity are visible. Key indicator species for the stakeholders include oysters in the Harbour, ‘wildlife’ returning back to Lane Cove, and migrating whales using the Harbour, where their presence suggests a healthy state of the Harbour water quality.

The green areas around the waterways and tributaries, from mangroves and saltmarsh to the more terrestrial species, provide several ecosystem services beyond their direct biodiversity impact of the riparian vegetation. These include flood control and management, reducing the urban heat island effect through cooling provided by shading and evapotranspiration (as reviewed by Hunter Block *et al.*, 2012), as well as the filtering of diffuse stormwater.

Social benefits

Sydney Harbour provides social benefits through its various recreational activities, and more generally, providing enjoyment for its natural beauty and a safe place for socialising (MEMA 2013). People feel a sense of belonging to the Marine estate. From the MEMA survey results, within Greater Sydney, Sydney Harbour was the most visited area with 44% of respondents claiming to have visited this area within the previous 12 months. This sense of belonging underpins an opportunity to improve public awareness of the health and management of the Harbour through education. The waterways of both the Harbour and its tributaries are used for swimming, canoeing, kayaking, paddling, diving, snorkeling, power boating, and sailing by the Sydney residents and visitors. Around 16% of the Lane Cove area is devoted to recreational activities.

Recreational fishing (from wharves, seawalls and natural foreshores) is a very popular recreational activity, and according to the 2011 Australian Bureau of Statistics, there are more than 490,000 adult recreational fishers in the Sydney region alone. It is anticipated that this figure could increase by another 100,000 during holiday periods when children would join their parents (Lockwood, 2014). Ghosn *et al.*, 2010 (in Hedge *et al.*, 2013) found that Sydney Harbour supports double the recreational fishing and catch compared to other estuaries in NSW, with recreational fishing dominated by residents.

The foreshore also provides for several recreational activities such as walking, cycling, picnicking and bird watching. Riparian vegetation, including that along smaller waterways and natural drainage lines, also provide aesthetic value.

As opposed to the primarily ‘natural’ social values discussed above, Sydney Harbour is also valued socially for its iconic structures (e.g. the Harbour Bridge and Opera House), shape and bays that give Sydney its identity, as well as the generally beautiful views, tranquility and serenity associated with the Harbour and its tributaries. Many stakeholders acknowledge the European and Aboriginal heritage values in and around the catchment as well as the working value of the Harbour for transport, maritime and industrial defense.

At all stakeholder workshops (see Appendix 1) concerns were raised about the impact of water quality upon the access to recreational activities and the general amenity of the Harbour region. In terms of recreation, the main water quality threshold of interest was for primary and secondary human contact activities. Several participants indicated that recreational opportunities had declined overtime, swimming being one of the main issues. Siltation can also hamper recreational boating activity.

The Parramatta River Catchment Group has launched an initiative called ‘Our Living River’, which aims to get the Parramatta River swimmable by 2025. The objective of this initiative is to create a clean and healthy river that can be accessed by everyone to increase the social benefits and connection of the community to the river.

Economic benefits

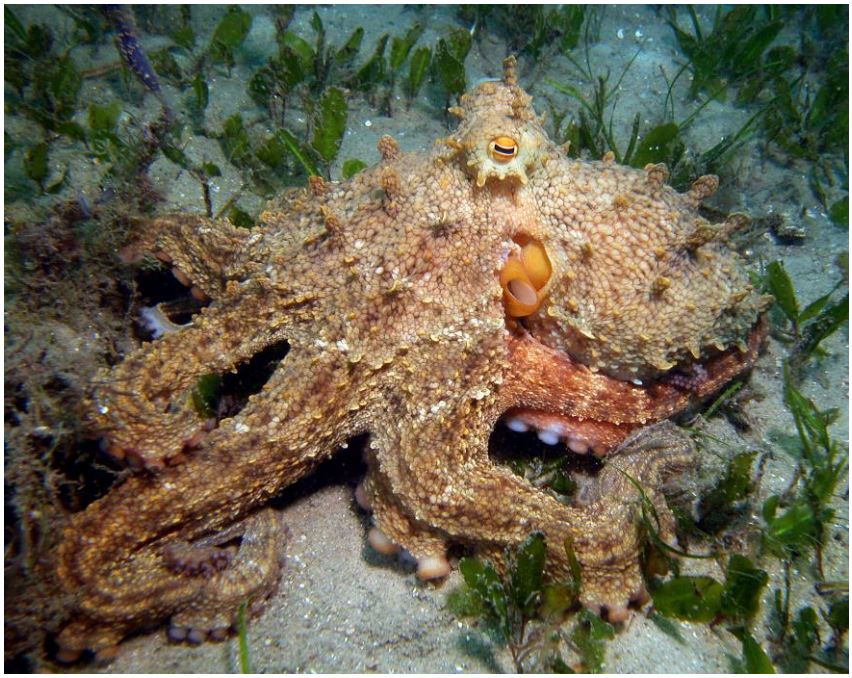
The Marine Estate and Sydney Harbour provides an important source of income for the locals (MEMA 2013), but it isn’t as significant as for other coastal areas of NSW. This is most likely to be because commercial fishing was banned in the Harbour in 2006 due to poor water quality and consequential high toxin levels found in fish and crustaceans (NSW Department of Primary Industries, 2015). The remaining key economic benefits that are supported by Sydney Harbour are tourism and commercial shipping.

The tourism benefit of the Harbour was highly valued by all stakeholders during workshops, as well as from the MEMA surveys. Marketing the beauty and biodiversity of the marine estate was seen as essential to promote the tourism value of the Harbour (MEMA 2013). The iconic structures and the

bays that give Sydney its identity, beauty, tranquility and serenity, were all believed to be key to attracting tourists to Sydney. Some workshop participants commented on how tourism can be affected by good water quality and amenity. Participants noted that '*having good water quality will provide good impressions'* and *'...maintaining good water quality to add to tourist enjoyment but also locals'* enjoyment is important.

The Harbour is also building a reputation as being a recreational fishing hub for both residents and visitors. The cessation of commercial fishing and the improvement of water quality since the deep ocean outfalls were opened are attributed to increasing fish numbers (Lockwood, 2014). Recreational fishing can make a significant contribution to the economy alone, with the "Recreational Fishing Expenditure Survey 2012 by the University of Wollongong finding that each Sydney angler spends an average $250.07 per trip on everything from travel to tackle. Sydney anglers account for almost a third of the $3.42 billion recreational fishing dollars generated in NSW each year" (Lockwood, 2014). Not to mention the flow-on effects to tourism.

Port Jackson is a premier port in Australia. In 1986, Cameron-McNamara estimated that 11 commercial vessels (over 10,000 tons gross) enter and leave the Harbour each day. In addition to this, numerous yachts, ferries and small crafts use the port accounting for an average of 700 boat movements per day on Port Jackson.



Sydney Octopus (*Octopus tetricus*) at Manly

SECTION 3. ASSESSMENT OF THREATS AND RISKS TO THESE BENEFITS

This section identifies potential threats to these benefits, including the sources of pollutant entering the Harbour, and the level of risk associated with each of these threats.

Research indicates that heavy metals in sediments are sufficient to have adverse effects on biota in the Harbour, impacting upon social and economic benefits through the loss of appeal of the Harbour (Birch and Taylor, 1999). MEMA (2013) also found that pollution threatens all three areas of benefit for Sydney Harbour (environmental, social and economic). The report has identified that the major threats to Sydney Harbour are pollution, including nutrient and sediment runoff, sewerage overflows and vessel waste discharge, toxic chemical pollution (domestic and commercial) and litter. As well as the urban/foreshore interfaces directly or indirectly killing foreshore vegetation, including mangroves, saltmarsh and seagrasses. Efforts to manage the Harbour water quality into the future are threatened by:

- a lack of knowledge about the water pollution cycle (generation, transport and impact);
- a lack of enforcement, punishment and determent against inappropriate actions; and
- a lack of cohesion in water quality management.

Table 2 shows the threats to Sydney Harbour water quality identified through literature review, modelling, key stakeholder workshops and community forums (see Appendix 1), and the report by the MEMA (2013).

Clown Nudibranch (*Cerastoma amoena*)
on Paddle weed (*Halophila ovalis)*

TABLE 2. THREATS TO SYDNEY HARBOUR WATER QUALITY

Threat	Description
Stormwater Runoff (including nutrients and sediments)	Large quantities of poor quality stormwater runoff flowing into the Harbour leads to restrictions on recreation and fish catch, depletes the aesthetics value, and has negative impacts upon the natural habitat for aquatic species. Modelling undertaken for this Plan indicates diffuse sources (primarily stormwater flows) account for the majority of nutrients (98% TN and TP) and sediments (90%) being discharged to the Harbour.
Sewerage overflows	Sewer overflows contribute a substantial proportion of the pathogen loads being discharged to the Harbour (93% *Enterococci*, over 20% *E.coli* and *faecal coliforms*).The frequency and concentration of sewer overflows will increase if the current system is not upgraded to be able to meet the current demand and then maintained to enable optimal function. Sewer overflows lead to restrictions on recreation and fish catch, depletes the aesthetics value, and has negative impacts upon the natural habitat for aquatic species.
Vessel waste discharge	Vessels that dump their waste directly into the Harbour degrade the water quality immediately. As the number of vessels using the waterways, and inevitably illegally dumping waste water increases, then restrictions on recreation and fish catch will increase and the aesthetic value and natural habitat for aquatic species will decrease.
Toxic chemical pollution (domestic)	Toxic household chemicals (including pesticides) dumped directly into the Harbour, its estuaries and tributaries or transported there through the stormwater and/or natural flow paths, degrade the water quality and its habitat value, and can also lead to more restrictions placed upon the recreational value of the water.
Toxic chemical pollution (commercial)	Toxic commercial chemicals dumped directly into the Harbour, its estuaries and tributaries, or transported there through the stormwater and/or natural flow paths degrades the water quality and its habitat value, and can also lead to more restrictions placed upon the recreational value of the water.
Litter	Large quantities of litter dumped, or transported into the Harbour degrades the Harbour's habitat and its recreational and aesthetic values.
Urban/foreshore interfaces directly or indirectly kills foreshore vegetation, including mangroves, saltmarsh and sea grass	Urban/foreshore interfaces directly (e.g. removed for further development and artificial walls) or indirectly (e.g. through crowding from other infrastructure, or boating and people traffic and damage) kill foreshore vegetation, including mangroves, saltmarsh and seagrass. Loss of habitat and natural boundaries will lead to loss of biodiversity
Lack of knowledge about the water pollution cycle (generation, transport and impact)	Lack of understanding of pollutants, their sources, transport within a catchment and impacts on the ecosystem usually results in community apathy and decisions resulting in poor water quality outcomes.
Lack of enforcement, punishment and deterrents against inappropriate actions	Lack of enforcement and punishment to deter illegal private and commercial actions undermine efforts to improve and protect water quality in the Harbour.
Lack of cohesion in water quality management	Individual and localised efforts to improve water quality, although gallant, are not as effective as a consolidated effort, which ensures that all parties are working towards the same goals. This has implications to actions as well as planning.

Chemical pollution and Litter

Due to a long industrial history in the catchment there has been an extended period where toxic chemicals have been disposed of in the estuaries and waterways, which have contaminated and remained in the sediments (Birch and McCready, 2009 in Hedge *et al.* 2013). This coupled with current discharges from stormwater, including 'hot spots' from specific industries along the shores have resulted in the current state of the Harbour *(*Birch and Scollen, 2003, Snowden and Birch, 2004 in Hedge *et al.*, 2013). Over 50% of sediments exceed Interim Sediment Guideline-High concentrations for lead and 100% of sediment exceeds trigger value (Hedge *et al.*, 2013). Birch and Taylor (2002a, b, c in Hedge *et al.*, 2013) report that for copper, lead and zinc 2%, 50% and 36% of the estuary, respectively, have metal concentrations that have a high risk of adverse effects to the benthic populations.

Litter is possibly of greater public concern in the water ways, because it is more visible, and meaningful to the general public. MEMA (2013) identified that litter, rubbish and marine debris was considered a threat to the environmental benefits of the Harbour, as well as oil and chemical spills. It is expected to get worse with an increase in population because community members note that there has already been an increase in rubbish in the marine estate and pollution of the water (compared with their own childhood memories). Local stakeholders also note issues such as visibly blocked stormwater drains and over full bins. It was felt by many stakeholders that there were not really programs addressing rubbish and not much policing of these issues.

Destruction of natural foreshore vegetation

Saltmarsh, mangroves and seagrasses, which grow in the soft sediments of estuaries are extremely valuable environmentally for their ecosystem services, as well as economically. Alive, seagrass mats help to stabilise the estuary floor and prevent erosion in high energy environments. Dead, they wash up on shore and provide a valuable food source (Hedge *et al.*, 2013). Mangroves and saltmarsh also provide stabilisation in the inter-tidal zone, play an important role in filtering nutrients and sediments from runoff and also provide food sources for the marine environment.

The area of saltmarsh, mangroves and seagrass are under threat from the construction of artificial seawalls, destroyed to improve views, trampling from recreational users, and indirect destruction from poor water quality and other habitat requirements. Estimates in 2005 indicate less than 37ha of saltmarsh in the Harbour, which is considered a dramatic decline from pre-European settlement (Hedge *et al.*, 2013). McLoughlin (2000) reports that once the Harbour area was well settled in the 20th century and sedimentation built up, mangroves began to colonise further up the tributary rivers creating a decline in the saltmarsh. The current area of mangroves is estimated at 184ha (Hedge *et al.*, 2013). The area of seagrass in the Harbour is estimated to have expanded from 59.2ha in 1978, to 87.4ha in 1986, but then decreased again in 2003 to 49.5 ha (Hedge *et al.*, 2013).

Stakeholders acknowledge that the loss of 'natural areas' is a threat to the economic benefit from 'nature tourism' MEMA (2013). From the macrophytes alone, using the dollar value figures given in Hedge *et al.*, (2013), the direct and indirect value of the seagrass in the Harbour is estimated to be $940,500 per year, and the mangrove and saltmarsh are $2,207,790 per year.

Stormwater – potential future loads and impacts on estuary condition

Sydney's population is growing faster than it did over the last 20 years. Consequently, to meet the needs of an increasing population, growth needs to be planned and managed. The NSW Government's future vision for Sydney is to have 'a strong global city [that is] a great place to live'. To achieve this, the Government has developed an action plan (*A Plan for Growing Sydney* – NSW Department Planning & Environment, 2014) focused on bringing all stakeholders together with the

common purpose of developing a competitive economy with world class services and transport; greater housing choices to meet residents changing lifestyles; healthy well connected communities and; a sustainable resilient city that cares for the natural environment and has a balanced approach toward the use of land and resources. It is recognised that as the city grows, good urban design and planning is critical so that the city's built environment is energy efficient, sustainable and protects the environment. For areas already established, urban renewal is also recognised as necessary for community benefit. That is, the process of planning and developing changes to streets, infrastructure and the public domain. One component of urban renewal planned for Sydney is the creation of interlinked green spaces across Sydney. Part of this entails investment into urban renewal in main transport corridors between strategic urban centers and CBD's.

Worst case option

A Plan for Growing Sydney aims to fashion a more resilient city that has connected green spaces, infrastructure and housing. This includes the acceleration of urban renewal at train stations, providing homes closer to jobs, growing Sydney CBD and greater Parramatta as Sydney's second CBD, increasing productivity of Western Sydney through growth and investment, enhancing Sydney's Gateways (Port Botany, Sydney Airport and Badgerys Creek Airport) and managing long-term growth. More intensive development across the city will need to be matched with adequate investment into infrastructure and services, open spaces and renewed bushland to support healthy lifestyles of the community. For example, water management including stormwater systems and implementation of Water Sensitive Urban Design (WSUD) are essential for reducing the pressures on water quality of an increasing population and built environment. To illustrate the importance of WSUD the Sydney Harbour CAPER DSS was used to estimate potential pollutant loads for the catchment as a whole and major subcatchments of Sydney Harbour if urban density increases in the future (in line with the Plan for Growth) without implementation of WSUD techniques in infill and new developments.

Catchment Loads

Without the implementation of WSUD, increasing urban density will result in increased pollutants from areas in and around growth centers and in the overall catchment. Using the Sydney Harbour CAPER DSS, the effect of increased urban density without the use of any WSUD was investigated in relation to key pollutants (TN, TP, Total Suspended Solids (TSS), *Enterococci* and *faecal coliforms*). Figure 13 represents estimated increases in the key pollutants for the 4 major subcatchments of Sydney Harbour (Parramatta, Lane Cove, Middle Harbour and Port Jackson) as well as the total catchment if WSUD is not implemented in conjunction with dense urban growth in the future.

Pygmy Leatherjacket (*Brachaluteres jacksonianus*)
Fairy Bower – Manly

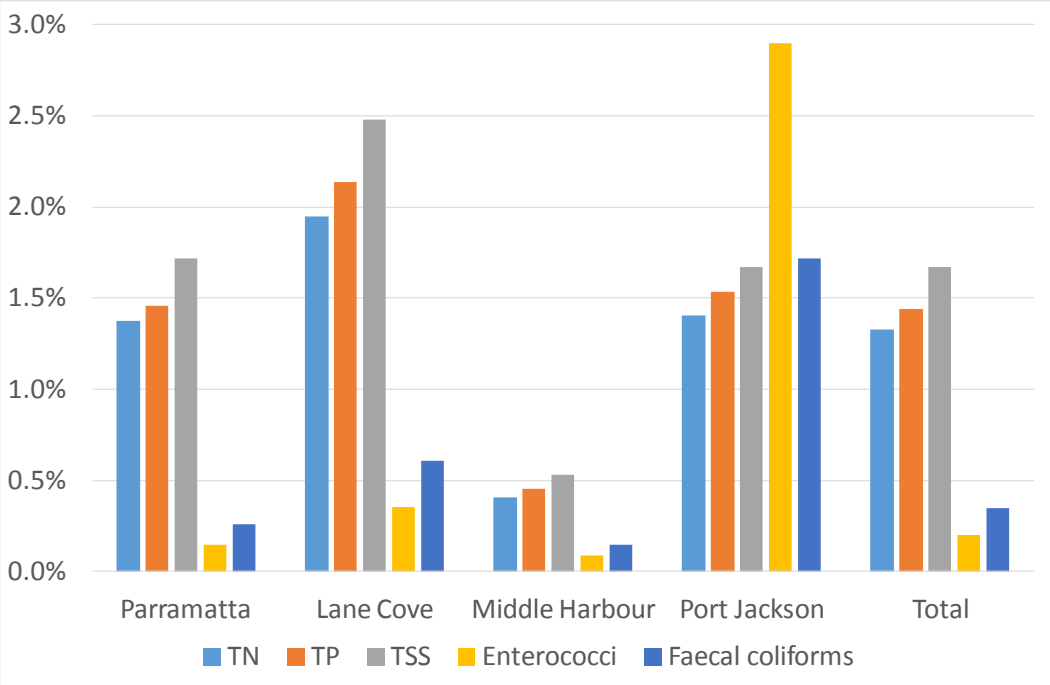


FIGURE 13. POLLUTANT IMPACT ON MAJOR SUBCATCHMENTS WITH INCREASING DENSITY OF URBAN AREAS AND NO WSUD

With increased urban density and no WSUD, in general, all subcatchments (as well as the catchment as a whole) are expected to have the greatest load increases in TSS, TP and TN compared to *Enterococci* and *faecal coliforms* loads. Increases in TSS, TP and TN for Parramatta, Port Jackson and the catchment as a whole are estimated to be around 1.5% with increases for Lane Cove slightly higher around 2-2.5%. The lowest impact is expected in Middle Harbour due to the relatively low level of urban infill redevelopment expected in this subcatchment. TN, TP and TSS loads are estimated to increase around 0.5% with increases in *Enterococci* and *faecal coliforms* even lower. The greatest load increases of *Enterococci* and *faecal coliforms* into the system are expected to come from the Port Jackson subcatchment with an increase in *Enterococci* estimated to be nearly 3% and an increase in *faecal coliforms* around 1.5%.

Estuary condition

Increases in pollutant loads of TN, TP and TSS have also been estimated for estuary zones associated with the 4 major subcatchments (Parramatta, Lane Cove, Middle Harbour and Sydney Harbour) if urban density were to increase without the implementation of WSUD as part of developments.

Figure 14 illustrates the estimated increases in pollutant loads in the Parramatta estuary zones for the worst case scenario. In general most areas in the Parramatta subcatchment are estimated to have the greatest increases in TSS loads followed by TP and then TN loads. Insignificant or no increases in concentrations of all three pollutants investigated are estimated to occur in the estuary zones of France Bay, Exile Bay and Hen and Chicken Bay; Lower Iron Cove; Manns Point to Downstream of Drummoyne Bay; Morrisons Bay to Looking Glass Bay and; from Duck River to Wentworth Point. All other estuary zones are estimated to have each pollutant increase loads marginally by approximately 0.3% or above.

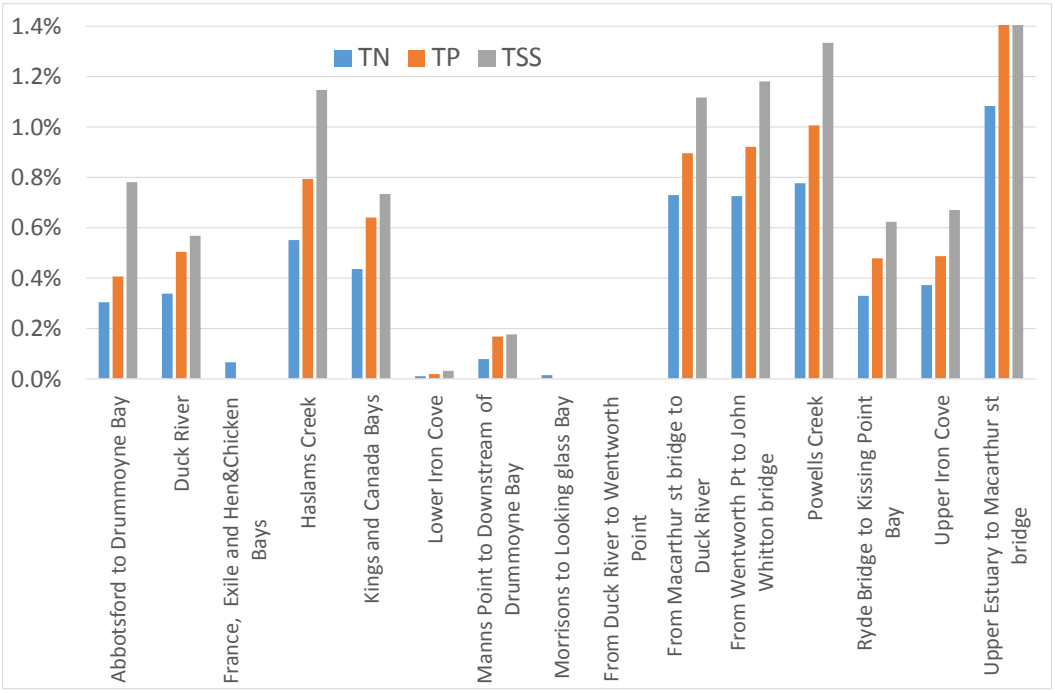


FIGURE 14. POLLUTANT LOADS ESTIMATED FOR URBAN GROWTH AREAS OF PARRAMATTA WITHOUT IMPLEMENTING WSUD

More specifically, the greatest increases in TSS are expected in the Upper Estuary to Macarthur Street Bridge (1.4%); Powells Creek (>1.2%); from Wentworth Point to John Whitton Bridge; Haslams Creek and; from Macarthur Street bridge to Duck River (each <1.2%). Similarly the greatest increases TP in the Parramatta subcatchment are expected in Upper Estuary to Macarthur Street Bridge (1.4%); Powells Creek (1%); from Wentworth Point to John Whitton Bridge and; from Macarthur Street Bridge to Duck River (each ~0.9%). The greatest increases expected in TN in this subcatchment are also estimated to occur in these four areas with Upper Estuary to Macarthur Street Bridge estimated to have the highest increase in loads of around 1.0% and Powells Creek; from Wentworth Point to John Whitton Bridge and; from Macarthur Street Bridge to Duck River each contributing increased TN loads of just under 0.8%.

