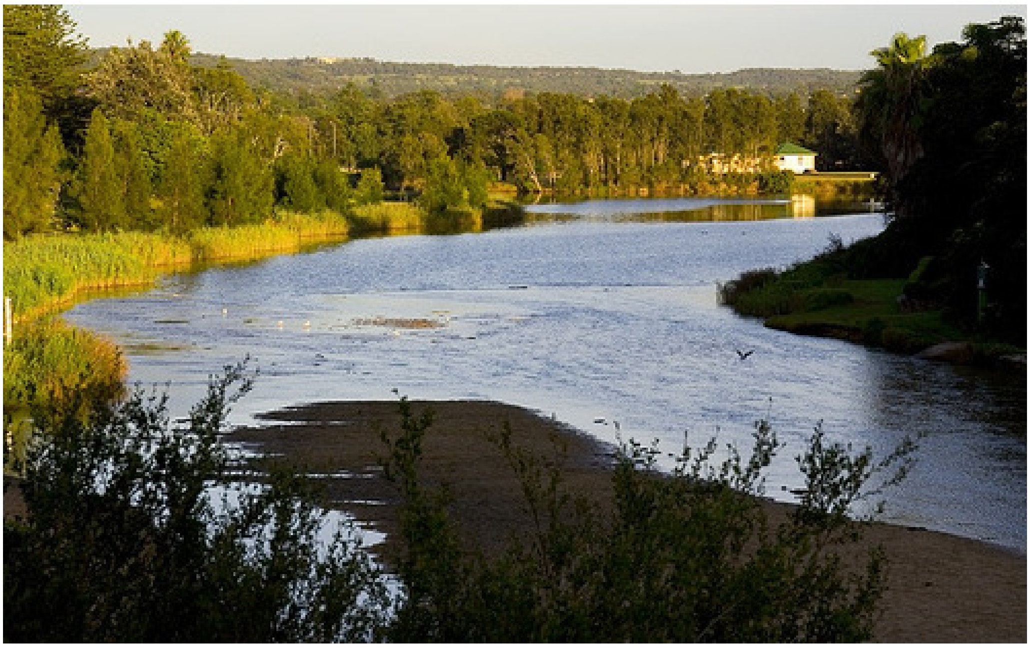
Manly Lagoon Catchment – Annual Sediment and Pollutant Loading



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1 Introduction

Warringah Council is undertaking this study to assess the sources of pollutants and the pollutant loads entering Manly Lagoon. The study includes two main elements – stormwater quality load modelling and reporting of sewer overflow loads – providing sediment and pollutant load data.

Based on an analysis of the land use within the catchment and relevant water quality monitoring a stormwater quality model has been developed which will establish sediment and pollutant loads and a pollutant budget for the Manly Lagoon Catchment. The model has adopted water quality data from local catchments.

Based on the results of the land use analysis and assessment of relevant water quality monitoring, a sediment source model has also been developed. This model provides the amount of sediment (in kg/yr) entering Manly Lagoon, generated in the catchment from different sources, including a breakdown based on landuses and subcatchments.

Overall, the pollutant budget and the sediment budget show the various inputs and outputs of key pollutants within the catchment on an annual average basis, including:

- Sediment
- Total Nitrogen
- Total Phosphorous
- Pathogen Indicators
- Heavy metals

The budget also provides a breakdown of the contributions from stormwater and sewer overflows.

2 Manly Lagoon Catchment

Manly Lagoon is an intermittently closed and open lake or lagoon (ICOLL). The lagoon has a catchment of 1800ha, of which nearly 40% of the catchment is residential, 24% forested, 16% roads, 10% public open space and 9% commercial (Table 1). The Catchment as shown in Figure 1 comprises of three sub-catchments including Manly Creek (and Dam), Brookvale Creek and Burnt Bridge Creek. Burnt Bridge Creek forms the boundary between Manly and Warringah LGAs.