The Lane Cove subcatchment has been divided into four main areas: Gore Creek to Tambourine Bay; from Epping Road to Tambourine Bay; from Millwood Avenue to Epping Bridge; and Upper Estuary to Millwood Avenue Bridge, for the purposes of estimating estuary zones that may experience the greatest change in pollutant concentrations if urban densities increase without the implementation of WSUD (Figure 15).

Overall most estuary zones associated with the Lane Cove subcatchment are estimated to have the greatest increases in TSS concentration followed by TP and then TN concentrations. The greatest increase in TSS concentrations is estimated to occur in Gore Creek to Tambourine Bay (<1.0%), followed by Upper Estuary to Millwood Avenue Bridge (~0.8%). From Epping Road to Tambourine Bay and from Millwood Avenue to Epping Bridge each zone is estimated to have TSS concentration increases greater than 0.6%. In contrast, the greatest increase in TP is expected to occur in the Upper Estuary to Millwood Avenue Bridge zone (~0.6%). The other three zones are estimated to have increases of TP around 0.5% each. Increases in TN concentrations range from approximately 0.3% in the Millwood Avenue to Epping Bridge zone up to greater than 0.4% in the Upper Estuary to Millwood Avenue Bridge zone.

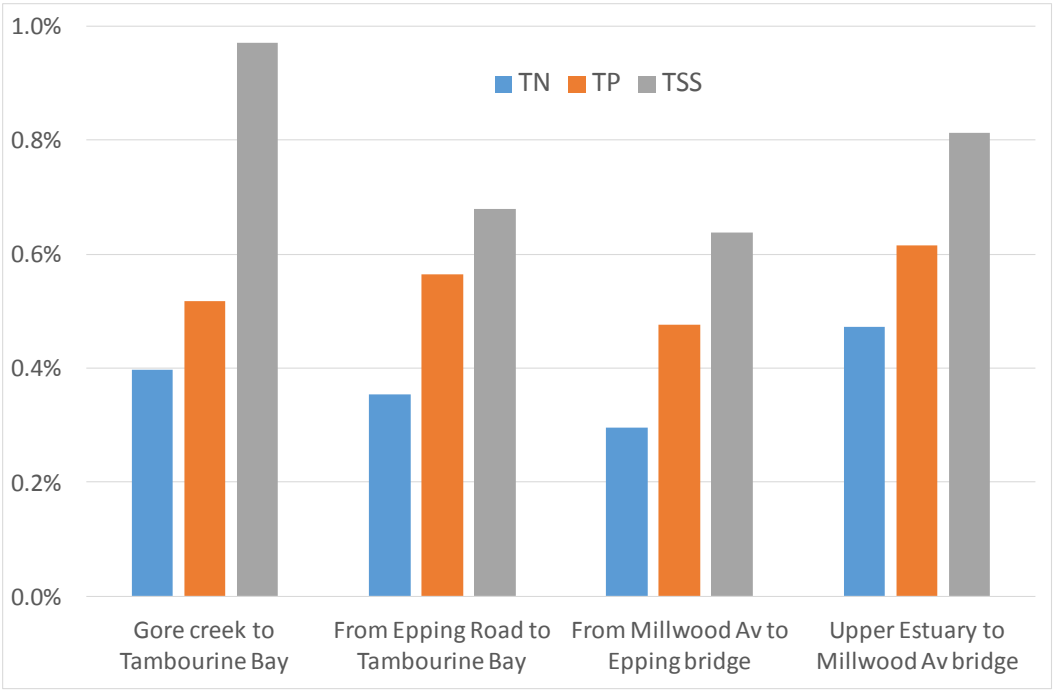


FIGURE 15. INCREASES IN POLLUTANT CONCENTRATIONS ESTIMATED FOR ESTUARY ZONES OF LANE COVE WITHOUT IMPLEMENTING WSUD

Five estuary zones have been considered in the Middle Harbour subcatchment in relation to increases in pollutant loads of TN, TP and TSS if urban density increases without applying WSUD (Figure 16).

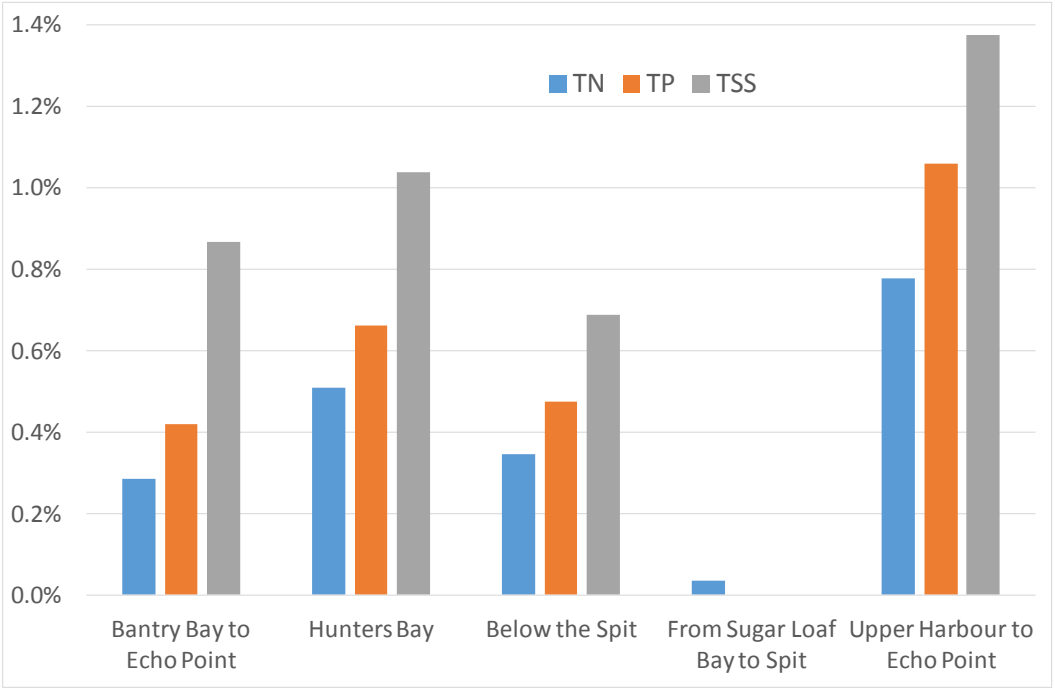


FIGURE 16. INCREASES IN POLLUTANT CONCENTRATIONS ESTIMATED FOR ESTUARY ZONES OF MIDDLE HARBOUR WITHOUT IMPLEMENTING WSUD

As with other estuary zones the greatest increases in pollutant loads for individual areas are generally estimated to be greatest for TSS followed by TP and then TN (apart from Sugar Loaf Bay to the Spit). The estuary zones with the greatest increases estimated for all pollutants is Upper Harbour to Echo Point (TSS <1.4%; TP >1.0% and; TN~0.8%). Hunters Bay is estimated to have the second highest pollutant concentrations increases (TSS ~1.0%; TP >0.6% and; TN ~0.5%). Lower increases in TSS pollutant concentrations are expected in the Bantry Bay to Echo Point area (around 0.9%) and Below the Spit (~0.7%). For both the zones, Bantry Bay to Echo Point and Below the Spit, increases in TP concentrations are estimated to be below 0.5% each and increases in TN are estimated to be lower (<0.4% in both zones). The only zone within the Middle Harbour subcatchment with insignificant or no estimated pollutant increases with increasing urban density and no WSUD techniques applied is from Sugar Loaf Bay to the Spit.

Individual estuary zones of Sydney Harbour subcatchment have also been investigated for expected rises in pollutant loads if urban density increases without using WSUD (Figure 17).

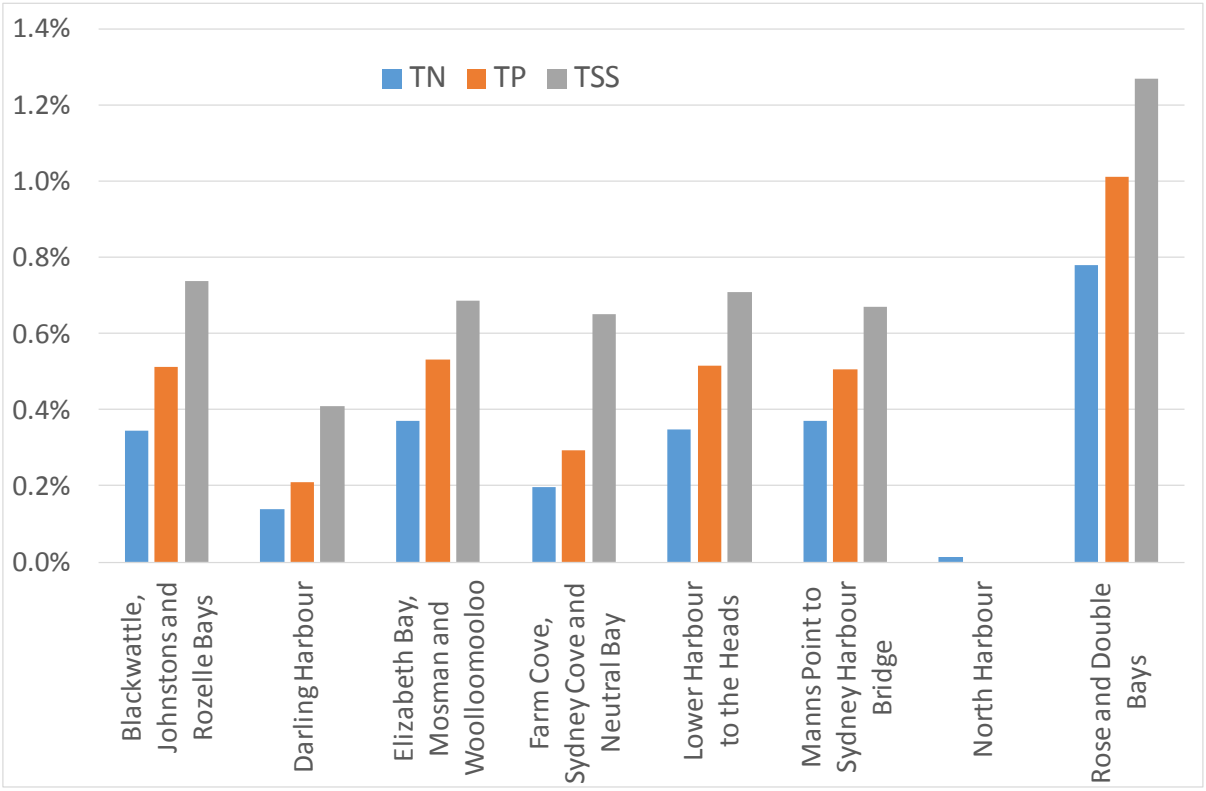


FIGURE 17. INCREASES IN POLLUTANT CONCENTRATIONS ESTIMATED FOR ESTUARY ZONES OF PORT JACKSON WITHOUT IMPLEMENTING WSUD

Similar to the other subcatchments investigated, individual areas are generally expected to have the greatest increases in TSS concentrations followed by TP and TN. In the Sydney Harbour subcatchment, one zone, Rose Bay and Double Bay, is clearly expected to have the greatest increases in all three pollutants (TSS >1.2%; TP ~1.0%; and TN ~0.8%). In contrast, the North Harbour zone is the only place where increases in all pollutants are expected to be insignificant or have no change. For all other areas investigated, increases in pollutants are estimated to be around 0.7% for TSS (except Darling Harbour (0.4%), between ~0.2- 0.5% for TP and approximately 0.1 to <0.4% for TN.

Best case options

Using *A Plan for Growing Sydney,* six options were considered for the expansion of Sydney's urban density that utilises urban renewal corridors as an opportunity to implement WSUD. WSUD options developed to illustrate impacts were chosen to represent middle ground effectiveness out of available treatment trains. For example, the use of rainwater tanks, swales, GPT and bioretention in a treatment train. Four of the six scenarios investigated also consider retrofitting given percentages of existing urban areas.

The six scenarios considered using urban renewal corridors for WSUD estimated from *A Plan for Growing Sydney* are:

1. Infill redevelopment with 90% WSUD (multiple treatment trains)
2. Infill redevelopment with 70% WSUD (multiple treatment trains)
3. Infill redevelopment with 90% WSUD PLUS retrofit 10% remaining urban catchment area
4. Infill redevelopment with 70% WSUD PLUS retrofit 10% remaining urban catchment area
5. Infill redevelopment with 90% WSUD PLUS retrofit 20% remaining urban catchment area
6. Infill redevelopment with 70% WSUD PLUS retrofit 20% remaining urban catchment area

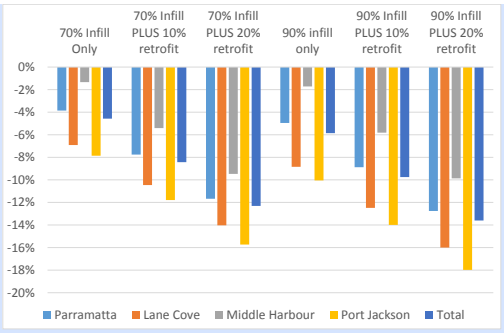
Catchment Loads

Growing urban density will result in increased pollutants in and around growth centers and in the overall catchment. Using the Sydney Harbour CAPER DSS, pollutant loads for TN, TP, TSS, *Enterococci* and *faecal coliforms* have been estimated for each major subcatchment and the catchment as a whole (total) if each of the six urban renewal scenarios were implemented.

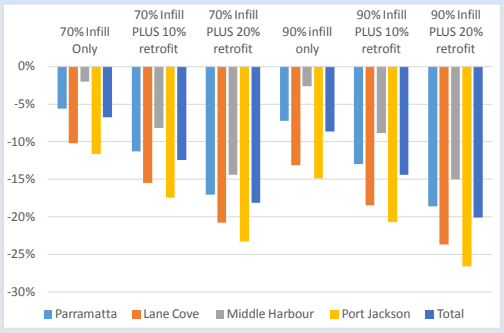
Figure 18 represents estimated reductions in each of the pollutants for all major subcatchments and the catchment as a whole according to each urban renewal scenario.

Sponge Garden at South Head

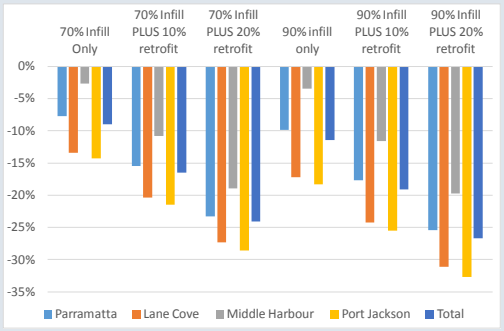
TN



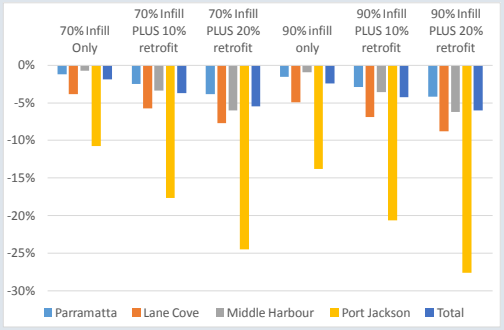
TP



TSS



Enterococci



Faecal coliforms

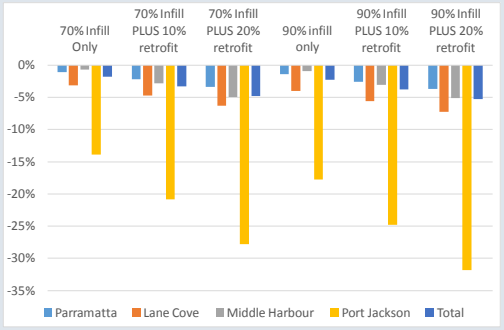


FIGURE 18. IMPACT OF BEST CASE GROWTH OPTIONS USING WSUD IN INFILL REDEVELOPMENT AND RETROFITTING EXISTING URBAN AREAS ON POLLUTANT LOADS

Figure 18 shows:

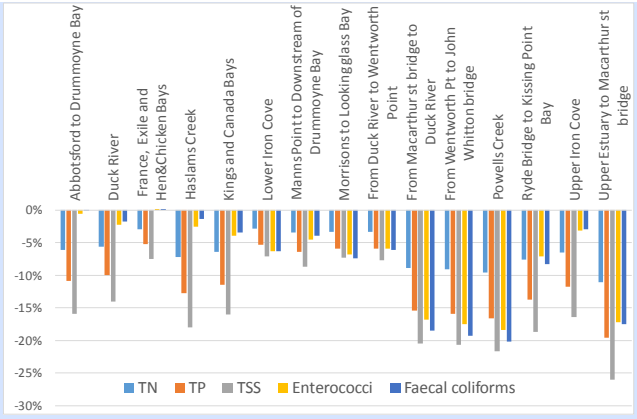
- As expected the greatest reductions in all pollutant loads throughout the subcatchments and for the catchment as a whole are expected to be achieved with infill redevelopment with 90% WSUD and retrofitting of 20% of the remaining urban catchment area with total reductions in:
    - TN ranging from approximately 10% in Middle Harbour up to 18% in Port Jackson.
    - TP ranging from 15% in Middle Harbour to 26% in Port Jackson.
    - TSS ranging from 20% in Middle Harbour to over 30% in Port Jackson.
    - *Enterococci* and *faecal coliforms* ranging from under 5% for Parramatta to over 30% for Port Jackson.
- Focusing on WSUD infill redevelopment only will address potential increases in pollutant loads expected under the 'worst case' option above and lead to slight improvements in water quality. High levels of adoption in these areas would be required to achieve this however, existing issues with water quality in Sydney Harbour would not be addressed. In order to improve water quality in Sydney Harbour, focusing on infill redevelopment alone is not the solution, some degree of retrofitting of existing areas must also be undertaken. Given physical restrictions on the extent to which infill areas are able to be treated retrofit is likely to be necessary to provide a buffer against potential increases in pollutant loads as the density of urban areas is increased.
- Some trade-off between the extents to which WSUD is focused in infill redevelopment areas versus being applied as retrofit to existing areas is possible. For example for all pollutants 70% WSUD in infill areas with 20% retrofit is similar in effectiveness (slightly more effective) than 90% infill with 10% retrofit. Given the relative expense and difficulty of retrofitting WSUD as compared to including it in redevelopments this has implications for the best strategy that can be adopted by Councils.
- When considering all six urban renewal options, there appears to be a general trend of reductions in pollutants. All options are most effective in Port Jackson, although differences between Port Jackson and Lane Cove are relatively small for nutrients and sediments. The least affected areas for nutrients and sediments are in Middle Harbour, while for pathogens the smallest impact is in Parramatta (due to the large proportion of pathogens sourced from sewer overflows in this area).

Estuary condition

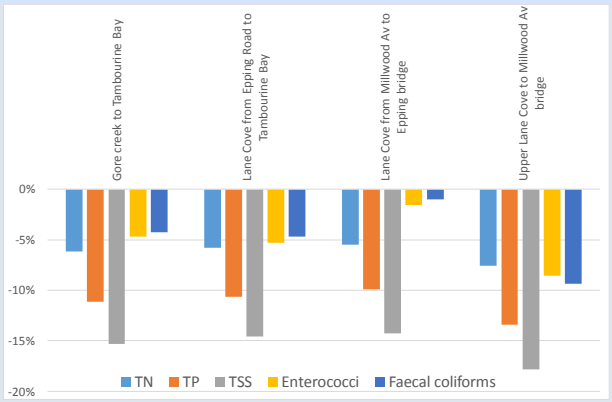
Changes in the future estuary condition (as measured by pollutant concentration) have been projected for estuary zones associated with the major subcatchments of Sydney Harbour (Parramatta, Lane Cove, Middle Harbour and Sydney Harbour) by estimating increases in pollutant loads of TN, TP, TSS, *Enterococci* and *faecal coliforms* if infill redevelopment with 70% WSUD and retrofitting of 10% of remaining urban subcatchment areas was implemented.

Future changes in pollutants estimated for estuary zones associated with each of the major subcatchments for the scenario of 70% WSUD in infill redevelopment and retrofitting of 10% of the remaining urban subcatchment area are represented in Figure 19.

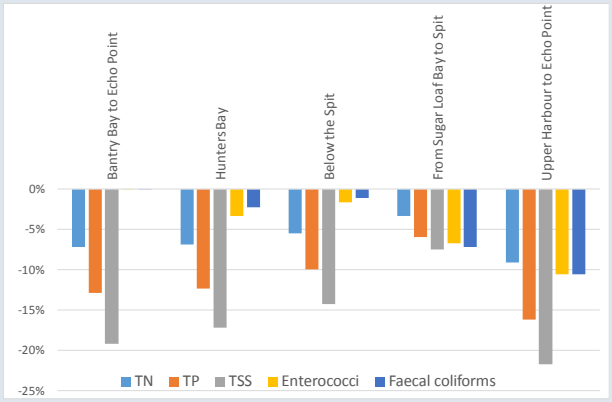
Parramatta



Lane Cove



Middle Harbour



Port Jackson

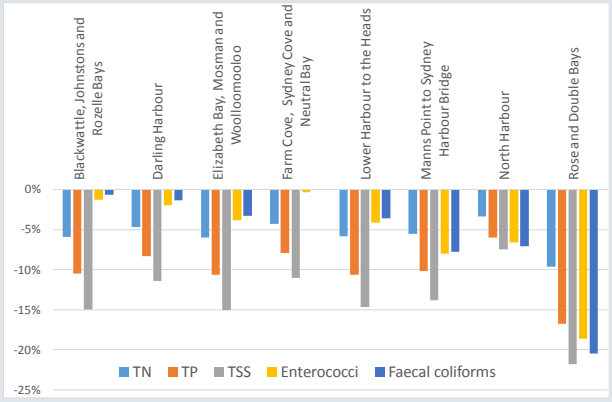


FIGURE 19. ESTUARY IMPACTS OF INFILL REDEVELOPMENT WITH 70% WSUD AND RETROFITTING OF 10% OF REMAINING URBAN SUBCATCHMENT AREA FOR ESTUARY ZONES ASSOCIATED WITH EACH OF THE MAJOR SUBCATCHMENTS

Figure 19 shows that:

- Estuary zones in Parramatta that are estimated to most benefit in overall pollutant reductions (TN, TP, TSS, *Enterococci* and *faecal coliforms*) with the implementation of 70% WSUD and retrofitting of 10% of the remaining urban subcatchment area are: Upper Estuary to Macarthur St Bridge; from Macarthur Street Bridge to Duck River; from Wentworth Point to John Whitton Bridge and; Powells Creek. In these four areas reductions in TSS are estimated to be around 20% or greater, TP, *Enterococci* and *faecal coliforms* around 15% or greater and TN around 10%. Pollutant reductions in the rest of the Parramatta estuary are varied and generally to a lesser extent. There is a general pattern indicating that TSS loads will be reduced the most in any of the subcatchment areas under the scenario applied, however the difference between TSS reductions and other pollutants in some areas is marginal.
- In Lane Cove, estimated reductions in TN, TP and TSS are similar for all 4 subcatchment areas considered (around 5%; 10% or greater and; around 15% respectively) with pollutant reductions estimated to be slightly higher in the Upper Lane Cove to Millwood Avenue Bridge compared to the other three zones. In comparison, reductions for *Enterococci* and *faecal coliforms* for the 4 zones considered in Lane Cove are varied. Lane Cove from Millwood Avenue to Epping Bridge is estimated to have the lesser marginal reductions in *Enterococci* and *faecal coliforms* compared to the other Lane Cove areas (each around 1%). In the estuary zones of Gore Creek to Tambourine Bay and Lane Cove from Epping Road to Tambourine Bay reductions in *Enterococci* and *faecal coliforms* are expected to be similar (~5% and <5% respectively). The greatest reductions in *Enterococci* and *faecal coliforms* are estimated to be the greatest in the Upper Lane Cove to Millwood Avenue ridge estuary zone (just under 10% for each pollutant).
- Estimated reductions in pollutants for each estuary zone in Middle Harbour were also considered. At Bantry Bay to Echo Point and Hunters Bay, estimated pollutant reductions are over 15% for TSS, over 10% for TP and greater than 5% for TN. The reductions in *Enterococci* and *faecal coliform* loads at Hunters Bay are estimated to be below 5% however at Bantry Bay to Echo Point there is expected to be no change in *Enterococci* and faecal coliform loads. Below the Spit, reductions in all key pollutants are estimated to occur but to a lesser extent than at Bantry Bay to Echo Point and Hunters Bay. Reductions in TSS are estimated to be the greatest in this zone; nearly 15%. For TP a reduction of 10% is estimated and for TN approximately a 5% reduction is predicted. Reductions in *Enterococci* and *faecal coliforms* are also expected but marginal (around 1% each). In the area from Sugar Loaf Bay to the Spit, a change in pollutant loads is expected to result in reduced TP, TSS, *Enterococci* and *faecal coliforms* loads by over 5% each and the TN load less than 5%. The Upper Harbour to Echo Point is estimated to experience the greatest reductions in all pollutant loads investigated compared to other areas in Middle Harbour with 70% WSUD and retrofitting of 10% of the remaining urban subcatchment area applied. These estimated reductions are around 10% for *Enterococci* and *faecal coliforms*, just under 10% for TN loads, more than 15% for TP loads and over 20% for TSS.
- In Port Jackson, the greatest load reductions for all pollutants are expected to occur in Rose and Double Bays, with decreases in TSS and *faecal coliforms* around 20% each, TP and *Enterococci* over 15% each and TN approximately 10%. All other (7) estuary zones are expected to experience less and varying degrees of pollutant reductions. Reductions in TSS are estimated to be between 10- 15% for all of the remaining subcatchments apart from North Harbour where decreases are estimated to be under 10%. Reductions in TP loads throughout the seven subcatchments are generally estimated to be between 5 -10% and for TN around a 5% or lower load decreases is estimated. *Enterococci* and *faecal coliform* load reductions are more varied with Manns Point to Sydney Harbour Bridge and; North Harbour estimated to have reductions of over 5% for each pollutant. The estuary zones of Elizabeth Bay, Mosman and

Woolloomooloo and Lower Harbour to the Heads are estimated to have reductions less than 5% for each of the pollutants *Enterococci* and *faecal coliforms*. The remaining subcatchments: Blackwattle, Johnstons and Rozelle Bays; Darling Harbour; and Farm Cove, Sydney Cove and Neutral Bay are estimated to have no change or marginal reductions in *Enterococci* and *faecal coliform* loads.

- In general the greatest improvements in estuary water quality are seen in upper estuary zones, in particular in the Lane Cove and Parramatta estuaries. This is because the greater flushing of the lower estuary and outer Harbour zones provides a buffer to changes in loads in these subcatchments.

Sewer overflows

As was shown in Section 1, sewer overflows are the primary source of pathogens, *Enterococci* and *faecal coliforms*, produce approximately 10% of nutrient inputs to Harbour but input only 2% of the sediment loads. As such is can be expected that sewer overflows impact most on recreational uses of the Harbour through pathogens. Impacts on nutrient inputs and subsequent nuisance algal growth and turbidity have the potential to produce recreational, aesthetic and environmental impacts.

Sydney Water has an ongoing program of works designed to reduce sewer overflows. This program targets particularly problematic overflow points by reducing the influx of stormwater to the sewer system, providing capacity for retention of flows to prevent spills, reducing pollutant concentrations of overflows and increasing the overall capacity of the system to cope with flows. In order to demonstrate the potential of management of sewer to affect water quality, a relatively simple scenario which limits the number of overflow events to at most 40 events over a 10 year period is used. In reality this scenario is unlikely to accurately reflect the prioritisation process or complexity of options for addressing overflow points but does demonstrate the feasible level of potential impacts of sewer overflow management on water quality.

Impacts of this scenario on pollutant loads from each of the major subcatchments are shown in Figure 20.

Anemone Hermit Crab (*Dardanus pedunculatus*)

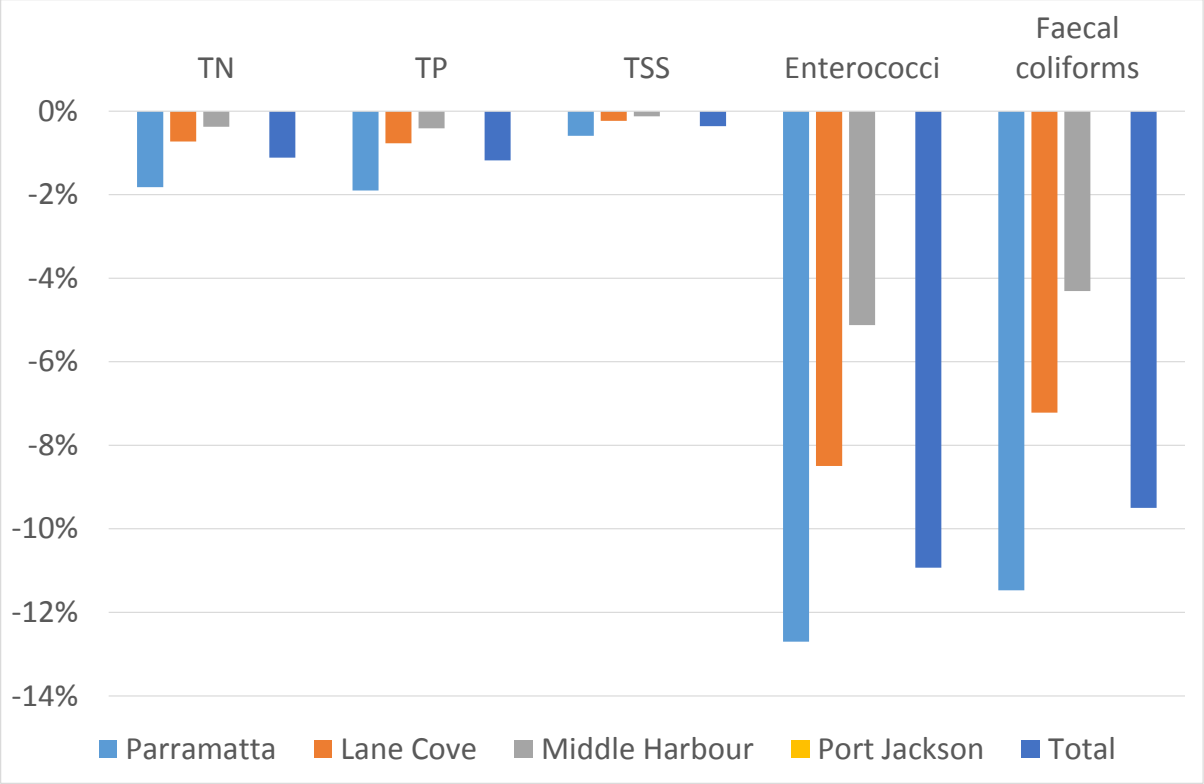


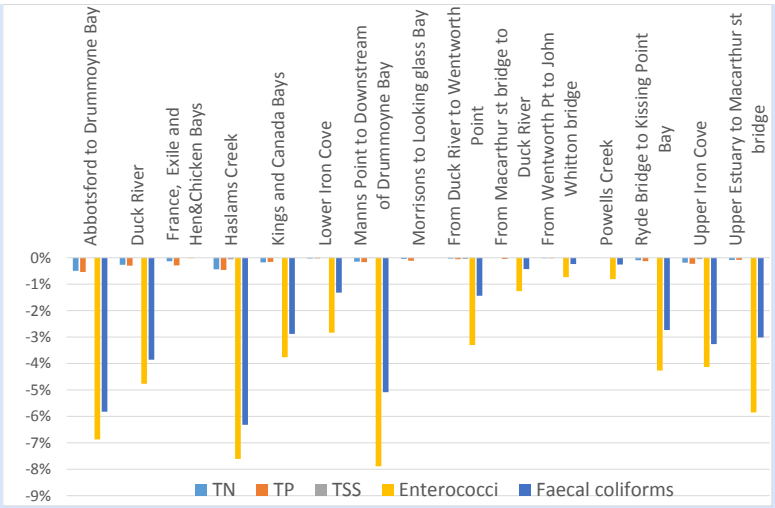
FIGURE 20. IMPACT OF LIMITING SEWER OVERFLOWS TO 40 EVENTS IN 10 YEARS ON POLLUTANT LOADS

Figure 20 shows that, as expected, the greatest impacts on loads are for *Enterococci* and *faecal coliforms*. Impacts on *Enterococci* range from 5% in Middle Harbour to 13% in Parramatta. Total *Enterococci* loads to the Harbour can be expected to decrease by 11%. Impacts on *faecal coliforms* are slightly less than for *Enterococci,* ranging from 4% in Middle Harbour to nearly 12% in Parramatta. Total *faecal coliform* loads to the Harbour would be expected to decrease by nearly 10%. Impacts on nutrients and sediments are substantially smaller than those on pathogens. Parramatta is the most affected subcatchment with a less than 2% decrease in nutrients and less than 1% impact on sediments. Impacts on total sediment and nutrient loads to Sydney Harbour are less than 1%.

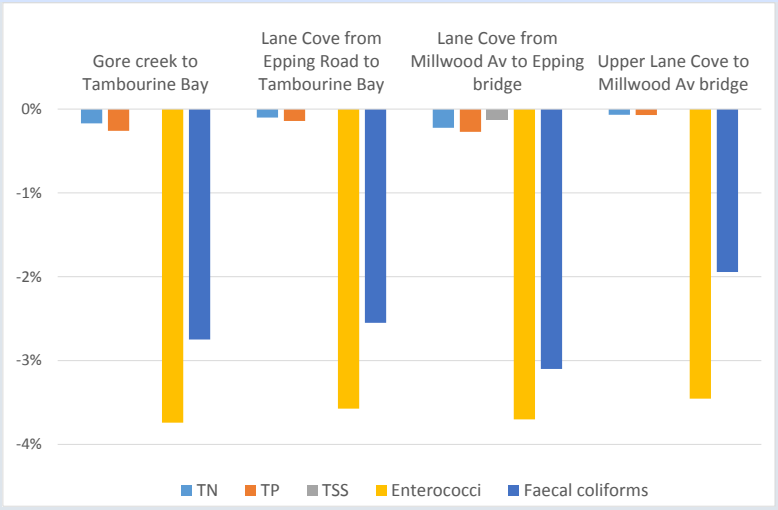
These changes in loads could be expected to impact on concentrations in the estuary, as shown in Figure 21.

Pineapple fish (*Cleidopus gloriamaris*)

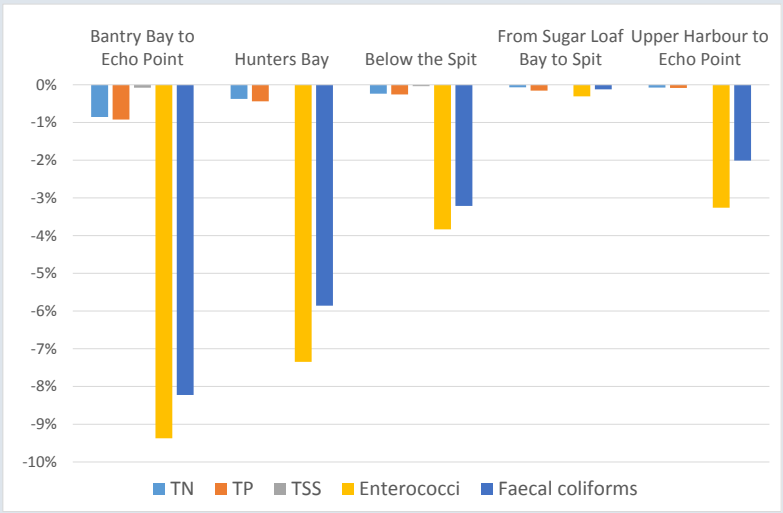
Parramatta



Lane Cove



Middle Harbour



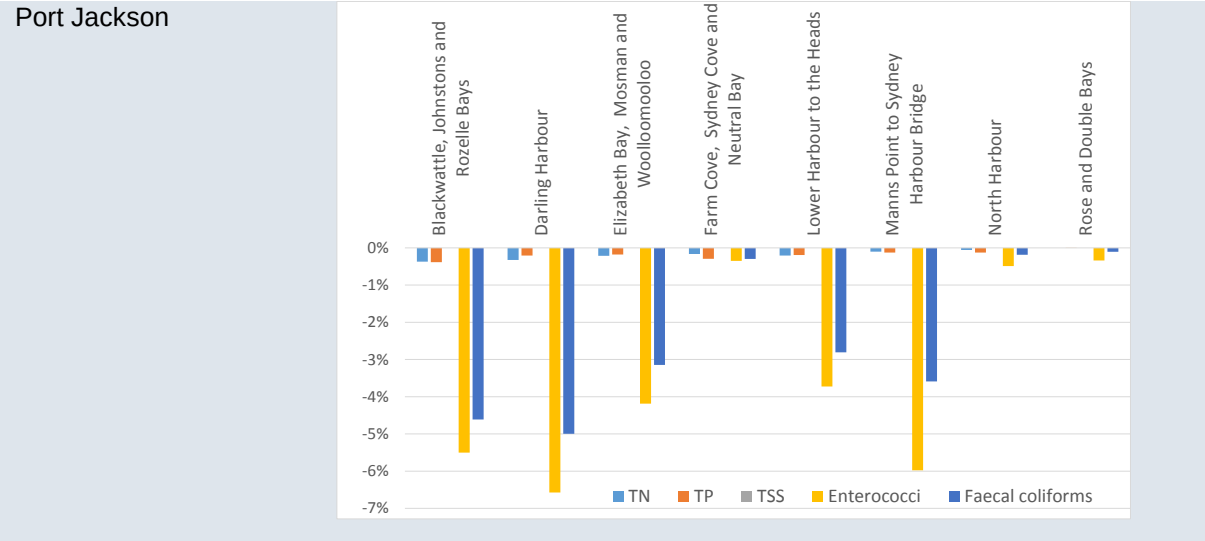


FIGURE 21. IMPACT OF LIMITING SEWER OVERFLOWS TO 40 EVENTS IN 10 YEARS ON ESTUARY WATER QUALITY

Figure 21 shows that the main impact on estuary water quality is in terms of pathogen concentrations. The largest impacts can be expected in Bantry Bay to Echo Point in Middle Harbour (9% *Enterococci*) and Haslams creek and Manns Point to downstream Drummoyne Bay in Parramatta (8% *Enterococci*). In general the lowest impact would be expected in estuary zones associated with Lane Cove. Relatively large impacts can be expected in zones in Port Jackson even though no subcatchment loads impacts are experienced here. This is because estuary water quality in this zone depends not only on the adjoining subcatchment areas but also on loads from upstream areas in Parramatta, Middle Harbour and Lane Cove.

Very little change in nutrient or sediment concentrations can be expected in any zone. These results show that improving sewer overflow performance can be expected to have substantial impacts on recreational water quality but relatively little impact on environmental outcomes.

Risk assessment of threats

Poor water quality from nutrients, sediment, pathogens, metals and chemicals, litter and the destruction of the natural vegetation to help ameliorate it, can have significant effects on the environmental condition, with flow-on effects to the social and economic benefits for Sydney Harbour and its community. Estimates of the change in pollutant loads from the catchment into the waterways are significant, and the poor water quality has, and will continue to, result in habitat destruction, loss of biodiversity and fish kills. The flow-on effects impact on the social benefit supplied by the Harbour. There is a general concern from the stakeholders about the water quality and litter pollution impacts on the visual amenity of the Harbour. Sedimentation, such as along the north and south arms of Sandyloaf Bay where Flat Rock Creek discharges into Long Bay and Sandy Bay, Clontarf, can make recreational boating difficult. Many community members report they do not catch the number of fish they used to expect (especially in the Greater Sydney region) and this is blamed in part on elements such as pollution but also to a perception of overfishing (MEMA, 2013). While other stakeholders feel that if the social value of the Harbour decreases, so does the tourism value of it, and also property values along the foreshores.

The likelihood of these threats (Table 2) eventuating, and the consequence if they eventuated, have been rated on the risk matrix used by MEMA (2013). The resulting risk assessment, given in Table 3, show that the major threats for the Sydney Harbour have a Low to Very High risk, and need to be addressed.

TABLE 3. LEVEL OF RISK ASSOCIATED WITH THREATS TO SYDNEY HARBOUR

Likelihood	Level of Risk				
Almost certain		* Vessel waste discharge * Domestic toxic chemical pollution	* Urban/ foreshore interface kills vegetation * Litter	*Stormwater runoff * Sewerage overflows * Lack of knowledge * Lack of enforcement	
Likely			* Lack of cohesion in WQ management		
Possible					
Unlikely				* Commercial toxic chemical pollution	
Rare					
Consequence level	Insignificant	Minor	Moderate	Major	Catastrophic

Legend

Very low	Low	Moderate	High-Very High

SECTION 4: ASSESSMENT OF MANAGEMENT OPTIONS TO MAXIMISE BENEFITS

This section proposes load and condition targets for Sydney Harbour and its catchment. Management actions to achieve these targets and address other threats raised in Table 2 are proposed and rated for their relative importance based on the risk level of the threat they address as well as their relative contribution to resolving the threat.

Load and condition targets

The CAPER DSS has been used to explore the potential impacts of land use change and management actions as well as to derive load and condition targets for Sydney Harbour. To model pollutant loads, the CAPER DSS uses a metamodel of several component models that have been calibrated and tested for Sydney Harbour:

- The Source Catchments model, which is used to estimate diffuse catchment loads given land use.
- The MUSIC model, which estimates the impacts of various WSUD options on pollutant loads from urban areas.
- Empirical data derived from models and monitoring held by Sydney Water on the quantity and quality of sewer overflows.

These metamodels are simplified versions of the original models. They abstract away from more complex calculations of daily and in some cases subdaily loads and flows to directly produce estimates of average annual loads. The metamodels in the DSS very accurately reproduce estimates of average annual loads from these source models. This allows the DSS to produce estimates of changes in annual loads in line with the original models so that differences between scenarios can be determined. The DSS does this without the overheads of the original more complex models, such as long run times. This type of model is best used to estimate the magnitude and direction of changes from a base case scenario, rather than to forecast specific loads. The variability of actual loads on a year to year basis is strongly affected by climate. As such, load targets that focus on relative changes to average annual loads, which remove this climate influence, are more appropriate than fixed loads. The DSS is designed to be able to model relative changes in loads that underpin load targets as accurately as the more detailed calibrated original models. A more detailed description of the Sydney Harbour CAPER DSS can be found in Appendix 4.

Catchment load and estuary condition targets have been developed using feasible scenario options for both the management of stormwater and improvements in sewer overflow performance. These targets are based on assumptions of feasible change developed in scenarios:

- 70% WSUD applied to infill redevelopment and 10% retrofit of existing areas.
- Improving sewer overflow performance to limit overflows to no more than 40 events in 10 years.

While targets have been developed considering feasible levels of change defined by these options, there are many other combinations of actions that could achieve these targets. These targets are designed to provide direction to change rather than being prescriptive of the exact management actions that should be undertaken to achieve these goals.

Load targets are presented as a trajectory showing both the target level of improvement in water quality as well as the potential worst case scenario if management is not improved. This worst case outcome assumes:

- Infill redevelopment with increased urban density with no WSUD.
- Declines in sewer overflow performance due to increases in stormwater volumes. The volume of sewer overflows under this scenario is assumed to increase proportional to the increase in stormwater.

In reality the benefits from management come from maximizing the differences between these two outcomes rather than simply in terms of any improvement in water quality.

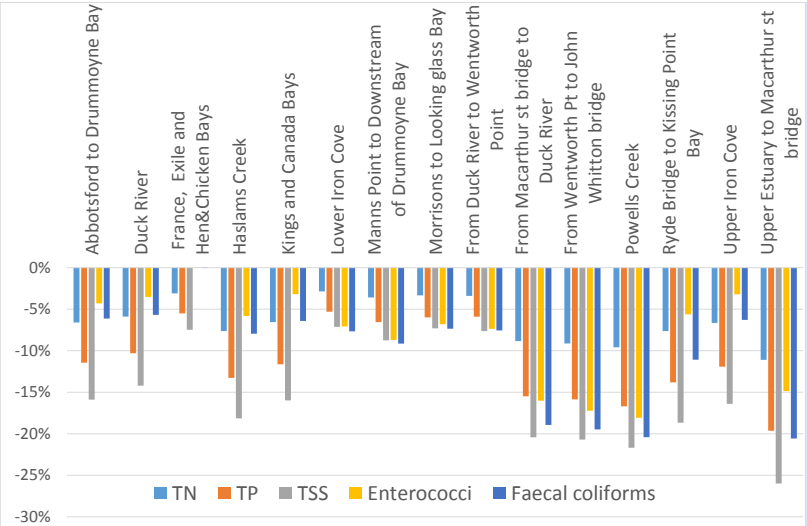
Table 4 shows the change in catchment loads under the target and worst case scenarios for the entire catchment and the major subcatchments. Detailed load reduction targets for individual subcatchments and LGAs are given in Appendix 3.

TABLE 4. CATCHMENT LOADS CHANGES UNDER TARGET AND WORST CASE SCENARIOS

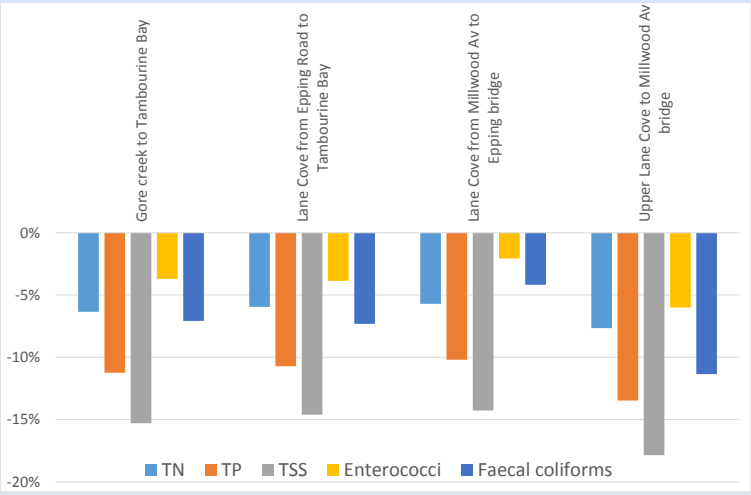
Catchment	Scenario	TN	TP	TSS	*Enterococci*	*Faecal coliforms*
Parramatta	Target	-0.1	-0.13	-0.16	-0.13	-0.14
	Worst case	0.02	0.02	0.02	0.02	0.02
Lane Cove	Target	-0.11	-0.16	-0.21	-0.1	-0.12
	Worst case	0.02	0.02	0.03	0.03	0.02
Middle Harbour	Target	-0.06	-0.09	-0.11	-0.06	-0.07
	Worst case	0	0.01	0.01	0.01	0.01
Port Jackson	Target	-0.12	-0.17	-0.21	-0.18	-0.21
	Worst case	0.01	0.02	0.02	0.29	0.02
Total	Target	-0.1	-0.14	-0.17	-0.12	-0.13
	Worst case	0.01	0.02	0.02	0.02	0.01

As can be seen here the catchment load targets are for decreases in pathogens between 6 and 21%, nutrients between 6 and 17% and sediments between 11 and 21%. Total loads for all pollutants would decrease by more than 10%. Without improved management, worst case increases in loads are between 0 and 29%. Total catchment loads would be expected to increase between 1 and 2%. Figure 22 shows the change in estuary water quality under the target scenario.