Table 1: Manly Lagoon Catchment Landuse

Landuse	Area (ha)	Area (%)
Residential	692.2	38.3%
Commercial / Industrial	158.5	8.8%
Roads	294.4	16.3%
Public Open Space	188.7	10.4%
Forested	432.8	23.9%
Open Water	41.3	2.3%
Total	**1807.9**	**100.0%**

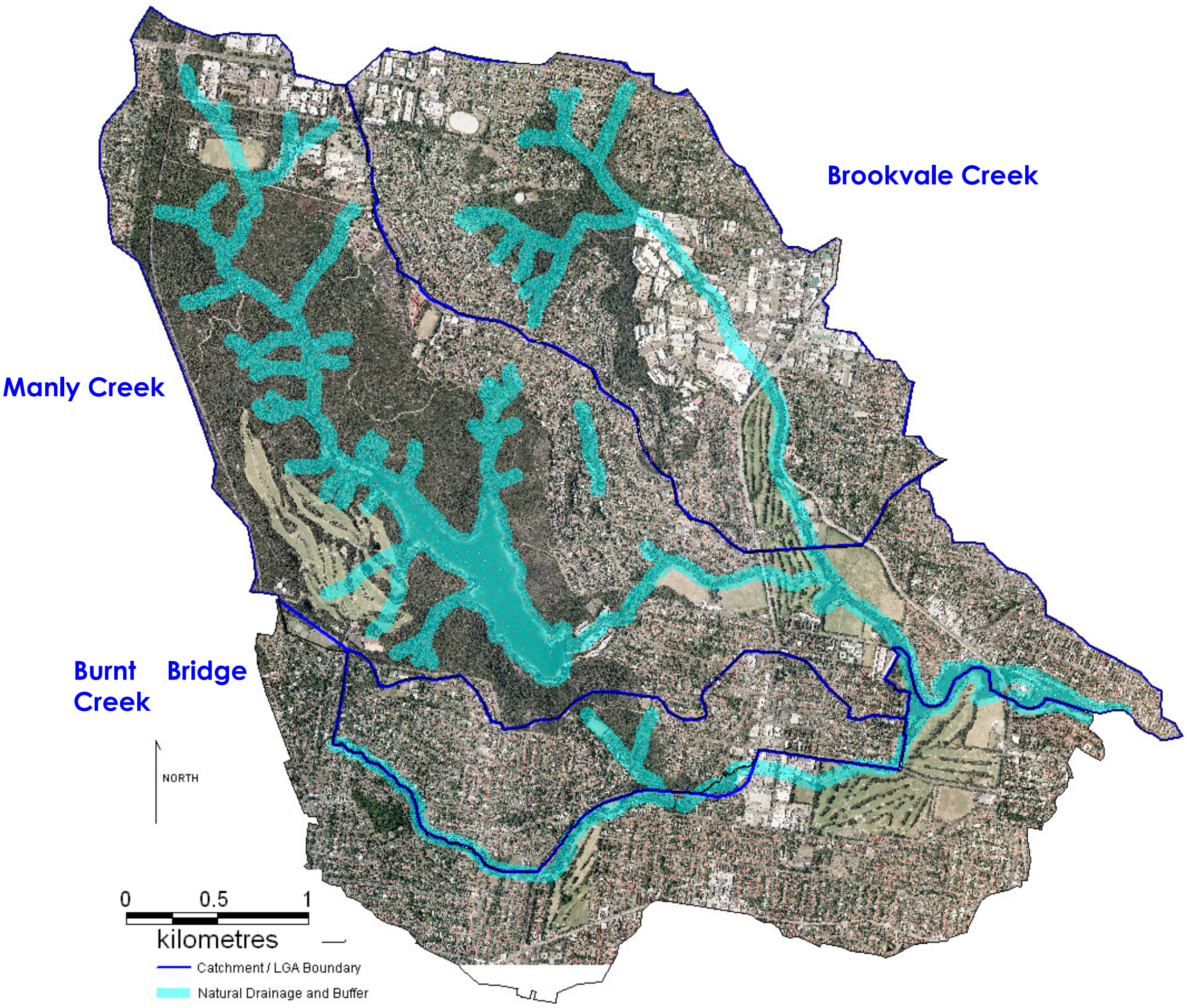


Figure 1: Manly Lagoon Catchment, with Natural drainage lines and catchment / LGA boundaries

2.1 Manly Lagoon

Manly Lagoon has an area of 12ha, with a maximum width of 190m and a length of 2.2km. While the current extent of the Lagoon is shown in Figure 2, there have been significant alterations to the lagoon over time, and currently only 10% of the original wetlands of the lagoon catchment remain (Warringah Council, 1998). The remaining 90% having been filled and/or reclaimed for uses such as Manly Golf Course, Hinkler Park, Warringah Golf Course, Nolan Reserve, Warringah Mall, Passmore Reserve and Wakehurst Golf Course. The infilling includes former tip sites Addiscombe Road, Lagoon Park, and the playing fields off Aquatic Drive.