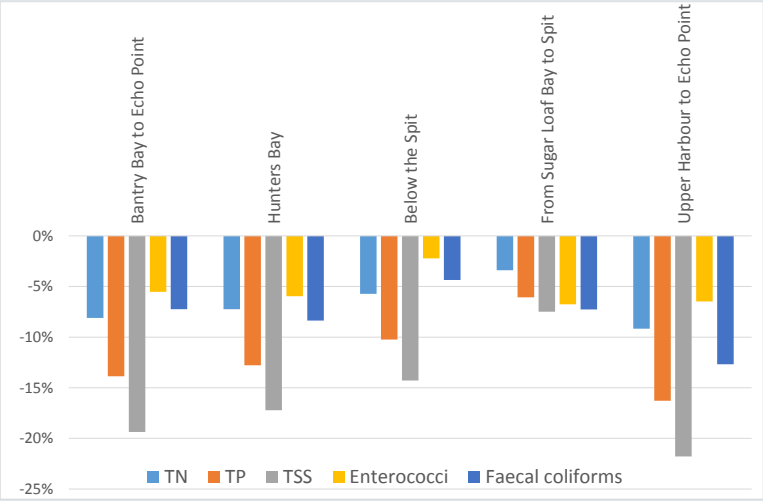
Parramatta



Lane Cove



Middle Harbour



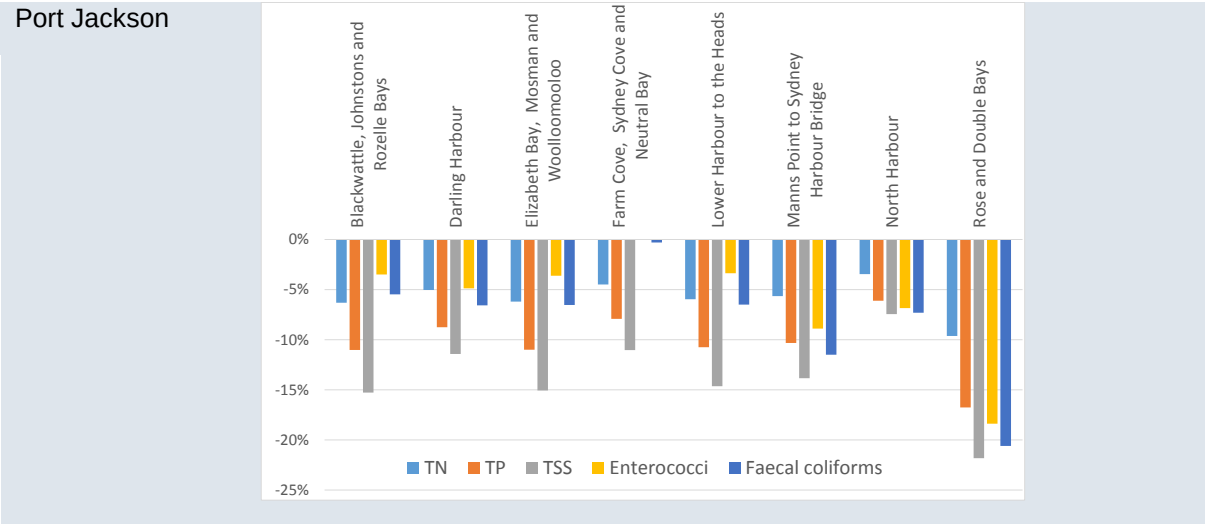


FIGURE 22. ESTUARY WATER QUALITY CHANGES UNDER TARGET SCENARIOS

Figure 22 shows that significant improvements in water quality would be expected across most zones of the estuary. In most zones the greatest improvement would be seen in TSS, although this is not always the case.

Benefits of the targets

Feedback from stakeholders (see Appendix 1) indicates that the Harbour and its freshwater tributaries are valued for recreation, their aesthetic values and for the biodiversity and ecological values they provide. Poor water quality was seen as a threat to all of these values. The load targets here aim to reduce the threat posed by declining water quality due to urban densification as well as providing benefits that increase the recreation, aesthetic and environmental values of Sydney Harbour and its tributaries. Meeting these load targets will help meet the goals and desires of the community, who said that they want to be able to:

- visit high quality, natural creeks and rivers close to where they live,
- eat fish from the Harbour and its tributaries, and,
- swim and recreate safely in the Harbour and its tributaries.

Modelling using the freshwater and estuary Bayesian Networks in the CAPER DSS (see Appendix 4) indicates that if these load targets are met, streams that have a natural base should see reduced turbidity, improved instream habitat, and as a result should have improved macroinvertebrate populations, more fish and frogs. These streams will not only provide greater environmental value but will also be safer areas for swimming and boating, more visibly appealing and be more likely to provide opportunities for fishing.

Decreasing loads delivered to the Harbour is also likely to lead to significant improvements in water quality in the Harbour and its estuaries, as shown above. Decreased nutrient and sediment loads will reduce the turbidity of the water through less suspended sediments and algal growth. This will in turn improve habitat condition by encouraging the growth of seagrass. Improved habitat will provide for increased fish populations. Improved water clarity along with decreased pathogen loads will improve recreational values associated with the Harbour as waterways become safer for swimming and boating. More natural water ways with greater water clarity will also increase the visual amenity associated with the Harbour and its tributaries.

By contrast, under a 'do nothing' scenario water quality can be expected to decline, leading to less habitat and poorer environmental values. The Harbour and its tributaries will be unsafe for recreation in more places and for a greater proportion of the time and visual amenity of all affected waterways will be reduced. This can be expected to lead to impact on tourism and other economic values as well as on the social and environmental benefits the Harbour provides.

Recommended management actions to address threats

Actions proposed to address the threats outlined in Table 2 are evaluated in Table 6. These recommendations were developed based on feedback from stakeholders received through the key stakeholder and community workshops (see Appendix 1) and in consultation with the project Advisory Committee. The relative priority of each recommendation has been addressed based on: the risk level of the threat it addresses; and, the relative contribution the action is likely to make in addressing the threat. Table 5 shows the way in which the priority of each action depends on both of these factors.

TABLE 5. ACTION PRIORITY RATING BASED ON RISK LEVEL OF THREAT AND CONTRIBUTION OF THE RECOMMENDATION IN ADDRESSING THE THREAT

Contribution to addressing threat	Risk level of threat			
	Very low	**Low**	**Moderate**	**High-Very high**
Low	Low	Low	Low	Low
Moderate	Low	Low	Moderate	Moderate
High	Low	Low	Moderate	High

Striped Anglerfish (*Antennarius striatus*)
with Paddle weed (*Halophila ovalis*)

TABLE 6. PRIORITY RECOMMENDATIONS BY COMMUNITY SECTOR

	Recommendation	Priority	Threat addressed										Contribution to addressing threat	Explanation
			Stormwater runoff	Sewerage overflows	Vessel waste discharge	Urban/foreshore interfaces directly or indirectly kills foreshore vegetation	Litter	Toxic chemical pollution (domestic)	Toxic chemical pollution (commercial)	Lack of knowledge about the water pollution cycle (generation, transport and impact)	Lack of enforcement, punishment and determent against inappropriate actions	Lack of cohesion in water quality management		
	Business		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**		
1	Use of biodegradable plastics and containers e.g. corn starch straws and cups to minimise plastic litter contaminating the Harbour.	Moderate					X						Moderate	Anecdotal evidence from community workshops suggests that a large proportion of litter is plastics from fast food outlets. These items are likely to persist in the environment in the form of microplastics. The use of biodegradable options such as corn starch straws and cups would reduce the impact of these types of rubbish

2	Incorporate WSUD into any redesign or redevelopment of commercial building sites – e.g. biofiltration systems for carpark runoff.	High	X										High	As was shown in the previous section, retrofitting and incorporating WSUD in redevelopments of existing urban areas are key to improving stormwater quality.
3	Undertake employee education focused on water quality and the links between their actions and the health and condition of the Harbour and its tributaries.	Moderate								X			Moderate	There is a vast literature that supports the idea that education and awareness leads to a change in practice, thus employees can be expected to improve their actions in relations to the water quality of their catchment with an increased awareness. Lack of community knowledge was seen as a particular problem by the stakeholders.
4	Incorporate ecoengineering in design phase of renewal of foreshore development and include public education/signage to educate the community on the benefits of these features.	Moderate				X				X			Moderate	Ecoengineered designs along the Harbour foreshores will enable a greater natural function at the interface between the urban and harbour environments. This will enable foreshore vegetation to maintain its ecological function, and be more aesthetically pleasing. Education of the community around the benefits of this approach to development is key to building community support for incorporating these concepts on renewal and development projects.

	Households, schools and community organisations													
5	Take actions on their own properties that support the load reduction targets for the catchment. These might include things like installing: rainwater tanks, permeable paving, rain gardens (small household scale bioretention systems).	High	X										High	Residential areas are a major contributor of stormwater to the Harbour and its waterways. Retrofitting existing urban areas with WSUD is essential to improving water quality. Household efforts to incorporate WSUD on their own properties are an important component of this change.
6	Let their friends, neighbours and/or customers know what actions they are taking to reduce stormwater pollution and improve the local waterways.	Low								X			.Low	Literature suggests that the adoption of new management practices is increased if some people trial the practice, and there is proof of concept that it works by someone's peers. Hence it would be expected that the adoption of WSUD practices would increase through the spread of word of mouth. Stakeholder feedback indicates that the general community have no idea of what happens to the stormwater and so act in ways that deteriorate water quality.
7	Raise awareness about the importance of proper disposal of litter and connection between disposal of chemicals, oils and paints through the stormwater system with poor water quality and environmental outcomes in the Harbour.	Moderate					X	X		X			Moderate	There is a vast literature that supports the idea that education and awareness leads to a change in practice, thus residents can be expected to improve their actions in relations to the water quality of their catchment with an increased awareness.

8	Participate in citizen science projects e.g. Streamwatch and volunteer with local Rivercare and Landcare groups to undertake environmental improvements in their own areas.	Moderate								X			Moderate	With the common perception from workshops that the general community has no idea of what happens to the storm water, there is a large potential for education and awareness to be increased. There is a vast literature that supports the idea that education and awareness leads to a change in practice, thus residents can be expected to improve their actions in relation to the water quality of their catchment with an increased awareness. Also citizen science projects have the added benefit of providing the participating community some ownership of the problem and the solution.
	Councils													
9	Signage to educate community about catchment they belong to – e.g. 'you are now entering the Sydney Harbour Catchment', stencilling of drains such as 'this drains to Sydney Harbour'.	Low								X			Low	Stakeholder feedback suggests a lack of awareness on the part of the general community of the connections between their areas of work and living and the waterways. Signage to increase awareness of these linkages was seen by stakeholders as an important part of educating the community on the influence of their actions on water quality in Sydney Harbour.
10	Councils should seek opportunities to incorporate WSUD principles and stormwater harvesting in asset renewal programs for their own stormwater infrastructure.	High	X										High	The importance of WSUD in improving water quality was demonstrated in the previous section. Councils are significant land managers in the catchment and asset renewal is an important point in leveraging investment in WSUD and stormwater harvesting.

11	Incorporate maintenance of WSUD such as GPTs, wetlands and biofiltration systems in their works plans and ensure devices are maintained on a regular basis.	High	X										High	The importance of WSUD in improving water quality was demonstrated in the previous section. Regular and appropriate maintenance of WSUD devices is necessary to ensure they are working as intended to improve water quality.
12	Provision of training to staff who are involved in the maintenance and on-ground works e.g. operational staff so they understand how WSUD works and potential impacts of their actions on water quality.	High	X							X			High	The importance of WSUD in improving water quality was demonstrated in the previous section. Regular and appropriate maintenance of WSUD devices is necessary to ensure they are working as intended to improve water quality.
13	Enforcement of sediment and erosion controls on building sites with fines and where necessary stop work orders for repeat offenders.	Moderate	x								X		Moderate	Building sites have the potential to contribute substantially to TSS loads if appropriate erosion and sediment controls are not used on building sites. Enforcement of erosion and sediment controls is seen by many stakeholders as a significant issue.
14	Provide better protection and restoration of mangroves, saltmarsh and foreshore vegetation. Avoid placing developments close to foreshore areas, leaving these as vegetated public open space.	Moderate				X					X	X	High	There is concern about the destruction of mangroves and trees for views. Allowing the mangroves, saltmarsh and foreshore vegetation room to migrate naturally will assist in their survival, and therefore in their contribution to habitat and the maintenance of biodiversity in the Harbour. Leaving more natural spaces along the foreshore will educate people on how the natural state of their shorelines should look, and hopefully raise awareness about it care and management.

15	Consider soft engineering solutions for foreshore management to allow for managed retreat of foreshore ecosystems.	Moderate				X							High	Allowing the mangroves, saltmarsh and foreshore vegetation room to migrate naturally under conditions of increasing sea levels will assist in their survival, and therefore in their contribution to habitat and the maintenance of biodiversity in the Harbour.
16	Use the Sydney Harbour CAPER DSS to test a range of scenarios and identify the most effective scenario(s) that will enable the LGA to meet their load reduction targets	Moderate	X										Moderate	In order to meet proposed load reduction targets Councils will need to develop their own implementation plans for this WQIP. The CAPER DSS is a tool that can be adopted by Councils to develop implementation plans consistent with the objectives of this Plan.
17	Use MUSIC or similar programs to evaluate individual and small scale WSUD projects.	Moderate	X										Moderate	The MUSIC model provides a platform for designing and assessing the potential benefits of individual and small scale WSUD projects. Use of this tool will assist Councils in designing schemes that contribute effectively to the implementation of this Plan.
18	Include the stormwater/WSUD clause developed by the GSLLS into the LGA's Local Environment Plan (LEP).	High	X									X	High	The inconsistency between government and council approaches to the significance of water quality is seen by many stakeholders as a significant issue. By including a consistent template for incorporating WSUD in new developments Council LEP's, WSUD can effectively be incorporated in infill redevelopments to improve stormwater quality.

19	Prepare or update the LGA's Development Control Plan(s) to include WSUD and the stormwater pollutant load reduction and flow control targets identified in the Plan,	High	X									X	High	The inconsistency between government and council approaches to the significance of water quality is seen by many stakeholders as a significant issue. By including a consistent template for incorporating WSUD in new developments Council DCP's, WSUD can effectively be incorporated in infill redevelopments to improve stormwater quality.
20	Ensure new or renewed local council infrastructure (i.e. roads, drainage, car parks, footpaths, bike paths, etc.) is designed from a WSUD perspective and meets the stormwater pollutant load reduction targets, to minimise impacts on waterways.	High	X										High	The importance of WSUD in improving water quality was demonstrated in the previous section. Councils are significant land managers in Council infrastructure is an important point in leveraging investment in WSUD.
21	Engage with and support local communities implementing actions consistent with the Sydney Harbour WQIP.	High	X									X	High	Consistent and collaborative efforts by all key stakeholders is required to improve water quality entering Sydney Harbour
22	Provide filtered cold water points to encourage people to use and fill own water bottles instead of buying drinks in disposable containers.	Low					X						Low	This will produce less plastics and litter, which could end up in the Harbour, Litter is noted by stakeholders as a big problem. E.G. RMS barge collects rubbish up and down Parramatta River and some councils spend considerable funds on GPTs and levies, The amount of litter is increasing with the population

	Sydney Water													
23	Continue improving sewer overflow performance through the catchment and identifying and managing illegal connections.	High		X									High	A substantial proportion of pathogen loads to Sydney Harbour are provided by sewer overflows. Reducing these loads is key to improving recreational values associated with the Harbour and its tributaries. Illegal connections to the sewer system are known to be a significant contributor to sewer overflows.
24	Sydney Water should seek opportunities to incorporate WSUD principles and stormwater harvesting in asset renewal programs for their own stormwater infrastructure.	High	X										High	Stormwater harvesting is a key action available to reduce stormwater discharges to Sydney Harbour as well as reducing the pressure on the sewer system through infiltration of stormwater to the sewer system. Stormwater and sewer overflows present a very high threat to all values associated with Sydney Harbour.
25	Conduct education campaigns with the community on the concept and importance of good management of stormwater on property rather than directing stormwater to the sewer system.	Moderate		X						X			Moderate	Stormwater directed into the sewer system is a major cause of sewer overflows. Management of this water on property has the potential to significantly reduce the frequency and magnitude of sewer overflow events.

	State													
26	Incorporate WSUD in BASIX, DCP and LEP guidelines, growth plans and other policy and planning instruments.	High	X									X	High	Feedback from key stakeholders indicates that a lack consistency and direction from State Government around the implementation of WSUD in DCP and LEP guidelines limits the extent to which WSUD adoption is enforced by Councils in new developments. Incorporation of WSUD in BASIX would provide this necessary direction and support to Councils in their implementation of these approaches.
27	Review the level of fines and other regulatory instruments used to enforce water quality requirements (such as for removal of vegetation or use and maintenance of erosion and sediment controls on building sites) to ensure they are adequate to ensure compliance.	High									X		High	Without enforcement, environmental regulations applying to new developments will not achieve any of their intended outcomes. Key stakeholders perceive that a lack of enforcement is reducing the effectiveness of restrictions on acts such as vegetation removal or adoption of erosion and sediment control on building sites.
28	Develop a management plan for mangroves to ensure their water quality and biodiversity.	Moderate				X							Moderate	This will raise awareness of the habitat requirements for mangroves, and also ensure a consistent approach to their management throughout the Harbour catchment. The destruction of mangroves and trees for views was of concern. Many stakeholders thought that a mangrove management plan was needed.

29	Provide funding and support to local government to implement recommendations of the WQIP.	High	X									X	High	Funding and other support is required to overcome previously mentioned barriers for the local councils having the resources to be able to implement the recommendations of this Plan
30	State Government to continue to investigate the influence of toxic sediments on ecological processes in Sydney Harbour and develop a strategy for their management	Moderate						X	X			X	High	Past practices including heavy industry are known to have contributed to accumulation of toxins in sediments in Sydney Harbour. These contaminated sediments impact on recreational values such as swimming and fishing in parts of the Harbour. The best approach for managing sediments has yet to be determined. An investigation into the toxic sediment will enable an informed decision to be made about the best long term management options the toxic sediments.
31	Increased monitoring of water quality and further investigation of the sources of pollution in the Harbour. This should include elements such as integrated real-time monitoring, the State Government adopting water quality and quantity targets (with different targets for freshwater, the estuary and stormwater) and a communication method that measures change overtime such as regular report cards.	Moderate	X	X								X	Moderate	Further ongoing information about the sources of pollutants and their impacts in the Harbour is required to effectively manage these into the future. Communication of the State of the Harbour through a report card approach based on this data would assist in increasing community understanding of the importance of water quality and the impact of their own actions on the condition of Sydney Harbour.

32	Trial, and if successful, implementation of direct measurement of pathogens and harmful algae in waterways to complement or replace measurement of *Enterococci* in waterways. Undertake public health surveys of extent to which people are eating fish or suffering adverse health outcomes from their use of waterways.	Moderate	X	X								X	Moderate	Further ongoing information about the sources of pollutants and their impacts in the Harbour is required to effectively manage these into the future. Communication of the State of the Harbour through a report card approach based on this data would assist in increasing community understanding of the importance of water quality and the impact of their own actions on the condition of Sydney Harbour. A social survey is required to understand the full extent of social costs and benefits associated with water quality, in particular pathogens, in the Harbour and its tributaries.
33	Incorporate the stormwater load reduction targets proposed in the Plan into regional planning policies.	High	X									X	High	Management of stormwater quality requires a consistent approach across government.
34	Ensure any new government policies or plans developed for, or that will have an impact on, the Sydney Harbour catchment are consistent with the objectives of Plan.	High	X									X	High	Having policies and plans that are consistent will ensure that all areas within the Harbour catchment will be implementing the best possible practices, and optimise the chance of achieving the water quality targets throughout the whole system. Inconsistent government and council approaches to the significance of water quality was also a big concern.

35	Ensure the use of the Sydney Harbour CAPER DSS to model the impacts of large scale projects proposed in the Sydney Harbour catchment before allocating funding or giving approval.	High	X									X	High	Large scale projects have the potential to undermine implementation of this Plan unless they are undertaken in a way which supports the objectives of the Plan. Government support of projects needs to be contingent on the consistency of projects with this Plan to ensure its effective implementation.
36	Ensure the GSLLS has the funding to continue to support the implementation of the Plan and to maintain and update the Sydney Harbour CAPER DSS and other catchment and estuary models developed,	High	X									X	High	Keeping the Sydney Harbour CAPER DSS maintained will provide an invaluable integration tool to consolidate the management of the Sydney Harbour water quality into the future, Inconsistent government and council approaches to the significance of water quality was also a big concern
37	Ensure Sydney Water continue to improve the sewer overflow performance throughout the catchment.	High		X									High	Sewer overflows are known to be a significant contributor to pathogen pollution of the Harbour and its tributaries. Improving sewer overflow performance will reduce the number of events where high concentrations of pathogens are released into the Harbour waterways, impacting upon the recreational and aesthetic values.
38	Consider placing levies on plastic packaging and providing a container deposit scheme.	Moderate					X						Moderate	This will reduce the amount of litter which could end up in the Harbour; Litter is noted by stakeholders as a big problem. RMS barge collects rubbish up and down Parramatta River and some councils spend considerable funds on GPTs and levies, The amount of litter is increasing with the population

39	Identify and remediate priority land fill sites along foreshore that are leaching pollutants to the Harbour and its estuaries.	Low						X					Moderate	Land fill sites are thought to contribute to pollution of waterways in some parts of the catchment. The cost effectiveness of remediating these sites needs to be investigated on a site by site basis.
40	Reduce recreational boats dumping sewage in the Harbour through more education of boat owners, checks on boats, enforcement and fines, and providing sufficient land based disposal options.	Low			X								High	It is most likely that the majority of the pathogens come from overflows of the main sewerage infrastructure. Therefore, although reducing recreational dumping of sewerage would decrease the pathogen concentration in the water, it is likely that the impact on the Harbour as a whole would be minimal.
	Federal													
41	Provide funding programs to support coordination of actions between Local and State Government and to encourage implementation and ongoing maintenance of WSUD.	High	X									X	High	Diffuse water quality loads are consistently high across all four Harbour subcatchments which will require a coordinated effort to manage. Lack of funding is a potential barrier to most of the recommendations given in this Plan, so it is a fundamental key to its success which will lead to maintenance and improvement of its environmental, recreational and aesthetic value which flows on to the economic and tourism value.
42	Ensure all environmental grants or funding allocated in the Sydney Harbour Catchment are consistent with and/or supports the implementation of this Plan.	High	X									X	High	Having projects consistent with this Plan will ensure that all areas within the Harbour catchment will be implementing the best possible practices, and optimise the chance of achieving the water quality targets throughout the whole system.

43	Continue to fund water quality improvement devices in the Sydney Harbour catchment that are consistent with this Plan.	High	X									X	High	Having water quality devices that are consistent with this Plan will ensure that all areas within the Harbour catchment will be implementing the best possible practices, and optimise the chance of achieving the water quality targets throughout the whole system.
44	Ensure that land under its control minimise their impacts on water quality.	Moderate	X										Moderate	The Federal Government is a land manager in the catchment. Appropriate management of water quality on this land will reduce its contribution to pollution of the Harbour. Also, for the city to be actively using WSUD, it will act as an awareness and education opportunity for the general community.
45	Invest in collaborative science programs between industry, government and research focused on the function of Sydney Harbour and its tributaries and management actions such as WSUD designed to improve their water quality and ecological condition.	Moderate										X	High	A collaborative approach to the research and management of Sydney Harbour will achieve the best possible results in finding answers to the questions that are most imperative to know. Including the broad range of stakeholders will lead to a greater acceptance and uptake of findings by the Sydney community.

	All Government													
46	Set up and adequately fund a program or initiative to coordinate management actions in the Sydney Harbour catchment and assist MEMA in the management of threats to the Harbour. This should facilitate collaboration between Local Government, State Government, Sydney Water and key business interests.	High	X	X								X	High	A collaborative approach to the management of Sydney Harbour will achieve the best possible results in supporting coordinated action to improve water quality in Sydney Harbour. The governance structure for such an Urban Water Management Program should be developed collaboratively by Local and State governments and the priorities should include: • Developing trust and relationships between organisations to enhance collaboration on water quality and other environmental management issues. • Undertaking catchment wide education programs such as: • Connection between what goes in the drain and water quality in the Harbour. • Impacts of littering • Education for developers on potential benefits of WSUD in their developments including higher land values around wetlands and desirable green features. Provide information on types of WSUD options that might provide amenity benefits in development as well as improve water quality • Building capacity to implement,

design and maintain WSUD and other environmental works such as habitat friendly seawalls within Councils.

- Reviewing legislation and regulatory impediments to water quality improvements in the catchment and Harbour.
- Joint monitoring activities and scientific investigations.
- Collation of monitoring data and activities to make this accessible to the public such as production of a report card or provision of real time stormwater monitoring data on a website.
- Developing a shared long term vision and action towards this by members.
- Development of a whole of catchment, whole of government management plan for Sydney Harbour, its tributaries and its catchment.

SECTION 5: ACCOUNTING FOR PLAN PERFORMANCE

Monitoring and modelling strategy and recommendations

In developing the models underlying this Plan numerous knowledge gaps were identified which form the basis for the monitoring and modelling strategy. Key knowledge gaps identified:

- A lack of catchment flow monitoring stations, in particular located at sites where water quality data is collected. Time series water quality monitoring at key freshwater sites co-located with flow gauge stations would be useful.
- Local monitoring of the effectiveness of existing WSUD treatment trains in the catchment, including a log of their location, size and type.
- Comprehensive water quality sampling in the Harbour and its estuaries
- Data and improved understanding of legacy sediment and water quality contaminants in the Harbour and its tributaries including dioxins and heavy metals. Improved knowledge about effective remediation strategies for these pollutants.
- Data measuring ecological condition able to be used to derive relationships between water quality, habitat condition and extent and key ecological indicator measures. Data needs to be collected on all of these parameters at the same locations over the same time periods and provide comprehensive coverage of habitat types and zones of the Harbour and its estuary as well as in the freshwater system. It also needs to be collected in such a way that trends and changes in water quality, habitat extent and condition and ecological indicators can be assessed. For example, seagrass extent and condition is mapped where water quality concentration data is collected. Fish and macroinvertebrate samples are also undertaken over the same period and locations. The same sites are then revisited in the future using the same methods to allow comparison of data over time.

It is proposed that the collaborative initiative or program recommended in this Plan be used to facilitate future monitoring and modelling activities to fill these gaps. Funding should be sought to strategically address research and monitoring activities proposed here. The scope for in-kind contributions from key stakeholders and collaborative monitoring efforts should be investigated as one of the first tasks of this program.

Improved data in these areas could be used to:

- Update the calibration and validation of the Source Catchments model for the Sydney Harbour catchment.
- Update the calibration and validation of a more detailed receiving water quality model for the Harbour.
- Test and update MUSIC model estimates of treatment efficiencies used in the CAPER DSS.
- Update the catchment and receiving water quality metamodels used in the CAPER DSS.
- Improve the estimates of conditional probabilities used to model impacts on freshwater and estuary condition as part of the ecological response models in the CAPER DSS.
- Measure the successful implementation of this Plan.

Evaluation framework for implementation of the Plan

Evaluation of the Plan is an essential part of ensuring actions are implemented and are achieving their desired objectives. A framework to underpin this evaluation has been developed based on the Program Logic approach. In this approach the Plan implementation occurs through measures designed to assess the extent to which actions and inputs (i.e. recommendations) have been undertaken, the extent to which these have then achieved the desired output and finally the level to which the desired outcome has been achieved.

Figure 23 shows the proposed evaluation framework for implementation of the Plan.

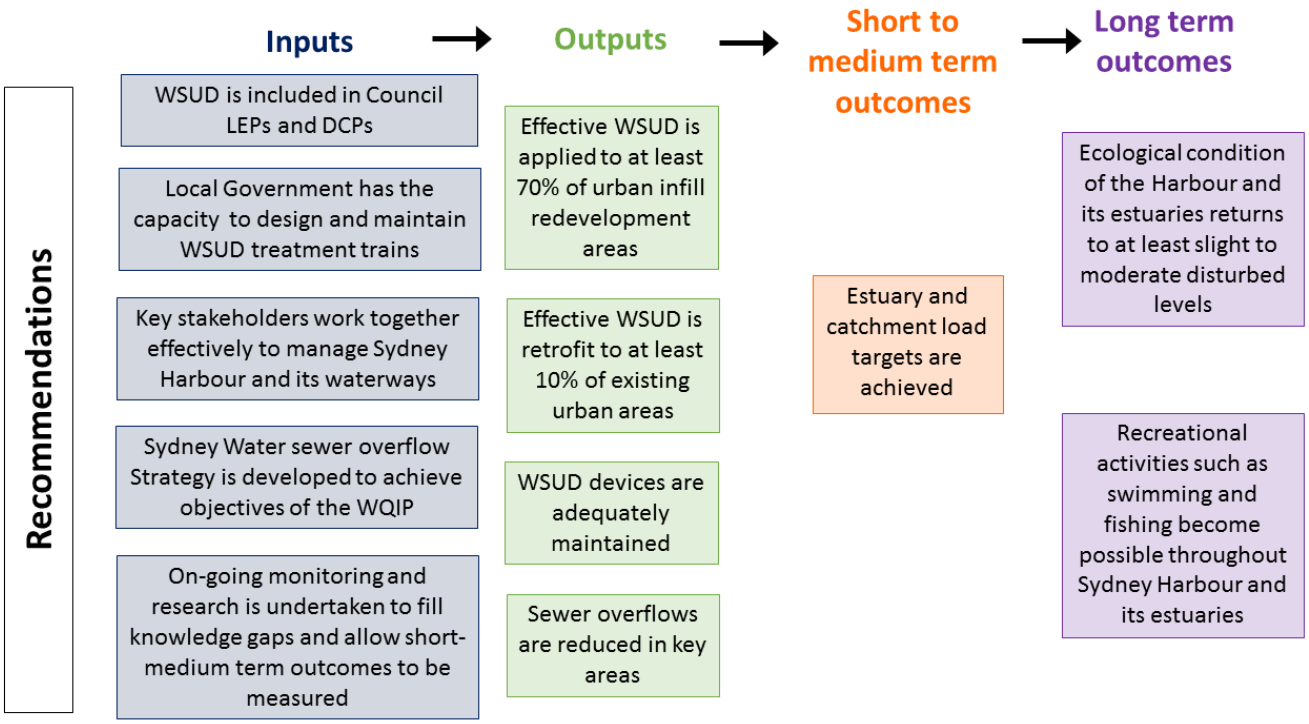


FIGURE 23. EVALUATION FRAMEWORK FOR IMPLEMENTATION OF THE SYDNEY HARBOUR WQIP

Measures for the achievement of each of the inputs, outputs, and outcomes in this framework are given in Table 7. These measures can be used to assess the degree to which this WQIP has been implemented and is achieving its desired goal.

Horned Blenny (*Parablennius intermedius*) at Clifton Gardens

TABLE 7. MEASURES CORRESPONDING TO THE EVALUATION FRAMEWORK FOR THE SYDNEY HARBOUR WQIP

Component	Measures
Recommendations	% recommendation implemented
Inputs	
WSUD is included in Council LEPs and DCPs	LEPs and DCPs incorporate WSUD requirements
Local Government has the capacity to design and maintain WSUD treatment trains	Council maintenance staff are trained in maintaining WSUD Maintenance of WSUD is included in Council work plans
Key stakeholders work effectively together to manage Sydney Harbour and its waterways	Key stakeholders engage in collaborative body to manage Sydney Harbour Funding provided to support collaborative efforts In-kind assistance provided to support collaborative efforts Number of collaborative projects undertaken by key stakeholders
Sydney Water sewer overflow strategy is developed to achieve objectives of WQIP	Strategy complete Strategy outcomes tested using the CAPER DSS to ensure consistent with objectives and targets of this WQIP
On-going monitoring and research is undertaken to fill knowledge gaps and allow short-medium term outcomes to be measured	Monitoring program established Data available Research findings, presentations and publications
Outputs	
Effective WSUD is applied to at least 70% of infill redevelopment areas	Location, scale, number, type and effectiveness of WSUD treatment trains
Effective WSUD is retrofit to at least 10% of existing urban areas	Location, scale, number, type and effectiveness of WSUD treatment trains
WSUD devices are adequately maintained	Council works and maintenance log
Sewer overflows are reduced in key areas	Location, type of works undertaken Monitoring of sewer overflow volumes and concentrations
Short to medium term outcomes	
Estuary and catchment load targets are achieved	Load and concentration changes estimated using models, DSS and monitoring data
Long term outcomes	
Ecological condition of the Harbour and its estuaries returns to at least slight to moderate disturbed levels	Monitoring data shows condition thresholds are met throughout the Harbour and its estuaries
Recreational activities such as swimming and fishing become possible throughout Sydney Harbour and its estuaries	Monitoring data shows ANZECC recreational water quality guidelines are met throughout the Harbour and its estuaries

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APPENDIX 1. SUMMARY OF STAKEHOLDER ENGAGEMENT IN THE DEVELOPMENT OF THE SYDNEY HARBOUR WQIP

Stakeholder engagement has been an ongoing and integral part of the development of the Sydney Harbour Water Quality Improvement Plan (WQIP). The first consultations took place in September 2012 with key stakeholders from management bodies such as SMCMA, Sydney Water, OEH and Local councils including Ryde, Ku-ring-gai, Canada Bay, Lane Cove, Parramatta, Marrickville, Auburn and City of Sydney. The objective of this meeting was to identify water quality issues and establish stakeholder perceptions of catchment processes, sources of sediment and nutrients in waterways, event timing/ frequency, the impacts of urbanisation and land uses in the catchment and ecological health issues. As part of this stakeholders use and non-use values, changes in water quality, future changes to water quality anticipated, possible scenarios and management options to be considered as part of the WQIP and who the end user of the Decision Support System (DSS) would be were discussed.

A broader group of key stakeholders met again in September 2014 when three separate stakeholder forums were conducted to inform the development of a Water Quality Improvement Plan for Sydney Harbour. The two main aims of these meetings were to: educate stakeholders about the WQIP and what it will do; and to seek stakeholder input on scenarios, impacts and management actions to be considered by the Plan. As part of this Stakeholders were asked their use and non-use values, impacts that they perceived as effecting water quality and health of the rivers and estuary as well as opportunities or actions they could see for protecting or improving water quality.

Three community forums were also held in September 2014. These meetings aimed to inform the community on the development of the Water Quality Plan for Sydney Harbour by educating the participants about the Plan and what it would do. As part of this community members were asked for their input on scenarios, impacts and management actions to be considered by the Plan. This involved stakeholders providing feedback on their use and non-use values of waterways, any impacts that they perceived as effecting water health and quality as well as any opportunities or actions that they believed could be considered for protecting and improving water quality.

This Appendix provides summaries of each of these stakeholder engagement meetings and provides brief overviews of feedback from participants.

Scoping workshop

A scoping workshop was conducted to establish the intention and direction of the Water Quality Improvement Plan (WQIP) for Sydney Harbour. The Forum was held in Parramatta on September 24, 2012 and had two main aims:

- To educate stakeholders about WQIP's, what they can do and who will be the end-users and;
- To seek stakeholder perceptions on water quality issues, catchment processes, values, scenarios and management actions to be considered in the plan.

The Forum devoted time to a facilitated discussion around three main themes:

- Catchment Processes
    - Where do you think sediments and nutrients come from?
    - Are there any sinks for flows and pollutants?
    - Does this change according to season?
    - What are the impacts of urbanization and other land use intensification?
- Water Quality and Ecological Health Impacts
    - What do you most value about the catchment, rivers and estuary?
    - What changes in the rivers and estuary are you concerned about?
    - What will be affected by future changes in use or management of the catchment or estuary?
    - What are some indicators to assess ecological impacts?

- Scenarios and Management Options
    - What are current/potential changes to the catchment or estuary use that you are concerned about?
    - What are some possible management options to reduce negative impacts?
    - What are some potential scenarios that could be considered as part of the plan?

A table of potential end-uses and users as well as a list of who to consult throughout the development of the plan was also established.

Catchment processes

Where do you think sediments and nutrients come from? Are there any sinks for flows and pollutants? Does this change according to season? What are the impacts of urbanization and other land use intensification?

Stakeholders suggested a range of pollutant sources to the rivers and estuary of Sydney Harbour. The most common sources suggested related to urbanization; Industrial, commercial and recreational activities; and flora/bushland, erosion and sediment.

Impacts of Urban Development, Stormwater and Sewer

Urbanisation and development is considered as a clear contributor to pollutants in waterways. It was suggested that redevelopment does not lessen erosive impacts on-site as detention activities reduce onsite floods but increase the time of erosive flow as well as increase flow rates on occasion. Stakeholders are also concerned about sewer overflows as well as the impacts of roads and their runoff.

Industrial, Commercial and Recreational Activities

There are a variety of urban activities that contribute to pollutant loads. Industrial and commercial activities stakeholders point out include:

- Leaching from and/or re-working of sediments in landfills;
- the mobilization of sediment by ferries;
- heavy metals from past industrial activity and;
- Grease traps.

Parks and golf courses are also a concern as sources of pollutants. Participants commented on fertilizer use on golf courses and suggest that while dams on golf courses act as good sinks for nitrogen (N), phosphorous (P) and sulphur (S) they do have environmental flow implications.

Urban park management was also discussed. Stakeholders highlight that major park maintenance only occurs once a year with management practices varying between local government authorities. For example, a sand top-dressing (low organic matter) may be applied to the ground but applications of soluble fertilizer are not trapped.

Flora, Bushland, Erosion and Sediment

Stakeholders suggested a range of natural processes that contribute to sediment and nutrient loads in waterways. Sediment slugs from upper catchment areas and sediment pushed up from the estuary into the rivers was discussed. Bushland is considered a significant source of sediment due to erosion under storm events which impacts on creek water quality. Further down the catchment windblown deposition of matter is of concern. Leichardt was mentioned as an example of an affected area. Leaf matter from trees that enter streams through runoff is also considered a widespread issue across most council areas. Major Bushfires (e.g. in Lane Cove) and buried fluvial sediments (e.g. Duck River) was also briefly discussed.

Water quality and ecological health impacts

What do you most value about the catchment, rivers and estuary? What changes in the rivers and estuary are you concerned about? What will be affected by future changes in use or management of the catchment or estuary? What are some indicators to assess ecological impacts?

There was a range of values people associated with the estuary and rivers of Sydney Harbour. The most common values people held for the Harbour and tributaries related to recreation, biodiversity and ecosystem services. However, participants conveyed a range of factors that could impact the health of the Harbour and its tributaries. These include pressures of urban development and the resulting loss of habitat as well as water pollution. Some indicators of ecological impacts were also briefly discussed.

Biodiversity

Stakeholders indicated that they value the biodiversity of the harbour and freshwater systems. The protection of marine biodiversity in the estuary is a high priority. Furthermore, stakeholders suggested that they would like to have diversity of species in the waterways but realize this is determined by more than just water quality. Invasive species was given as an example of a limiting factor of species diversity.

Ecosystem Services

Natural systems were recognized as important for providing ecosystem services. For example, the role rivers and riparian areas play in water purification. Forested areas of the catchment were also mentioned as good habitat for fauna. However, it was pointed out that they are susceptible to drought and any management actions need to consider habitat connectivity as well as refuge particularly during dry seasons/ years. Some people questioned what the cumulative effects of management practices prescribed in Development Control Plans (DCP) for parks and developments etc. are?

Recreation

Social values are strongly tied to ecological values for the waterways but they are also person dependent. Swimming was the main recreational activity discussed. Many participants expressed that they would like to be able to swim in the Harbour and creeks but they are currently unable to due to primary water contact restrictions. Generally, it appears that this value is age related; if people have memories of swimming in the system then they would like the previous condition of waterways that they valued returned (e.g. people used to swim at Parramatta Park in the 1960s then went to Lake Parramatta in the 1970s after water quality in Parramatta Park deteriorated). Alternatively, other people who do not necessarily want to swim in the system suggest that it would be good for creeks not to smell like a sewer. For those who like fishing, the reality that fish can't or shouldn't be eaten west of the Sydney Harbour Bridge was mentioned as something that people would like to see changed as a result of improving water quality.

Urban Development and Habitat Loss

Habitat loss is recognized as being linked to urbanization and a range of anthropogenic activities. The main topic discussed was the loss of habitat for saltmarsh, mangroves, seagrass and smaller marine fauna. These species are under threat from a number of activities including:

- redevelopments of clubhouses (although small scale individually the clubhouses are located in close proximity to each other)
- Renewal of seawalls. Many Councils have seawalls that provide reasonable habitat because they are deteriorating. Renewal programs involve concrete walls that reduce habitat. While ecologically friendly walls are available they are much more expensive.
- Infill of saltmarsh areas due to actions such as sediment movement/ build-up, development activity and encroachment of mangroves (which can result in flooding problems).
- Increased bank erosion possibly due to changes in wave frequency from boat wash

- Increased nutrients, boat wash and sea level rise could be related to disappearing seagrass
- Clearing and washing out of mangroves

Water Pollution

A substantial list of pollutants and indicators of water quality that participants are concerned about in the estuary and tributaries was developed. This includes:

- Dissolved oxygen, water chemistry and physical condition that all impact species diversity
- *Enterococci*
    - In the Harbour boats pump-out effluent and there is no/limited numbers of compliance.
    - Primary and Secondary contact must be avoided in some areas (e.g. secondary contact in the freshwater area of Parramatta River).
- Elevated ammonia concentrations
    - Temporal considerations (peaks)
    - Links with dissolved oxygen sags (?)
- Iron bacteria blooms
    - Uncertain ecological impact but the blooms are of community concern
    - Related to flow, rainfall, temperature and pH
- Optical brighteners are being detected in waterways
- Medicine/endocrine receptors
- Gross pollutants
- Anti-fouling paints

Blue green algae is not considered a major issue at this stage as it is not present even in golf course dams on the tributaries. While Burwood Council had a localised problem in one lake it was due to a large numbers of ducks and ibis in the areas. Participants noted that mainstream rivers are too turbid for blue green algae to grow. However, they suggested that nutrients in the waterway are high enough so if management actions result in reduced suspended sediment concentrations a perverse outcome may lead to conditions suitable for blooms.

Stakeholders suggest that indicators to assess some of the ecological impacts on waterways are whether or not areas are safe to swim in and visual amenity.

Scenarios and management options

What are current/potential changes to the catchment or estuary use that you are concerned about? What are some possible management options to reduce negative impacts? What are some potential scenarios that could be considered as part of the plan?

Participants were concerned about a broad range of current and potential changes to the catchment that could affect water quality. The greatest concerns related to sewer infrastructure and varying council (and other bodies) management practices throughout the catchment. In response to these concerns stakeholders came up with a broad list of management actions that may reduce impacts on water quality. They also established some management scenarios that they would like to see investigated as part of the WQIP.

Sewer infrastructure

Sewer infrastructure is a concern to stakeholders particularly in relation to the cost effectiveness of storage and treatment options.

Management practices

Different councils have varying management approaches for water management, developments, and maintenance of parks. Management practices at parks involve fertilizer use and low organic content, as these are

high use areas stakeholders point out that if subsoil systems are used there is a lot of potential for nutrients to enter waterways.

For the management of water, each council has different implementation levels of Water Sensitive Urban Design (WSUD). Stakeholders suggest that Council's try to keep costs to a minimum and WSUD is expensive. However they point out that some Council's including Sydney, Marrickville, Ku-ring-gai and Ryde have implemented some WSUD and are currently undertaking monitoring.

Stakeholders questioned the appropriateness of the 'effective imperviousness' approach where a certain amount of land area is disconnected from streams. This is because the method is dependent on local environmental factors such as landscape, soil and vegetation etc. An alternative approach suggested was to consider what can be done to reduce the amount of days overland flow/runoff occurs and aim to increase base flow. The Upper Georges was suggested as an example of a 'good condition' area to look at as well as the headwater streams of Ku-ring-gai Chase and Garrigal however mining catchments must be avoided.

Potential management options

Stakeholders came up with a large number of management actions they felt would improve water quality. The most frequently raised options were:

- Incorporating WSUD during renewals of parks, streetscapes and roads (already occurring in some parts of the catchment)
- Strategic WSUD retrofitting (e.g. impervious pavements)
- Stormwater management
    - Installation of SQUIDS
    - Strategic planning (e.g. land use zoning)
    - Education
    - Assessment of large development applications (no WSUD verses all WSUD verses combination WSUD)
- On non-council land (Must get private land involved)
    - Green roofs
    - Rainwater tanks (now currently implemented (e.g. Ku-ring-gai Council) but how can they be improved to achieve better outcomes?)
    - On-site detention offsets
    - Promotion/coinvestment on works (e.g. Marrickville council doing works with shared cost-benefits)
- Rehabilitation of creek riparian zones
- Commercial/Industrial
    - Use/ implement WSUD
    - Stormwater management
    - More regulations/ compliance (e.g. for grease traps)

Scenarios

A number of management scenarios were proposed for investigation in the WQIP. These include:

- Native bushland:
    - Controlled burns
    - Creek stabilisation (small scale)
- Stream naturalisation
- Dredging: Even though it is not likely to be systematic or to a large extent. The responsibility falls on the Port Authority. It was looked into in the Parramatta River but was too expensive.
- Flood mitigation: impacts on the catchment
- Culverts

- Ferries: Currently there is 1 per hour which does quite a bit of ecological damage. It would be good to consider the impacts of lower wash but higher frequency alternatives.
- Climate change and sea level rise:
    - Stormwater infrastructure
    - Saltmarsh ecology
    - Sea walls
    - Encroachments on land fill that are currently dry (more leachate?)
    - Erosion
    - Sewerage infrastructure
    - Increased intensity and frequency of floods
    - Bushfires
- Controlled/uncontrolled overflows:
    - Identify/prioritise point and diffuse sources
    - Events are more important than seasons to consider
    - Effects on dissolved oxygen, duration and frequency of flow events
    - Loads as well as frequency
- Growth projections
    - Check out Local Environment Plans (LEP) and Development Control Plans (DCP)
    - Offsets are meant to negate effect of increased impervious areas

Potential end-users and uses

Participants were engaged in developing a list of potential end-users and uses for the Sydney Harbour WQIP. These are summarized in Table 8.

Table 8. Identified potential end-users and uses of the WQIP for Sydney Harbour

End user(s)	Uses
Local Government Authorities (esp. the Sustainability and Environment and Infrastructure Integration sections of council[1])	- Strategic/master planning - Asset management
Local Government Authorities Catchment Management Authority	- Cumulative impacts / whole-of-system - State of environment reporting - Catchment rating tool (link to BASICS, PRECINX) (benefit of commercial tool) - setting water quality targets
Department of Planning	- Landuse planning - Metropolitan / subregional plans
Drainage engineers	- infrastructure - community strategic planning
Council, Office of Environment and Heritage	- directing funding and priorities
Parks and Open Spaces	- master plans
Roads authority	- stormwater management and planning
Sydney Water	- planning and asset management

[1] without these sections committed it will not be possible to get other sections of council using the DSS

Who to consult

Participants helped develop a list of key stakeholders who should be consulted throughout the development of the WQIP for Sydney Harbour. These Stakeholders include:

- GIS officers
- Environmental Health Officers (EHO)
- Operational staff
- Sydney Harbour Foreshore Authority (SHFA)
- Department of Primary Industries (DPI)
- Non Government Organisations (NGO's)
- Environmental and community groups (e.g. the former 'Ecodivers')
- Participants in old 'Streamwater' program
- Sydney Olympic Park Authority (SOPA)
- National Parks

Community forums

Three community forums were conducted to inform the development of a Water Quality Improvement Plan for Sydney Harbour. Community Forums were held in Lane Cove, Parramatta and the MLC Centre on consecutive days in September 2014. The meetings had two main aims:

- To educate the community about the WQIP and what it will do.
- To seek community input on scenarios, impacts and management actions to be considered by the Plan.