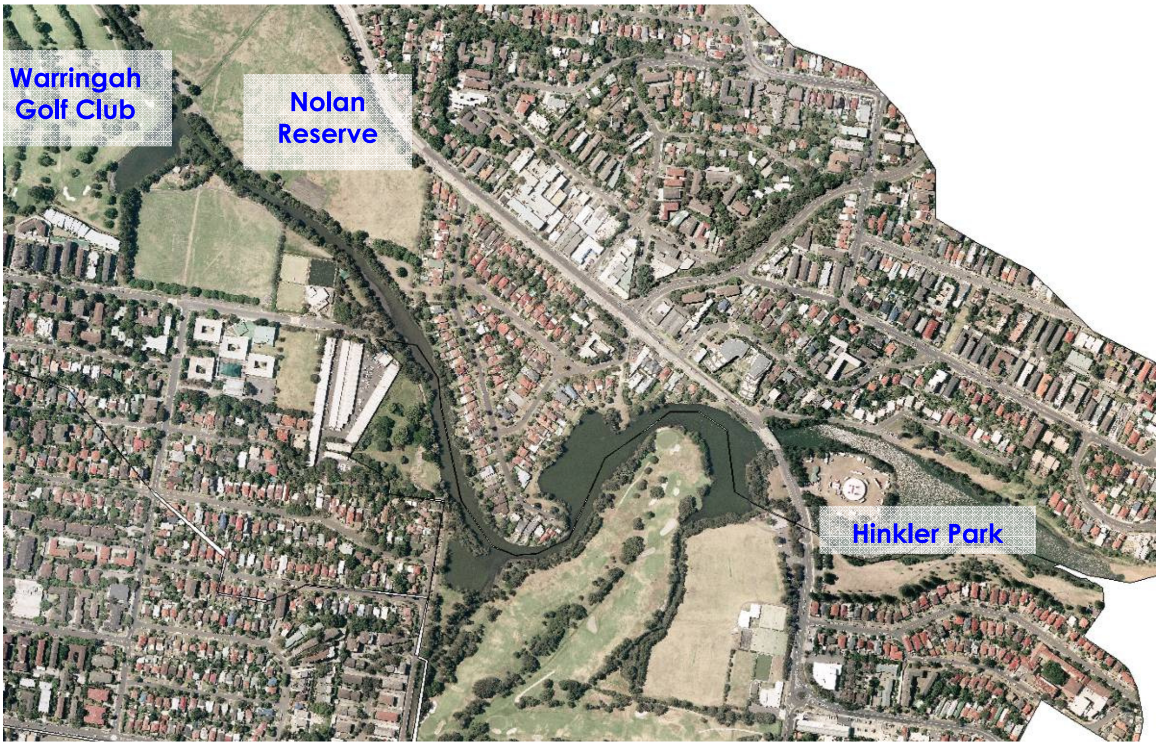


Figure 2: Manly Lagoon

The Manly Lagoon Estuary Management Study (Patterson Britton and Partners, 1995) contains a detailed description of the history of the alterations to the lagoon and surrounding landuse and infrastructure. The key alterations identified in this study include (Patterson Britton and Partners, 2005):

- Hinkler Park, having probably originally been created by dredging in the 1920s was an island up until the 1950s at which time the southern channel was artificially closed during bridge and road works;
- the side bays west of the mouth of Burnt Bridge Creek and upstream of the footbridge at Nolan Reserve have been artificially created;
- two tips have existed adjacent to the waterway, one at the eastern end of Lagoon Park in the 1920s and one near the end of Addiscombe Road in the 1950s and 1960s;
- All 3 creeks have supplied sediment to Manly Lagoon for many decades;
- market gardens were a feature of the foreshore development in the 1940s to 1960s along the southern side of the waterway from Manly Creek downstream to the eastern end of Campbell Parade.