Forums ran for two hours: a half hour presentation followed by an hour and a half devoted to facilitated discussion around three main themes:

- Values
    - What do you most value about the catchment, rivers and estuary?
    - What do you use them for?
    - What attributes would you like to see protected?
- Impacts
    - What are you most concerned about in terms of the future health of the river and estuary?
    - What changes do you see could harm the estuary and rivers?
    - What changes do you see that could benefit the estuary or rivers?
- Management actions
    - What opportunities do you see to improve and protect our rivers and estuary?
    - What actions do you think should be taken to protect and enhance water quality in the rivers and estuary?

Participants were also asked to complete and return an individual feedback form to ensure the views of the entire audience were heard. In total approximately 19 people attended the 3 workshops.

Values

What do you most value about the catchment, rivers and estuary? What do you use them for? What attributes would you like to see protected?

There was a range of values people associated with the estuary and rivers of Sydney Harbour. The most common values people held for the Harbour and tributaries related to fishing, recreation, aesthetics, tourism, heritage, natural habitats, biodiversity and public transport.

Fishing

Fishing was a common value amongst workshops, mostly in terms of fish in the Harbour. People indicated they valued fishing both as a recreational activity and as a food source. However, it was pointed out by some that bait sources in the Harbour have been destroyed by dioxins and that you are '*not supposed to eat fish west of Harbour Bridge*'. Few participants commented on commercial fishing in and around the Harbour but one said that their 50 year vision would be to have the Harbour healthy enough to see '*Sydney Harbour Oysters… on the menu* '.

Recreation

Various recreational activities were rated highly by workshop participants. People indicated they value access to the Harbour and its tributaries for recreational activities including swimming, kayaking, dinghy sailing, rowing, snorkelling and boating. Foreshore activities such as walking, cycling, picnicking and barbeques are also popular recreational activities. However, all workshops expressed varying safety concerns about water quality being adequate for contact. Some pointed out that water quality does not allow for swimming and boating and danger signage restricting water access is not uncommon. Legacy issues of dioxins and toxins were discussed and Lane Cove participants commented on an increase in oil and the smell of diesel when kayaking. Many participants also commented on industrial pollution, sewer and stormwater overflows, fertilizers and pesticides used on sports grounds and newer inorganic and organic pollutants such as pharmaceuticals entering the waterways as a concern for safe water based recreation. While some people felt water quality was better now than it had been, several participants indicated that recreational opportunities had declined; swimming in harbour pools was one of the main activities people wanted back.

Tourism, Heritage, Public Transport and Aesthetics

The tourism and aesthetic value of the Harbour was highly valued by participants. The unique configuration of the bays, inlets and beaches; '*views from icons and local landmarks'* as well as naturalist settings and places of tranquility and relaxation were all common values. All forums acknowledged that '*the Harbour is what makes Sydney special'* being '*one of most spectacular entrances to a city in the world*' and that *'beautiful harbour areas [are] Sydney's most valuable asset'.* Several participants acknowledged the heritage values in and around the catchment both European and Aboriginal mentioning places like Cockatoo Island. Many people also commented on the value of public transport and ferries around Harbour but some expressed concern for increased bank and beach erosion due to ferry and boat use close to shore.

Natural Settings and Biodiversity

The value of natural settings, green spaces and biodiversity were common themes amongst the forums. The intrinsic value of ecosystems in themselves; the services nature provides such as air, water and noise filtering as well as the amenity it provides for people including health benefits, relaxation and quality of life we all mentioned. Participants valued the amount of green space accessible to the city considering the level of urbanization. They also recognized that these open spaces are becoming more valuable as the population rises. Backwater areas, natural riparian zones, creeks, native habitats with flora and fauna, naturalized banks connecting land and water, mature trees and the quality of trees as well as being able to bushwalk 20 minutes from the city in native habitats were all common values between forums. Participants recognized the need to keep the top of the catchment clean as it feeds the Harbour. They felt a need to preserve sandstone environments along foreshores and commented on the reclamation of foreshores to public land. Participants had negative feelings toward developments such as Barrangaroo and redevelopments in Lane Cove due to the loss of natural environments.

Freshwater and Saltwater biodiversity was also valued by the community. It was widely recognised by participants that the Harbour is dynamic and living and that there are some threatened and endangered marine life, wetlands and mangroves around the catchment. Several participants commented that '*it is nice to see fish [and] seahorses'* '*...seals, penguins [and] sea birds'*.

Impacts

What are you most concerned about in terms of the future health of the river and estuary? What changes do you see could harm the estuary and rivers? What changes do you see that could benefit the estuary or rivers? (e.g. move towards water sensitive urban design).

Participants conveyed a relatively broad range of concerns about factors that could impact on the Harbour and its tributaries. These included pressures of urban development, rubbish and pollution and boating activities. Several people also indicated various factors that could benefit the system.

Sewer Overflows

Several participants cited concerns about sewerage and its impact on water quality. Participant responses included concerns about '*Bacteria & faecal coliforms*…', *'Mircoplastics, hormones, antibiotics, nanoparticles etc.'* and '*pharmaceuticals in sewer* overflows'. In general it was felt that sewer overflows were a bigger concern than people attribute to it. It was considered that the old sewerage system must be getting worse with increasing population pressures and that resources are not being put into maintenance or upgrades of the sewer network. It was also felt that some Councils are approving new developments without considering the extra load on sewage lines that are already working near capacity. Some forum participants said that TP and TN are increasing from sewer discharges while others commented on the smell and look of sewage during overflows. Some participants gave examples of *'Sewer overflows [in] Stringy Bark Ck [and] Lane Cove'.* People felt that the smell from sewer vents were a big impact and one participant commented *on '…smells from sewage in bushland e.g. Warraroon'. One community member suggested the need for an 'enquiry into Sydney water re. upgrading sewers to control overflows'.*

Stormwater, Urban Development and Runoff

One of the most cited issues was stormwater overflows and runoff. In general it was felt that more intense developments including the rezoning of green space and infill expansion are contributing increased amounts of sediments and nutrients to stormwater. Participants were concerned that planning does not consider prevention of runoff during and after construction. Furthermore, it was stated that while uncovered land surface on properties is supposed to be approximately 25% some participants suggested that the council does not police this as they '*can't afford to fight in Land & Environment Court'*. Hence, in general it was felt that laws need to be tougher to address increasing impervious surfaces.

Runoff from roadways and other impervious surfaces was also highlighted as a concern by participants for detracting from the visual amenity of the waterway as well as water quality. For example, runoff from streets contains '*petrol, rubber, dog poo, cigarette butts, fertilizers, plastics*' and other rubbish. Common issues mentioned in the waterway include the smell of diesel and look of oil, visibly blocked drains, plastic bottles and shopping bags, the general look of pollution and silt. Participants felt that 'rubbish' is increasing with population, urban consolidation and human consumption. One participant commented that the '*Naturalist setting [is] damaged by visual impact of pollution & rubbish*'. All forums commented on cigarette butts, plastic bottles and bags on small beaches, rubbish coming out of overflows and poor maintenance and lack of emptying of gross pollutant traps (GPT's). In general it was felt that there is *'increased litter & no attempt to collect or maintain litter traps'* by authorities. It was pointed out that often water from canals is not filtered for rubbish or pollutants and that the rubbish builds up in rocky areas. Goat Island was used as an example of where rubbish ends up as it travels with the tides. Participants suggested that more GPT's are needed with better maintenance schedules to collect rubbish before it enters the waterways. It was felt that container deposit schemes may help reduce the amount of plastic bottles that end up in GPT's and the Harbour.

Some participants also felt that residents in areas near creeks don't have an appreciation for the impacts they are having on the waterway. It was also mentioned that some people intentionally throw rubbish into creeks and waterways. Community education was suggested as a method to help make people aware of the impacts of their actions.

Industrial, Commercial and Recreational Activities

Community members expressed a broad range of concerns about industrial, commercial and recreational activities that contribute to poor water quality. Discharges from industry and factories are a big concern to stakeholders as they contribute high levels of contamination to some areas of Sydney Harbour and its tributaries. All workshops discussed dioxins, noxious chemicals and heavy metals in sediments from past industrial activities; Parramatta River as well as the radium factory (Hunters Hill) was given as an example. One participant commented that *'Industrial pollution from dioxin - Homebush Bay, oil + trash likely to increase w/o concentrated efforts 2 clean up'.* Industrial spills as part of today's industry activity are also impacting water quality. Some participants mentioned a large petroleum company having a spill into the Harbour in recent times and expressed concern for the harmful effects to the water and marine life. It was questioned as to how aggressive the EPA are in chasing spills as many felt that they are not well resourced.

Leachate sites were also considered. Some people pointed out that industrial rubbish had been used to backfill retaining walls along waterways; now a possible source of leachate. Quarry and tip leachate and runoff were also highlighted as a concern to the participants. It was said that there is no sediment control at some of these sites. Bare Creek was given as an example of an area affected.

Boating, ships and the working harbour environment was also a common concern between workshops. Stakeholders discussed water quality being affected by the release of sewage from recreational boats as well as oil and petrol spills from boating, ships and industry/ Harbour activities. People cleaning boats and dinghies without traps under the boat or at slipways to capture detergents and other cleaning products were also a concern. Other concerns raised in relation to boating activities included '*foreign species attached to hulls*', '*things thrown or falling off boats'*, '*wash from rivercats* [and other boats causing] *erosion and disturbing the shoreline'*, '*dredging and boats stirring up bottom sediments'* and *'antifouling paints'*. Participants noted increases in cruise ships in the Harbour and commented on the greater risk for diesel and fuel spills. They also pointed out the increase in recreational boats moored in and around the Harbour and many felt that there are no plans in place to limit their numbers.

Other recreational activities mentioned that effect water quality include litter from New Year's Eve celebrations, left over fireworks and floating rubbish on the water. Community members also commented on dog owner's lack of use of bags or their neglect to disposing of them properly. It was also pointed out that the bags used are not compostable. Some participants were also concerned maintenance of sports ground and recreational areas; one person said that they were apprehensive about '*fertilizers used on sports grounds - Birchgrove - Iron cove - Callan Park Ovals'*.

Plant and Animal Biodiversity, Vegetation and Invasive Species

Participants discussed the changing nature of plant and animal biodiversity in and around the Harbour and catchment. The Parramatta River forum highlighted poor water and sediment quality with increasing eutrophication and lack of aquatic life. Community members pointed out that there were no longer platypus in rivers in the area and hardly any frogs with only a single species remaining. Carp was highlighted as a pest in the river and even after having days catching & removing them, they are still an issue. Willows are also a substantial issue and the degradation of stream edges by council bulldozing and weed invasion were a concern to community members. Volunteer and contract labour in addressing weeds was seen as not enough action.

Loss of native vegetation was a concern for participants. In general it was felt that there is little regard for bushland and there is a struggle to preserve the urban to bushland interface. It was suggested that people don't acknowledge when they have riparian corridors on their properties and existing fines for clearing does not dissuade people from removing existing vegetation. Another concern raised was the impact of rubbish on vegetation with one participant raising the concern that the '*Lane Cove River, Woodford Bay storm water outlets disgorge rubbish into mangroves*'.

Several community members suggested that the 1050 vegetation code was dissatisfactory regarding the preservation of trees and maintaining water quality. One participant commented that the '10/ 50 legislation... absurdly applies to narrow bushland reserves + surrounds in Lane Cove' another said that 'siltation from building sites... will increase with the 10/50 vegetation clearing code'. In general it was felt that the extra loss of bushland and canopy would increase the impacts of runoff. Some suggested that the 1050 legislation needed to distinguish between small pockets of bushland in Sydney verses forest.

With regard to protecting natural areas, participants were pleased that 1000 hectares of crown land (Aboriginal land) was put into the National Park to protect, attract tourism and have as a cultural hub rather than selling for development. Marine reserves were also seen as a positive however some participants questioned why there is less biodiversity inside reserves when compared to outside reserves. Hence, it was questioned as to whether small pockets of fish reserves work and/or if bigger reserves are needed?

There were concerns for the health and safety of wildlife in and around the Harbour. When considering marine life, participants expressed concern for the large number of boats being moored in the Harbour and their effect on benthic environments. Concerns were raised about speedboats and river cats churning up sediment and causing erosion as well as dredging damaging underwater environments and marine life. The impact of oil, diesel and other pollutants on marine life was also raised. Some felt that more dry storage of boats may assist in limiting some of these impacts.

Other concerns for wildlife and vegetation were also raised as community members acknowledged the increasing use of green zones around the Harbour. Dinghy's dragged through bushland was seen as a threat to native vegetation and water quality. Bike paths through bushland were highlighted as being fought based with wildlife impacts. One individual expressed a concern for the '*Effect on marine life from exotic invasive species*'. Climate change and sea level rise were also raised as issues effecting biodiversity. One participant summed up by asking '*Has anyone done an environmental biodiversity audit? ... [to] get a... baseline!*'.

Community Attitudes, Legislation and Management Bodies

Lack of community knowledge of what contributes to poor water quality was seen as part of the problem. It was felt that more community education is required and that this should not just be the responsibility of schools or individual teachers. It was suggested that the Streamwatch program had been taken over by the Australian Museum but had been largely disbanded due to liability issues hence schools were no longer involved. While there are still volunteers involved in education in general it was felt that the costs of educative processes are inhibitive and programs are often fragmented due to reliance on individuals. Overall it was felt that people being more aware of their impacts and what they can do would be a good step forward for improving water quality. This may be helped if monitoring data is made public in a quick easily accessible way.

Participants felt that the Harbour and tributaries needed to be better managed by Councils. It was said that there needed to better legislation on controlling the Harbour so as to not divide communities with poor governance. Furthermore they pointed out that there is no one person or place to go to with regard to Harbour Management. It was felt that this should be addressed so any issues could be dealt with via an easy and efficient means.

Management actions

What opportunities do you see to improve and protect our rivers and estuary? What actions do you think should be taken to protect and enhance water quality in the rivers and estuary?

People came up with a large number of management actions they felt would improve water quality. The most frequently raised options were:

- Higher levels of sewerage infrastructure maintenance and renewal to cater for current and future population. Some wastewater treatment plants may need capacity increase to cope with large areas

serviced (e.g. North Head). A public enquiry into the status of the metropolitan sewage system may be beneficial for checking and identifying overflows and chokes.

- Put GPT's on all stormwater outlets and maintain regularly. It may be beneficial to look for options that automatically clear or to collect rubbish from streets before it enters the stormwater system.
- Standardise and implement WSUD & specifications throughout catchment. This would include the use of WSUDs such as: parks used as filtering systems for wetlands, water tanks on new houses, WSUD stipulations such as rain gardens when house renovations are done, stormwater recycling and other WSUD on infill developments and the use of permeable paths etc. on properties. WSUD should also be used on large road transport projects such as West Connect.
- Education of the community. Use ongoing broad scale campaigns for example 'Do the right thing', 'drain is just for rain' and 'Clean up Australia Day' that reach migrants, create new cultural norms and encourage personal responsibility. Ongoing education of students is also important to ensure their understanding of issues like: where stormwater goes, what happens to rubbish and what they can do. Also have schools participate in programs like Streamwatch. Education should also specifically target groups like Harbour side residents and dog owners.
- A collaborative effort between councils, Sydney water, State government & other authorities to work together on improving water quality. This may involve a common coordinating body and/or a set of principles for preserving the Harbour made at a State level that councils all have to meet. This may include the discontinuation of independent certifiers.
- Reduce littering of waterways through further environmental legislation and law enforcement. For example the enforcement of rules on littering, dumping, erosion and sediment control. This would include having the power to stop development works until any problems are fixed.
- Container deposit scheme to encourage recycling

Other options raised were:

- The removal of charges at garbage tips as they encourage dumping in bush land
- Relocate all industrial plants
- Provide rainwater tank rebates
- Plastic bag ban
- Rubbish collection of large waste by Council could be changed to on demand/ phone in rather than 2 times per year.
- Cigarette tax into cleaning up cigarette butts.
- Putting in wetlands particularly in the western part of the catchment to process runoff.
- Encourage and protect mangroves. Stop big residential developments removing mangroves and aim to minimise ferry impacts on mangroves.
- Catch all septic overflows
- Permaculture & Council programs on growing without fertilizer by using mulching and earthworms etc.
- Place more speed limits on big boats in Sydney Harbour and slow down other boats in general to limit damage and erosion to marine environments. Alternatively, ban jet boats and modify Rivercats to limit damage.
- Need guidelines/ rules of washing procedures for boats. Most slipways are not designed to catch antifouling material etc. and direct it to sewage during washing, but they should.
- Fish friendly marinas through operation, design and by providing structures for habitat.
- Conduct a biodiversity audit of the Harbour to get a baseline for future audits.
- Make big multinational companies responsible for educating customers on littering and have the packaging industry more responsible for their packaging.
- Adopt a bay or creek program which encourages investment in river health on the part of industry.

Impediments to Implementing Actions

Participants explored some of the impediments to these actions being implemented. One major action that was seen to have considerable impediments associated with it was GPTs and their maintenance and cleaning. Participants saw the need for more litter traps; one group using Duck Creek/ Abeckett Creek as an example of a large area with only one GPT at risk of bursting when a flood occurs. In general it was suggested that while councils are putting in more GPT's there is a lack of them on Crown Land and RMS land. It was recognized clearing traditional GPT's is inefficient and that due to lack of council funding regular cleaning and maintenance of GPT is not occurring. As there is no single authority taking ownership of GPT's there are no set procedures or guarantee of regular maintenance of GPT's.

Sewerage infrastructure, maintenance and renewal were seen as an important action toward improving water quality. In general it was felt that a lot of focus during developments is on infrastructure like roads rather than sewers. While participants acknowledged works were happening such as large installations to catch septic overflows in Western Sydney they recognised that the costs of infrastructure is likely to be inhibiting more works going ahead. One participant also questioned if a '*lack of legislation?*' was the cause of what appeared to be a low commitment to upgrading infrastructure.

Participants felt that WSUD is not being widely implemented due to the lack of catchment wide agreement, legislation and enforcement. As each council have different priorities with regard to WSUD implementation and enforcement is varied and often lacking. It was thought that independent certifiers are also part of the problem.

Other impediments that related to a broad set of actions are associated with a lack of public knowledge, accountability and a general sense of apathy. A lack of knowledge about the waterways and infrastructure/systems were discussed. In general it was felt that there is a lack of understanding about the importance to improve and maintain the health of the Harbour. Education of the public via schooling and the mass media were seen as possible avenues to improve understanding. However, media costs, lack of funding, no environmental levies, lack of government finance for school education, short term political cycles, no single management authority and people's general lack of time were all seen as impediments to successful ongoing education campaigns and initiatives to improve water quality.

A common impediment to action mentioned was the lack of a single Harbour management authority. Participants could see several environmental benefits to having a single authority controlling Harbour issues such as applying legislation and enforcing compliance, the sharing of resources and the ability to declare catchment areas in need and prioritise efforts. However, several impediments to a single body forming were identified including lack of government and council will or resolve lack of funding and lack of money to provide adequate enforcement.

Initiatives such as container deposit schemes, the ban of single use plastic bags and return deposits on shopping trolleys were commonly mentioned actions for improving rubbishing of the waterways. In general participants felt that these types of schemes should not be difficult to implement however they suggested a lack of government/ parliament member will and pressure from big companies (i.e. major supermarkets, fast food outlets, drink manufacturers) may be preventing these types of initiatives going ahead. The "rights" of fast food outlets and manufacturers of packaging were also mentioned as an impediment. These types of business are not made responsible for their packaging that becomes rubbish when disposed of by customers inappropriately. The lack of power and resources available to OEH and EPA following up pollution incidents was also mentioned.

Remediation of sites in the Harbour is controversial particularly in relation to dredging. Some people argued that the target for water quality should be zero pollution and that sediment dredging should start immediately. But others pointed out that with dredging comes the potential release of dioxins and metals and that dealing with spoil is very costly.

Key stakeholder workshops

Three key stakeholder workshops were conducted to inform the development of a Water Quality Improvement Plan for Sydney Harbour. Key stakeholder workshops were held in Lane Cove, Parramatta and the MLC Centre on consecutive days in September 2014. The meetings had two main aims:

- To educate stakeholders about the WQIP and what it will do.
- To seek stakeholder input on scenarios, impacts and management actions to be considered by the Plan.

Forums ran for two hours: a half hour presentation followed by an hour and a half devoted to facilitated discussion around three main themes:

- Values
    - What do you most value about the catchment, rivers and estuary?
    - What do you use them for?
    - What attributes would you like to see protected?
- Impacts
    - What are you most concerned about in terms of the future health of the river and estuary?
    - What changes do you see could harm the estuary and rivers?
    - What changes do you see that could benefit the estuary or rivers?
- Management actions
    - What opportunities do you see to improve and protect our rivers and estuary?
    - What actions do you think should be taken to protect and enhance water quality in the rivers and estuary?

Participants were also asked to complete and return an individual feedback form to ensure the views of the entire audience were heard. In total approximately 25 people attended the 3 workshops.

Values

What do you most value about the catchment, rivers and estuary? What do you use them for? What attributes would you like to see protected?

There was range of values people associated with the estuary and rivers of Sydney Harbour. The most common values people held for the harbour and rivers related to biodiversity, fishing, recreation, aesthetics, tourism and ecosystem services.

Biodiversity

Many people indicated that they value the biodiversity of the harbour and freshwater systems that feed it. This value stemmed from different reasons. Many saw that river life such as birds, fish, sharks, visiting whales and other marine life were intrinsically of value and deserved to be protected. Others also indicated *'as with [the] Harbour, [Tributaries]... are sanctuary and breeding ground for many aquatic species'.* The value of nutrients brought into the marine environment from freshwater was seen as important for driving ecology and productivity of ocean ecology. It was also noted that there were several aquatic reserves and high value ecosystems around the marine zone. Stakeholders in general felt that there was a '*decent benthic population'* some commenting that it is nice to see oysters coming back to the Harbour. Lane Cove stakeholders mentioned that lost wildlife was also coming back which partly depended on water quality and corridors along streams. Seahorses in Manly and the NSW mainland breeding colony for penguins were also mentioned. It was felt by some that visiting whales and other big marine life was a powerful sign of water quality but acknowledged that there would *be 'improved aquatic life with improved water quality'*.

Fishing

Fishing was a common theme amongst the workshops, both in terms of fish in the Harbour and freshwater fishing. People indicated they valued fishing both as a recreational activity and as a food source but the MLC Stakeholder

group in particular pointed out that you '*can't eat fish [and oysters] west of [the] bridge*' '*which suggests something about water quality in the Harbour'*. It was suggested by some that it would be good to bring back prawning in Gladesville and that there is a potential for commercial fishing in the area once remediated. Stakeholders acknowledged heavy industry in the past around Darling Harbour had contaminated sediments and suggested that they would value sediments being cleaned up enough so fish could be eaten.

Recreation

Various recreational activities were rated very highly by workshop participants. People indicated they value both the Harbour and its tributaries for the opportunities it provided them with for swimming, kayaking, paddling, diving, snorkeling and boating. Foreshore activities such as walking, cycling, picnicking and bird watching were also popular recreational activities. Public access was considered important for keeping the community values of beauty and recreation and it was suggested that in most areas access could be improved. However, all workshops expressed safety concerns about water quality being adequate for human health primary and secondary contact activities. Several participants indicated that recreational opportunities had declined overtime, swimming being one of the main issues. Stakeholders gave examples of E.coli and *Enterococci* values being too high for Harbour pools to be used (e.g. Manly), Blackwattle Bay being very dirty during rain events and paddling in the eastern Harbour in general a health concern. The Parramatta community suggested that they would like to have primary contact in the river again. One participant summed up *'…Access; paths around the harbour, peaceful, relaxing, usually clean. But wouldn't let my dog swim in it'.*

Tourism, visual amenity and aesthetic values

The Tourism value of the Harbour was highly valued by all stakeholders. The iconic structures, shape and bays that give Sydney its identity, as well as beautiful views, tranquility and serenity were all common values. Many acknowledged the heritage values in and around the catchment; European and Aboriginal as well as the working value of the Harbour for transport, maritime and industrial defense. However, rubbish, litter, pollution and sedimentation all detract from the visual amenity of the waterway. Common issues discussed include stormwater drains and visibly blocked drains, over full bins, the smell of anoxic waterways and the general look of pollution. Algal blooms with its cost to the economy and tourism are a concern as it gives a poor message about water quality. It was felt by many stakeholders that there were not really programs addressing rubbish and not much policing of these issues. Some participants commented on how property values and tourism can be affected by good water quality and amenity and how important built in common green areas are in urban developments. Participants noted that '*having good water quality will provide good impressions'* and *'...maintaining good water quality to add to tourist enjoyment but also locals'* is important. Future generations and their experiences were also mentioned by some, one participant commenting that they value '*future generations being able to experience the same or better than what I have*'.

Ecosystem Services

Natural systems were recognized as important for providing ecosystem services. This value stemmed from many different reasons. The non-use values of smaller creeks, riparian corridors and bushland were considered important as ecosystems in themselves and for aesthetics. Services such as flooding and flood management as well as the value of green areas in reducing summer heat in urban areas were seen as important for liveability in urban areas. Returning mangroves at Cooks River was seen to enhance the value of riparian corridors and rehabilitation activities including saltmarsh and wetlands by Sydney Olympic Park Authority (SOPA) at Olympic Park are considered positive environmental actions. However, it was thought that urbanization is continually challenging the ecosystem benefits of naturalized areas provide. It was recognized that it is very costly to remediate creek lines and a lot of works are grant dependent with ongoing costs to councils. In general it was felt that people drawn to naturalized areas and streams start to care about them more but they give up when remediated areas get impacted by weeds.

Impacts

What are you most concerned about in terms of the future health of the river and estuary? What changes do you see could harm the estuary and rivers? What changes do you see that could benefit the estuary or rivers? (e.g. move towards water sensitive urban design).

There were a relatively broad range of concerns people had about factors that could impact on the rivers and harbour. These covered pressures of land use: urban development and population growth, as well as problems with maintenance of past works, drainage and a lack of community ownership of problems. People also indicated various factors that could benefit the system.

Sewer Overflows and Stormwater

The most cited issues were sewer and stormwater overflows. The majority of people who answered the survey indicated that this was a concern for them. Participant responses included concerns about *'sewer overflows leading to infections from recreational use*', '*accumulation of toxic chemicals from sewerage overflows and metals and chemicals in stormwater runoff*' and '*...lack of enforcing legislation and encouraging guidelines for better stormwater quality*'. It is felt that stormwater quality is a limiting factor in estuarine condition. A common conception amongst workshops was that the general community has no idea of what happens to stormwater. One participant used the example of some 'painters washing their brushes out in the gutter' as a sign of ignorance.

Rubbish was seen as a big issue, for example it was highlighted that the RMS barge collects rubbish up and down Parramatta River every day and that some councils are spending considerable funding on gross pollutant traps (GPT) and levies. It was recognized that ongoing maintenance of GPTs and devices are a big issue for councils. It was suggested by participants that some councils were pulling racks out of GPTs to avoid maintenance costs. In general it was felt that the amount of litter is increasing with population growth and that there is a lack of consistency between councils on the importance of water quality. Participants summed up by saying '*There is a lack of enforcing legislation and encouraging guidelines for better stormwater quality',* it is *'...Too easy to pass responsibility to another organisation/ department*' and there is a '*lack of integrated and agreed approach from State Gov. on stormwater'.* Participants suggested that community education aimed at changing behaviour, levies on plastics, container deposits and/or providing alternatives to packaging like biodegradable packaging or allowing people to fill their own bottles may assist with reducing rubbish entering the waterways.

Invisible pollutants were also highlighted as a big issue in stormwater and sewer overflows. Copper, Zinc, and Lead from brake-pads, petrol and roofs respectively, pathogens, microbial contaminants, micro plastics, ammonia and pharmaceuticals were all listed as water quality concerns. Some stakeholders suggested that there are sewer overflow hotspots and illegal connections in the catchment still. One participant commented that *'Invisible pollutants [are] continually washing in and not being managed'* but added that it is a '*Challenge of councils to maintain what they have, least of all be proactive about additional future needs*'.

Impacts of Urban Development, Stormwater Runoff and Population Increases

Urban areas and stormwater runoff were raised by many as drivers of poor water quality. People indicated that urban sprawl was an issue due to new roads, dense subdivisions and a lack of erosion and sediment controls on new building developments and subdivisions. New development trends and infill development decrease open space and increase impervious land surface. People were concerned about population increase as it places more pressure on housing, transport, land and existing infrastructure.

People value water views and land values around the Harbour and there is a trend toward gentrification of river side properties. Stakeholders saw this as an opportunity and a threat. A positive outcome could be getting residents to push for wetland views and high water quality. However, the destruction of mangroves and trees for views, more imperviousness, the pressure for high rise developments along floodplains (e.g. Parramatta), as well

as climate change and more extreme weather events such as flooding and higher regular storm flows were all concerns for stakeholders.

The construction phase was also noted as a key time for pollutants to be generated through erosion. Stakeholders said that development planning is uncoordinated and construction works are often done without adequate erosion and sediment control. There is often no maintenance of erosion and sediment control on development sites and larger companies are being repeatedly fined but this is no disincentive for them. Some participants questioned whether a name and shame approach toward larger companies may be more of a disincentive than fines? One stakeholder said that the problem is a '*Lack of consistent regulation on sediment controls and WSUD integration into planning*'. New developments are going directly to stormwater rather than using water sensitive urban design (WSUD). It was seen that the benefits of WSUD was not being realized because people don't know how to use them properly: Planners have good intentions but poor implementation, there is a lack of skilled people and the people on the ground are doing things the way they have always done it. Stakeholders acknowledged that these impediments will take a few years to overcome. It was also suggested that when WSUD is used there is no system in place to check that they are being maintained.

Industrial, Commercial and Recreational Activities

Various anthropogenic influences were raised as issues contributing to poor water quality. Discharges from industry and factories are a big concern to stakeholders as they contribute high levels of contamination to some areas of Sydney Harbour and its tributaries. Lane Cove participants remarked that Lane Cove River used to be biologically dead and that there is heavy metal accumulation in shellfish. They said the area is becoming more polluted (e.g. smell, rubbish, colour, clarity) but there have been efforts to slow down the decline. Stakeholders suggested that they have seen big changes in the last 10 years especially since some industries had closed. The presence of oysters was perceived as a good indicator of health.

As the result from a push to have industries move out or treat discharge, it was suggested that inflows in the Harbour have improved since 1974. However, irregular and illegal dumping cause fish kills and contribute significant contaminants to the estuary. Stakeholders questioned regulation of commercial and industrial activities, one participants concern was '*poorly regulated commercial activities that pollute the waterway e.g. grease trays dumping*'. It was felt by many stakeholders that it is hard to get authorities to find the source of waste and industrial discharge and follow up with fines etc.

Boating, ships and the working harbour environment was also a common concern between workshops. Stakeholders discussed water quality being affected by the release of sewage from recreational boats as well as oil and petrol spills from boating, ships and industry/ Harbour activities. It was said that boats skimming pick up oil and grease. Individuals suggested further issues affecting water quality including *'Ferry/ boat wake and associated erosion + sedimentation*', the '*impacts of anchoring & mooring on habitats'* and '*…introduction of foreign species*' from bilge water. It was suggested that sediment quality is improving as new sediment buries the older sediments but it was recognised that ships, barges and dredging can result in sediment eddies that stir up bottom sediments. Some participants also added that resuspension of heavy metals and other toxins will occur with sea level rise and that ocean acidification poses further threats to water quality. The ban on tin in antifouling paint was seen as a step forward but there has not yet been a significant return of crustaceans to rocks or rock walls.

Leachate from various landfill sites along the river was raised as a big source of nutrient levels. When developments are planned along the foreshore this affects project costs as the waste that can include asbestos, toxins, pesticides and plastic has to be disposed of correctly.

Recreational activities including rubbish after New Year's celebrations and dogs causing erosion through digging holes and making new tracks in riparian areas was also briefly discussed in some workshops as affecting water quality.

Erosion and Loss of Biodiversity

Stakeholders discussed the changing nature and reduction of biodiversity of plant and animal species in and around the harbour and catchment. With regard to vegetation hard structures such as sea walls are seen to displace and disturb natural vegetation. Hard edges are encroaching on mangroves and saltmarsh and it is felt that opportunities are not being created for these habitats to live. Habitat friendly seawalls and areas without seawalls were suggested by several participants as important for preventing further loss of mangroves and saltmarsh and preventing erosion caused by concrete structures. With climate change and sea level rise, one participant pointed out 'Saltmarsh *migration opportunities → hard surfaces + nowhere to migrate with sea level rise*'. Mangroves and other riparian vegetation are also under threat from people wanting water views. This has created conflict between local councils and property owners. Metal fencing, hessian and council leaving dead trees as disincentives have all been tried management actions for preventing habitat destruction. Some suggested that councils will allow people to remove some canopy rather than have the tree poisoned to retain the ecological benefits of water quality and prevention of erosion. It was felt by many stakeholders that a management plan for mangroves is needed.

Participants expressed their concern for the growing number of boat owners with bigger boats and jet skis with regard to the '*impacts of anchoring & mooring on habitats'*. Environmentally friendly moorings were seen as a positive step to prevention of seagrass and habitat destruction but it was recognized that they are expensive and research into lower cost alternatives is needed.

Degraded ecosystems and erosion were considered an ongoing issue effecting water quality and biodiversity. Tributaries were seen as major contributors of sediment into the harbour and onto beaches. Streams were seen to have a lack of space due to the built environment and as a result cause flooding issues. '*Ferry/ boat wake and associated erosion + sedimentation'* of beaches was raised by several stakeholders and beach erosion was also a concern. While beach replenishment does take place, stakeholders commented that the public complain when sand is not the same colour. Renaturalising streams and tributaries was considered a good option to prevent erosion but it was acknowledged as being difficult and expensive.

The reduction of animal and plant biodiversity due to varied threats such as invasive species, weeds and garden escapees, people flushing dead diseased fish and axolotls down the toilet and the possible impact of micro plastics in the future was also a common concern between workshops.

Fish passages were also a concern for some. One stakeholder commented that '*Parra River. Fish passage - Marsden St weir - fishway doesn't work. Asylum weir - no fishway. Duck Creek - low weir + railway culvert is problem for fish passage*'.

Community Attitudes, Legislation and Management Bodies

Community knowledge of what contributes to poor water quality was commonly seen as part of the problem. Stakeholders described '*peoples lack of understanding of what happens to stormwater'*, the '*lack of education of the community'* and '*poor visual amenity - due to litter and then leading to poor attitude to link streets use to Harbour*'. It was felt that education programs had not been sustained and there is a need for a high profile person to bring the community attention to bear. One participant said that there is a need for '*Community Awareness Program [to be] increased. Including developers and wide range of stakeholders*.' While some of the community commit to doing maintenance (e.g. street, park and bush care) it was noted that it takes a lot of energy to keep them going. More involvement of local communities in specific community focused solutions was also seen as a potential beneficial action.

Inconsistent government and council approaches to the significance of water quality was also a big concern. It was suggested that no consistent State Government pressure on water quality has resulted in different Councils having various emphasis on its importance. One participant commented that there is a '*lack of drivers → no real desire from local government (community, councils to spend money) and state/ fed gov to provide grants etc*.'. Another said there is '*Lacking resources and political will to prioritise water quality in government & provide*

funding, strategy & regulatory support'. A lack of horizontal integration within councils between planners, environment departments and infrastructure sections was also seen as needing coordination. Furthermore, it was generally felt that changes in government result in lost momentum for water quality related issues. Stakeholders felt that council collaboration and cost sharing may be a positive step forward.

Water quality monitoring was also a contentious issue. One participant listed the '*Co-ordination of existing monitoring'* as a concern. Due to the different emphasis of councils on water quality, some participants suggested that the catchment is one of the poorest monitored estuaries in the country due to lack of coordination and collation. It was also felt by some that any monitoring data collected is not used to its full potential. Many stakeholders considered monitoring important to help identify issues so that improvement procedures can be put in place. Strategic communication and education to the community is also important. Stakeholders expressed the importance of making technical information accessible to the community. One person suggested '*Publically available data on stormwater quality in real time*' would be useful.

Management actions

What opportunities do you see to improve and protect our rivers and estuary? What actions do you think should be taken to protect and enhance water quality in the rivers and estuary?

People came up with a large number of management actions they felt would improve water quality. The most frequently raised options were:

- Higher levels of sewerage infrastructure maintenance including wet and dry weather overflow abatements.
- Standardise WSUD & specifications throughout catchment including enforcement of design standards, and erosion and sediment controls. This may include implementation of water sensitive cities policies and strategies.
- Education to inform community of the science and costs involved with management and of no action. This should include broad scale campaigns and some education that focus on children to ensure they carry the message home to their families. It should also target others whose decisions directly affect the rivers and Harbour such as building contractors and developers etc.
- Increased monitoring of water quality and further investigation of the sources of pollution in the Harbour. This should include elements such as integrated real-time monitoring, the State Government adopting water quality and quantity targets (with different targets for freshwater, the estuary and stormwater) and a communication method that measures change overtime such as regular report cards.
- A collaborative effort between councils, Sydney water, State government & other authorities to work together on improving water quality. (e.g. Parramatta River Catchment Group). This may involve a common coordinating body or the increased flow of information between state organisations, developers and catchment authorities on management plans & their specific consideration.
- Reduce littering of waterways through further law enforcement. For example by increasing fines in the Land and Environment Court or closing down sites/ corporations that are non-compliant.

Other options raised were:

- Restoration of riparian corridors, including revegetation. Also removal and replacement of exotic species and pest control.
- An 'adopt a stream' program which encourages investment in river health on the part of industry.
- Research into what contributions make for sustainable nutrient loads. Some stakeholders suggested that leaf litter is a major source of nutrients and sediments and that the Harbour has very high organic content (~5% TOC).
- Stormwater harvesting.

- Hold catchment days and tours where school students, community, local government, engineers and developers can become educated on catchment issues such as weeds, litter, sediment controls and WSUD.
- As part of any management plans there needs to be a list of physical actions to implement year after year not just general plans.
- Need for better greening planning/ practices. 202020 re-vegetation movement was mentioned.
- Increase in public rubbish bins to deter littering.
- More strategic street sweeping regime e.g. map deciduous trees and sweep more frequently during key months and at timing when cars aren't parked.
- Proper training (annually?) on WSUD maintenance for all people involved including operational staff.
- Cash for container scheme to encourage recycling

Impediments to Implementing Actions

Participants explored some of the impediments to these actions being implemented. One major action that was seen to have significant impediments associated with it is catchment wide WSUD implementation and maintenance. It was suggested that a State-wide design and construction standards would be best with mass adoption by Councils. While many suggested that WSUD should be in Development Control Plan's (DCP), currently adoption is up to individual councils. The difficulty in implementing initiatives such as WSUD in Councils was acknowledged due to a lack of ability and skills in designing WSUD & implementation. Furthermore, there is a low capacity in Councils to assess WSD in developments and make sure they are built properly. For example during planning, decision support tools such as MUSIC only allow users to identify the sizes of devices and do not give detailed design, construction and maintenance guidelines that make them work. It was acknowledged that WSUD was more likely to occur in greenfield but not necessarily in infill developments. It was also recognised that enforcement of devices such as rain gardens and issues such as creek line remediation during/ after developments is an important step forward. However this is very costly.

Stormwater harvesting was considered by some as a good option for reducing peak flows as well as capture and use of water. It was noted that key beneficiaries of large stormwater harvesting need to be identified but this is expensive and relies on grant funding.

Other impediments that related to a broad set of actions related to lack of knowledge, lack of accountability and a general sense of public apathy. A lack of engagement between Council and community and lack of knowledge about the waterways and infrastructure/systems were discussed. It was felt that how the stormwater system works was not well understood by the community and that areas with litter attract more litter. Cost sharing, lack of political will and no single management authority were seen as impediments to ongoing education campaigns and initiatives to improve water quality.

Continuous monitoring of water quality was seen as important however it is very costly and it was felt that there is currently no agenda for using the data.

Many stakeholders felt that regulatory processes, application of legislation and fines for pollution need reviewing. For larger oil refineries it was felt that fines for oil spills and poor compliance is not a disincentive. It was suggested that some big developers will build without development applications and hold up courts. The implementation of fines for the disposal, bilge & ballast water was also discussed. Many acknowledged the importance of tightening requirements for noncompliance actions as noted above however the politics of applying the legislation, the lack of enforcement of existing rules and not enough compliance officers were all seen as impediments.

Proactive planting and re-vegetation of riparian zones is complex and limited because it cannot be done in all sites due to flooding or seawalls and sometimes the cost is considered to out way the water quality benefits. It was also noted that often the driver is based on '*assets falling apart rather than environmental benefit*'. Funding and community involvement is also an impediment.

The potential to remediate sites in the Harbour is controversial. While some highly contaminated sites have been remediated successfully there are still a lot of medium and low contaminated areas. Some argue that in the long run digging up contaminated sediment is not worth the effort because the spoil needs to be dealt with and over many decades it gets buried, becoming less of an issue. But some pointed out that this is only the case where original sources are stormwater not an industrial source. On average it was considered best to leave contaminates there as dredging and dealing with spoil is expensive.

APPENDIX 2. CURRENT POLLUTANT LOADS

Table 9 gives the current predicted annual pollutant loads for TN, TP, TSS, and *Enterococci, faecal coliforms* as well as the estimated average annual flow (ML/yr), according to the CAPER DSS (see Appendix 4). The loads are classed by land use and sewer overflows for each of the major subcatchments.

TABLE 9. ESTIMATED AVERAGE ANNUAL LOADS FROM THE CAPER DSS

	Parramatta	Lane Cove	Middle Harbour	Port Jackson	Total
TN (kg/yr)					
Bushland	2,725	3,579	8,021	2,086	16,411
Commercial	29,408	16,525	4,603	18,082	68,618
Industrial	24,039	1,969	2,355	3,078	31,440
Parkland	10,761	8,417	9,823	3,839	32,841
Rail	4,265	672	963	1,105	7,005
Residential	156,891	73,664	62,181	39,274	332,010
Roads	81,714	31,756	27,633	26,439	167,542
Rural	831	0	0	0	831
Sewer overflows	48,820	11,426	8,047	0	68,293
TP (kg/yr)					
Bushland	201	265	594	154	1,215
Commercial	3,389	1,900	529	2,077	7,894
Industrial	2,788	228	272	356	3,644
Parkland	795	623	727	284	2,430
Rail	494	78	111	128	811
Residential	17,936	8,402	7,084	4,475	37,898
Roads	9,475	3,675	3,196	3,058	19,404
Rural	35	0	0	0	35
Sewer overflows	5,800	1,358	956	0	8,114
TSS (t/yr)					
Bushland	90	120	271	71	553
Commercial	2,042	1,141	318	1,247	4,748
Industrial	1,692	138	165	215	2,211
Parkland	356	283	332	131	1,102
Rail	300	47	67	77	492
Residential	10,707	5,002	4,211	2,661	22,582
Roads	5,750	2,225	1,934	1,850	11,760
Rural	50	0	0	0	50
Sewer overflows	967	226	159	0	1,352
***Enterococci* (cfu/yr)**					
Bushland	1843313	2451394	5527982	1440465	11263153
Commercial	1E+08	5.8E+07	1.6E+07	63444553	241016361
Industrial	8.5E+07	6946999	8302024	10848662	110996866
Parkland	1.6E+07	1.2E+07	1.4E+07	5486514	47593484
Rail	1.5E+07	2372131	3395249	3893474	24720069
Residential	2.1E+09	9.9E+08	8.3E+08	524878811	4452567866
Roads	2.8E+08	1.1E+08	9.5E+07	91035004	578523585

Rural	316954	0	0	0	316954
Sewer overflows	4.8E+10	1.1E+10	8E+09	0	67617000000
***Faecal coliforms* (cfu/yr)**					
Bushland	9216566	1.2E+07	2.8E+07	7202324	56315767
Commercial	1E+09	5.6E+08	1.6E+08	610247811	2323850297
Industrial	8.3E+08	6.8E+07	8.1E+07	105440981	1082518906
Parkland	3.6E+07	2.9E+07	3.4E+07	13297949	112245831
Rail	1.5E+08	2.3E+07	3.3E+07	37746967	240320676
Residential	5.2E+09	2.4E+09	2.1E+09	1301743320	11047507734
Roads	2.8E+09	1.1E+09	9.5E+08	905796666	5758590918
Rural	1584769	0	0	0	1584769
Sewer overflows	6E+10	1.4E+10	1E+10	0	84521250000
Flow (ML/yr)					
Bushland	2,282	2,989	6,689	1,739	13,698
Commercial	11,454	6,492	1,810	7,123	26,879
Industrial	9,144	752	904	1,183	11,983
Parkland	9,015	7,031	8,195	3,198	27,438
Rail	1,624	258	370	425	2,676
Residential	62,854	29,747	25,215	15,915	133,731
Roads	31,098	12,174	10,613	10,162	64,047
Rural	399	0	0	0	399
Sewer overflows	4,834	1,131	797	0	6,762

APPENDIX 3. DETAILED LOAD TARGETS

Loads targets by subcatchment for the Sydney Harbour catchment are given in Table 10.

TABLE 10. LOAD TARGETS BY SUBCATCHMENT BASED ON 70% WSUD TO INFILL REDEVELOPMENT, 10% RETROFIT TO EXISTING URBAN AREAS AND CAPPING SEWER OVERFLOWS TO NO MORE THAN 40 IN 10 YEARS

Subcatchment	TN	TP	TSS	*Enterococci*	*Faecal coliforms*
Abbotsford Bay	-5%	-8%	-9%	-8%	-9%
Abecketts Creek	-11%	-16%	-19%	-16%	-18%
Alexandra Bay	-5%	-8%	-9%	-8%	-9%
Archer Creek	-8%	-12%	-15%	-14%	-15%
Athol Bay	-5%	-8%	-9%	-8%	-9%
Balls Head Bay	-19%	-29%	-36%	-33%	-35%
Bantry Bay	-4%	-6%	-8%	-8%	-9%
Bare creek	-2%	-3%	-4%	-5%	-7%
Belmore Branch	-5%	-8%	-9%	-8%	-9%
Berrys creek	-21%	-30%	-37%	-34%	-36%
Blackbutt creek	-21%	-31%	-38%	-35%	-37%
Blacktown Creek	-5%	-8%	-9%	-8%	-9%
Blackwattle Bay	-20%	-29%	-36%	-33%	-35%
Bluegum creek	-33%	-50%	-61%	-56%	-60%
Brays Point	-7%	-10%	-13%	-12%	-13%
Brickfield Creek	-5%	-8%	-9%	-8%	-9%
Brickmakers creek	-5%	-7%	-9%	-8%	-9%
Buffalo creek	-5%	-8%	-9%	-8%	-9%
Byles creek	-4%	-7%	-9%	-8%	-9%
Carroll creek	-5%	-7%	-9%	-8%	-9%
Charity Creek	-6%	-9%	-11%	-10%	-11%
Clay Cliff Creek	-18%	-26%	-32%	-27%	-31%
Coopers Creek	-5%	-8%	-9%	-8%	-9%
Coups creek	-9%	-13%	-16%	-14%	-16%
Darling Harbour	-25%	-37%	-45%	-41%	-43%
Darling Mills Creek	-5%	-7%	-9%	-8%	-9%
Devlin creek	-13%	-20%	-24%	-22%	-24%
Double Bay foreshore	-14%	-20%	-24%	-22%	-23%
Drummoyne Bay to Cockatoo island	-5%	-8%	-9%	-8%	-9%
Duck Creek	-6%	-8%	-10%	-9%	-10%
Duck River	-10%	-15%	-18%	-15%	-17%
Elizabeth Bay foreshore	-15%	-21%	-26%	-23%	-25%
Estuary foreshore between Sugarloaf & Sailors Bays	-5%	-8%	-9%	-8%	-9%
Finlaysons Creek	-5%	-8%	-9%	-8%	-9%
Five Dock Bay	-5%	-8%	-9%	-8%	-9%
Flat rock creek	-12%	-18%	-22%	-20%	-21%
Frenchs creek	-4%	-7%	-8%	-8%	-9%
Glades Bay	-5%	-8%	-9%	-8%	-9%
Gordon creek	-6%	-9%	-11%	-10%	-11%

Gore creek	-7%	-10%	-12%	-11%	-12%
Grantham Creek	-5%	-8%	-9%	-8%	-9%
Greystanes Creek	-5%	-8%	-9%	-8%	-9%
Grove Creek	-5%	-8%	-9%	-8%	-9%
Haslams Creek	-13%	-19%	-23%	-21%	-22%
Hawthorn Canal	-12%	-18%	-22%	-20%	-21%
Hunts Creek	-5%	-7%	-9%	-8%	-9%
Iron Cove	-6%	-9%	-11%	-10%	-11%
Iron Cove Creek	-15%	-21%	-26%	-24%	-25%
John Whitton bridge to Kissing Point Bay	-5%	-8%	-9%	-8%	-9%
Johnstons Bay foreshore	-8%	-12%	-14%	-13%	-13%
Johnstons creek	-8%	-11%	-14%	-12%	-13%
Kendall Bay	-5%	-8%	-9%	-8%	-9%
Lalor Creek	-5%	-8%	-9%	-8%	-9%
Lane Cove River Headwaters	-4%	-7%	-8%	-8%	-9%
Lavender & Berrys Bay	-17%	-26%	-31%	-29%	-31%
Linley Point	-5%	-7%	-9%	-8%	-9%
Little Bluegum creek	-25%	-37%	-45%	-42%	-45%
Little Duck Creek	-5%	-8%	-9%	-8%	-9%
Long Bay foreshore	-5%	-7%	-9%	-8%	-9%
Looking Glass to Wallamatta Bay	-5%	-7%	-9%	-8%	-9%
Lower Middle Harbour foreshore	-5%	-7%	-9%	-8%	-9%
Lower Parramatta River	-5%	-7%	-9%	-8%	-9%
Lower Toongabbie Creek	-5%	-8%	-9%	-8%	-9%
Majors Bay	-17%	-25%	-32%	-30%	-32%
Martins & Kitty creeks	-5%	-7%	-9%	-8%	-9%
Mid Lane Cove River	-12%	-19%	-24%	-26%	-24%
Middle Harbour creek	-4%	-6%	-8%	-8%	-9%
Moores creek	-5%	-8%	-9%	-9%	-9%
Mort and Snails Bays	-5%	-7%	-9%	-8%	-9%
Mosmans Bay	-5%	-8%	-9%	-8%	-9%
North Harbour foreshore	-4%	-6%	-8%	-8%	-9%
Northmead Gully	-5%	-8%	-9%	-8%	-9%
Pendle Hill Creek	-5%	-8%	-9%	-8%	-9%
Ponds Creek	-5%	-7%	-9%	-8%	-9%
Powells Creek	-22%	-32%	-39%	-36%	-37%
Quarry creek	-8%	-12%	-15%	-14%	-15%
Rocky creek	-5%	-8%	-10%	-9%	-10%
Rose Bay foreshore	-5%	-7%	-9%	-8%	-9%
Sailors Bay creek	-5%	-7%	-9%	-8%	-9%
Sailors Bay foreshore	-5%	-8%	-9%	-8%	-9%
Saltwater Creek	-8%	-12%	-14%	-13%	-14%
Scotts creek	-9%	-14%	-17%	-15%	-17%
Scout creek	-4%	-6%	-8%	-8%	-9%
Shrimptons creek	-6%	-9%	-11%	-10%	-11%

Smalls Creek	-26%	-38%	-47%	-42%	-45%
Stringy Bark creek	-5%	-8%	-9%	-8%	-9%
Subiaco Creek	-5%	-8%	-9%	-8%	-9%
Sugarloaf & Camp creeks	-5%	-7%	-9%	-8%	-9%
Swaines creek	-9%	-14%	-17%	-16%	-17%
Sydney Cove to Woolloomooloo Bay	-19%	-28%	-35%	-32%	-35%
Tambourine creek	-5%	-8%	-9%	-8%	-9%
Tannery creek	-5%	-8%	-9%	-8%	-9%
Tarban Creek	-5%	-8%	-9%	-8%	-9%
Taylors to Obelisk Bay	-3%	-5%	-7%	-8%	-8%
Terrys creek	-13%	-19%	-24%	-22%	-23%
Toongabbie Creek	-5%	-8%	-9%	-8%	-9%
Upper Darling Mills Creek	-12%	-17%	-21%	-19%	-21%
Upper Lane Cove River	-11%	-17%	-21%	-19%	-21%
Upper Middle Harbour Estuary foreshore	-4%	-7%	-8%	-8%	-9%
Upper Parramatta River	-10%	-15%	-18%	-15%	-18%
Upper Parramatta River Estuary	-6%	-8%	-10%	-9%	-10%
Upper Toongabbie Creek	-6%	-8%	-10%	-9%	-10%
Vineyard Creek	-5%	-7%	-9%	-8%	-9%
Watsons Bay	-5%	-7%	-9%	-8%	-9%
Whites creek	-16%	-24%	-29%	-26%	-27%
Willoughby creek	-5%	-7%	-9%	-8%	-9%
Yarralla Bay	-12%	-18%	-22%	-20%	-21%

Load targets by LGA for Sydney Harbour are given in Table 11. Note these targets apply to the section of the LGA within the Sydney Harbour catchment only.

TABLE 11. LOAD TARGETS BY LGA BASED ON 70% WSUD TO INFILL REDEVELOPMENT, 10% RETROFIT TO EXISTING URBAN AREAS AND CAPPING SEWER OVERFLOWS TO NO MORE THAN 40 IN 10 YEARS

	TN	TP	TSS	*Enterococci*	*Faecal coliforms*
Ashfield	-13%	-20%	-24%	-21%	-23%
Auburn	-13%	-19%	-23%	-21%	-22%
Bankstown	-5%	-8%	-9%	-8%	-9%
Blacktown	-5%	-8%	-9%	-8%	-9%
Burwood	-20%	-29%	-35%	-33%	-34%
Canada Bay	-12%	-17%	-21%	-18%	-20%
Canterbury	-5%	-8%	-9%	-8%	-9%
Holroyd	-5%	-8%	-10%	-9%	-9%
Hornsby	-12%	-18%	-23%	-21%	-22%
Hunters Hill	-5%	-7%	-9%	-8%	-9%
Ku-ring-gai	-11%	-16%	-20%	-19%	-20%
Lane Cove	-7%	-10%	-12%	-11%	-12%
Leichhardt	-12%	-17%	-21%	-18%	-20%
Manly	-4%	-7%	-9%	-8%	-9%
Marrickville	-9%	-13%	-15%	-14%	-15%
Mosman	-5%	-7%	-9%	-8%	-9%
North Sydney	-9%	-14%	-17%	-15%	-16%
Parramatta	-8%	-12%	-14%	-12%	-14%
Ryde	-9%	-13%	-16%	-14%	-16%
Strathfield	-16%	-23%	-28%	-25%	-27%
Sydney	-19%	-28%	-35%	-30%	-34%
The Hills	-8%	-12%	-14%	-13%	-14%
Warringah	-4%	-6%	-8%	-8%	-9%
Waverley	-5%	-8%	-9%	-8%	-9%
Willoughby	-10%	-15%	-19%	-17%	-18%
Woollahra	-10%	-14%	-18%	-16%	-17%

APPENDIX 4. SYDNEY HARBOUR CAPER DSS

The CAPER DSS has been constructed to support the development of this Sydney Harbour Water Quality Improvement Plan. The DSS integrates management actions, land use and climate, catchment water quality, receiving water quality and management costs to:

- Allow the examination and prioritization of catchment management scenarios that could be implemented to protect water quality in Sydney Harbour and its tributaries
- Provide a tool that can be used by local councils and catchment managers to facilitate the testing of local scale catchment management scenarios and prioritise local water quality improvement interventions
- Management costs

The CAPER DSS is a decision support system designed to:

- *Integrate* information from catchment water quality models, receiving water quality models, MUSIC modeling, literature and expert opinion;
- Provide information on the *costs and benefits* associated with different management options;
- Allow the *trade-offs* associated with different *land use and land management* options in the catchment to be assessed;
- Be *accessible to non-technical users* (i.e. people without any modeling skills or background) and stakeholders; and,
- Provide a *memory of project methods and outputs* and make models more accessible to stakeholders, managers and policy makers.

The CAPER DSS delivers on these needs by using a generic modeling platform and an easy-to-use interface shell that can be rapidly tailored to meet the needs of new applications. The system has been designed to include ‘soft’ data such as text descriptions, photos and maps. It contains a significant amount of contextual information and provides internal documentation of assumptions and models used in each application to make these available to people without significant modelling skills.

Components of the DSS

The Sydney Harbour CAPER DSS is underpinned by an integrated model, as shown in Figure 24. A detailed description of each of the components can be found in the DSS. A brief overview is provided below.

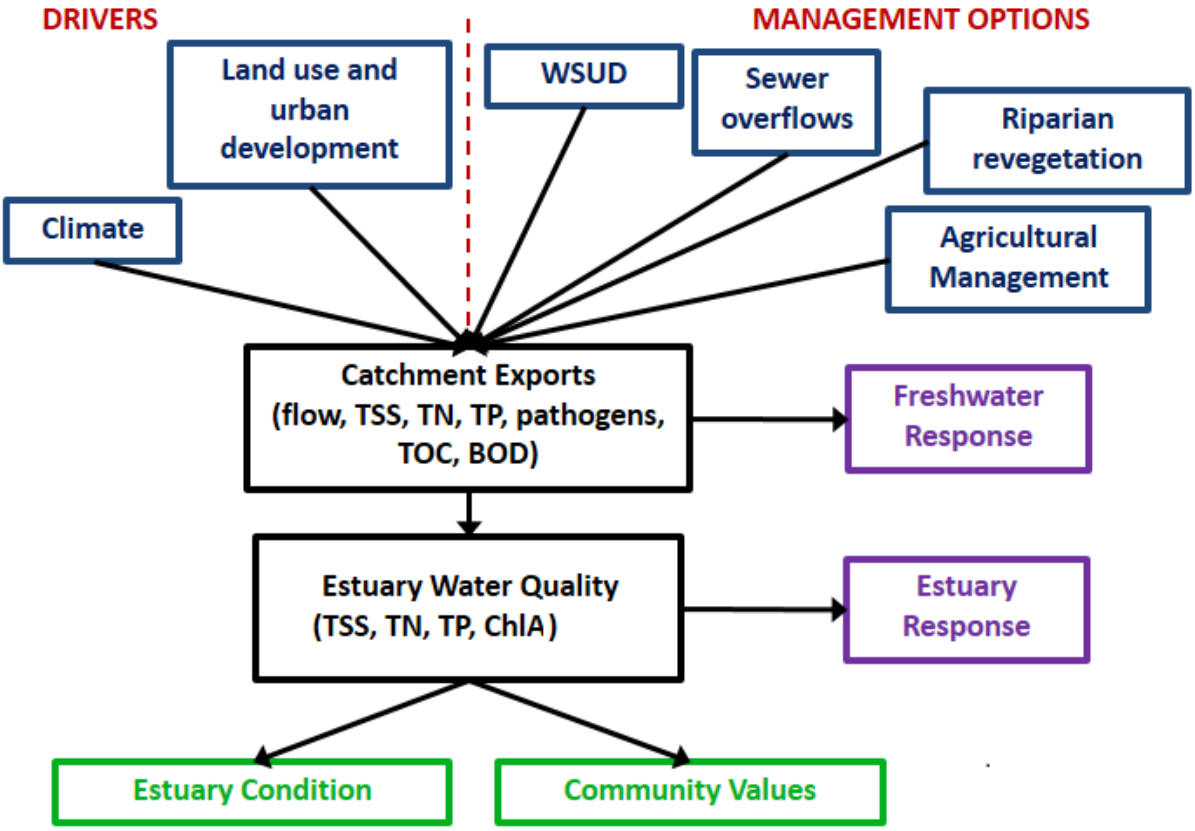

FIGURE 24. CONCEPTUAL FRAMEWORK UNDERLYING THE SYDNEY HARBOUR CAPER DSS

Source Catchments - Land use and climate

Catchment pollutant loads are modelled using a metamodel of the Source Catchments model that has been developed for Sydney Harbour. This metamodel uses per ha annual average quick flow and slow flow for each land use in a subcatchment in combination with Event Mean concentrations (EMC) and Dry Weather concentrations. This is combined with land use area to produce an estimated pollutant load for the subcatchment/LGA combination. Further detail on the Source Catchments model for Sydney Harbour can be found in Stewart (2013).

Water Sensitive Urban Design

The effects of water sensitive urban design (WSUD) on pollutant loads and flows are modelled in the DSS using a metamodel of the MUSIC model. This metamodel uses removal efficiencies derived for each pollutant from runs of the MUSIC model for each of the treatment trains included in the DSS. Lifecycle, upfront and maintenance costs for each of the options on a per ha treated basis are also incorporated in the DSS based on values derived from the MUSIC model.

Sewer overflows

Sewer overflows are modelled using data provided by Sydney Water on the location of overflow points, total volume of overflows and the number of events over a 10 year period. Pollutant concentrations are used with these flow estimates to calculate annual average loads.

Riparian vegetation

The effect of riparian corridors on TN, TP and TSS has been modelled using relationships described in Zhang *et al.* (2010). This paper provides a review of literature on the effectiveness of vegetated buffers in removing nutrients and sediments from runoff. Modelled relationships are of the form:

$$\text{Reduction}=A+B(1-e^{Cw}),$$

where A, B and C are parameters given below and w is the width of the riparian zone in metres. Table 12 gives the parameters used in this model within the DSS.

TABLE 12. PARAMETERS USED IN THE RIPARIAN CORRIDOR MODEL

Constituent	A	B	C
Trees only			
Sediment	41.7	61	-0.35
Nitrogen	23.9	91.4	-0.11
Phosphorus	59.8	147	-0.03
Mixed grass and trees			
Sediment	26.9	61	-0.35
Nitrogen	10.2	91.4	-0.11
Phosphorus	30.5	147	-0.03

Note that a slope of 10% has been assumed for the buffer. These equations are used to derive a removal efficiency that is then combined multiplicatively with the percentage of the riparian zone vegetated to give a total removal efficiency.

Agricultural management

Agriculture is not a significant land use in the Sydney Harbour catchment. A very simple user defined option has been incorporated to allow for management options to be run on rural areas in the model.

Receiving water quality

The impacts of catchment loads on receiving water quality in the DSS are modelled using a metamodel of a Box-model developed by developed by Baird Australia Pty Ltd. The box-model produces a time series of pollutant concentrations based on times series loads for each of 32 estuary zones. The DSS metamodel uses a tracer approach, where the influence 33 subcatchment inputs on water quality in each of these zones is modelled by turning these inputs on one at a time, with all other catchment inputs set to zero. An ambient value for nutrients is used to represent the background pollutant concentration with no catchment input, based on results from the box-model run. The tracer uses average concentrations for each estuary zone over the time series.

Ecological response models

The CAPER DSS for Sydney Harbour estimates the impact of changes in catchment loads and estuary pollutant concentrations on estuary and stream health using a Bayesian Network approach. A Bayesian Network is an acyclic graphical model representing the linkages between random variables, described using conditional probabilities. Bayesian Networks use Bayes law to describe the probability of outputs states, that is,

$P(B)=P(B|A)xP(A).$

Bayesian networks are unidirectional, that is, they do not allow for feedback loops.

Changes in pollutant concentrations in major subcatchments and in estuary zones are calculated. These are then used, in conjunction with several other non-water quality based management options (such as dredging), as

inputs to the response models. An initial conceptual framework was developed based on outcomes of a workshop held during the scoping phase of the DSS. This was then refined based on literature and data review.

The BN has been populated with data from numerous sources:

- Monitoring data and the results of scientific investigations where possible;
- Local expert opinion where available; and,
- Literature values where no other source of information is available.

An important part of the development of any BN is the explicit representation of local expert knowledge in the form of a conceptual framework and the identification of key knowledge and information gaps that require further research. The source of data underpinning each of the links (i.e. conditional probabilities) in the network is documented in the DSS.

The framework for the estuary ecological response model used in the DSS is shown in Figure 25.

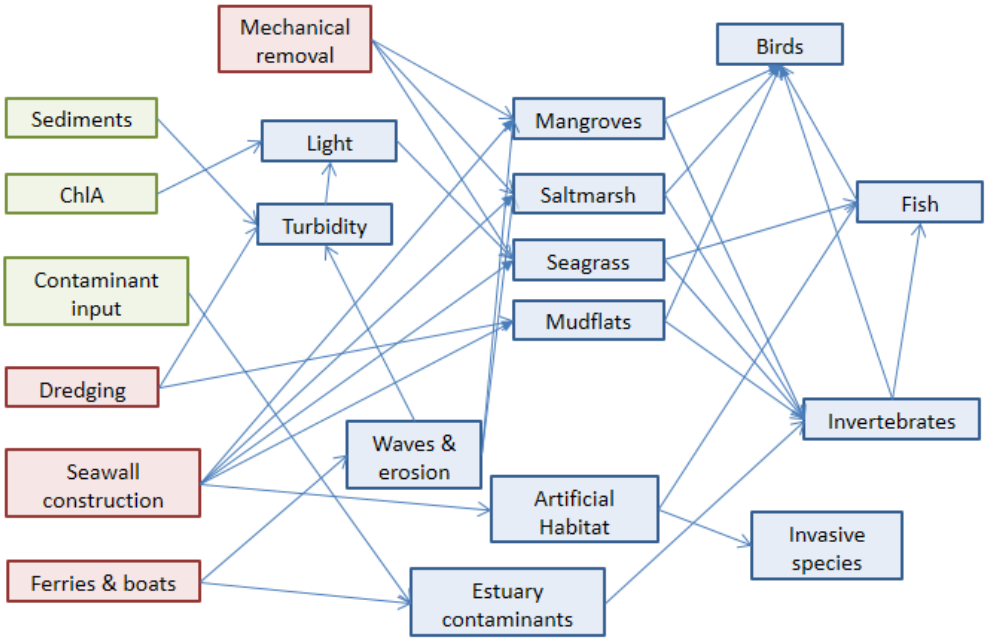

FIGURE 25. FRAMEWORK FOR THE ESTUARY ECOLOGICAL RESPONSE MODEL USED IN THE DSS

The framework for the freshwater ecological response model used in the DSS is shown in Figure 26.

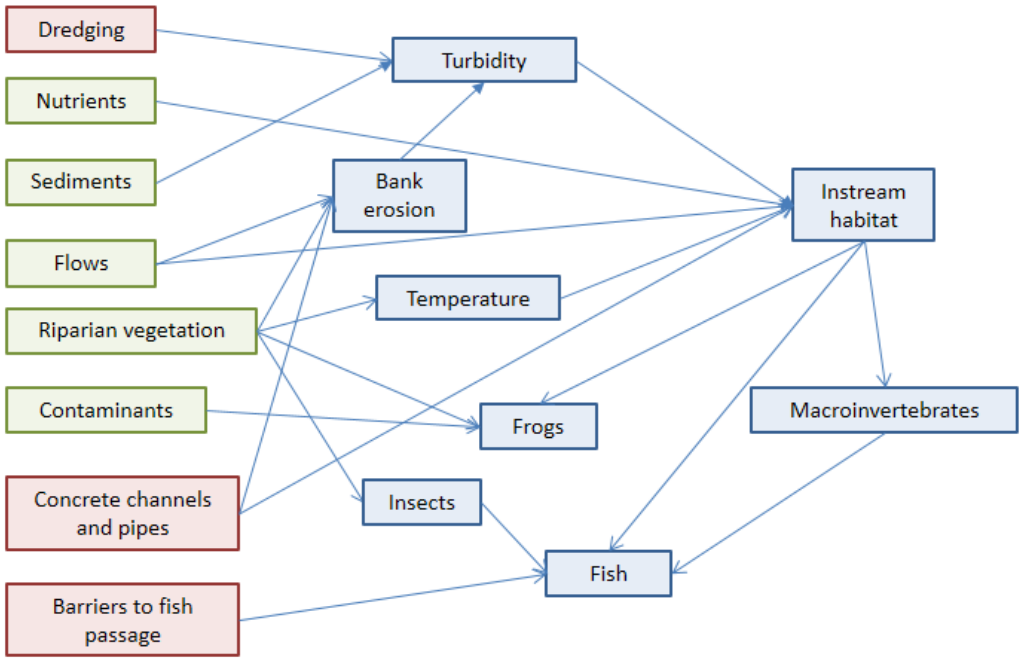

FIGURE 26. FRAMEWORK FOR THE FRESHWATER RESPONSE MODEL USED IN THE DSS

Estuary condition and community values

Estuary condition is modelled in the DSS using a set of thresholds derived by DECW for Botany Bay and ANZECC guidelines for TN and TP. These thresholds represent values below which the condition of the estuary could be considered to be slightly to moderately disturbed. Different threshold values are used for the upper and lower estuary zones. While these thresholds are used as specific values it should be noted that the transition between states will be more continual such that as these values are approached condition will decline or improve incrementally. Thresholds used in the DSS are given in Table 13. These condition measures in the DSS are indicative only as they applied to the mean concentration value for the zone over the year. It would be expected that for much of the year concentrations may be well above this threshold value even where the mean sits below the value.

TABLE 13. THRESHOLDS FOR ESTUARY CONDITION USED IN THE SYDNEY HARBOUR CAPER DSS TO REPRESENT SLIGHTLY TO MODERATELY DISTURBED CONDITION

	ChlA (mg/L)	TP (mg/L)	TN (mg/L)
Upper estuary	5.3	30	300
Lower estuary	3.3	25	120

In this CAPER DSS *faecal coliforms* and *Enterococci* concentrations are used to reflect the likely impacts on community values for primary and secondary contact activities. Threshold values for these uses were taken from the ANZECC Guidelines for recreational water quality and aesthetics. The values used are as shown in Table 14. Note that thresholds are given in cfu/100mL.

TABLE 14. THRESHOLDS FOR COMMUNITY VALUES USED IN THE SYDNEY HARBOUR CAPER DSS

Activity	*Faecal coliforms*	*Enterococci*
Primary contact	150	35
Secondary contact	1000	230

Note that these impacts are indicative only. The DSS provided information on the expected mean value of a pollutant. Concentrations on any given day may be much higher or lower than this value, given that they are influenced by the magnitude and timing of rainfall events.