Manly Lagoon is connected to the sea at the northern edge of Queenscliff Beach, via drainage infrastructure. The drainage infrastructure was constructed in the 1930s and facilitates the discharge of stormwater from Manly Lagoon, as well as allowing tidal flows into and out of Manly Lagoon. The drainage infrastructure comprises two pipes that become a single box-culvert on the seaward side. The pipes have been installed with grates for safety of swimmers and surfers.

2.1.1 Existing Water Quality

Manly Lagoon exhibits water quality typical of most existing water bodies located within urban areas. The lagoon has elevated levels of nutrients, including nitrogen and phosphorous, elevated levels of suspended solids and turbidity, and pathogens.

The lagoon frequently does not meet ANZECC standards for ecological health (Warringah Council, 1998). Poor water quality can adversely impacts on public health, ecosystems, and the overall aesthetic value of Manly Lagoon.

2.1.2 Recreational Use

Manly Lagoon is a popular recreational area. The main recreational uses of the lagoon and its foreshores at the present include fishing, walking, bicycling, and general observation; and prior to an awareness of the poor water quality in the lagoon it was also used for swimming and boating.

Manly Lagoon often does not meet the standards for use for both primary and secondary contact recreation (Warringah Council, 1998). For this reason Manly Lagoon is currently closed for various recreation uses (see image on left from Cardno, 2010)

2.1.3 Biological Diversity and Abundance

A benthic fauna study was undertaken by Cardno (2010). 503 animals were collected in the study. The samples found low abundance with twelve samples containing no animals. Diversity was considered low compared to previous studies, and no gastropod molluscs were collected as in previous studies.

2.2 Geology

As with most of the Sydney Basin, the Manly region's underlying geology is dominated by the Hawkesbury Sandstone Group which forms the large headlands of North Head, Queenscliff, and Long Reef as well as the drowned valleys where the present day lagoons of Manly, Dee Why, Curl Curl and Narrabeen Lagoons are situated. The Hawkesbury Sandstone is interlaid with the Liverpool sub-group of Wianamatta Shale Groups. The sediments forming these two geological formations were deposited in the Triassic Period, over 200 million years ago when large floods delivered large volumes of sand, silt and clay filling the Sydney Basin area (Benson et al, 1999).

The coarser sandy sediments formed Hawkesbury sandstone while the finer sediments formed the mudstones and shales. The underlying geology has a strong influence on the overlying soils and the vegetation. Hawkesbury sandstone forms 'poorer' quality rocky, shallow and lower nutrient soils. The shales form 'better' quality clay and higher nutrient soils. Shale derived soils on the ridgelines and away form the coast are typically deeper and better drained than those on the floodplain.

2.3 Soils

The soils within the catchment are related to the geology, being derived from sandstone and shale formations as well as erosion and depositional environments activities. Hawkesbury sandstone is predominantly sandstone with sandy, shallow soils. Yellow Earths and Earthy Sands are found on crests and siliceous sands and leached sands found along drainage lines. The yellow soils are typically sandy and shallow, with grey topsoil and yellow or light grey sand to sandy clay subsoil which may be very stony. Clay content gradually increases with depth and there is no distinct boundary between topsoil and subsoil. Slightly acid to neutral, these sandy soils are shallow, permeable and very infertile.

Podzolic soils form on shale lenses, and podzolic soils are acid throughout and have a clear boundary between the topsoil and subsoil. The topsoils are loams with a brownish grey colour. The lower part of the topsoil has a pale light colour and may be bleached with a nearly white, light grey colour (bleached A2 horizon).

Red and Brown Podzolic soils are found in well-drained areas on crests and upper slopes. Yellow Podzolics are found on lower slopes in areas of poor drainage. The fertility of these soils is low and drainage poor.

Potential acid sulphate soils (PASS) have been mapped by Warringah Council and Manly Council and are shown in Figure 3. Acid sulphate soils are naturally occurring and often occur in water logged soils below 10 m AHD. Acid sulphate soils contain iron sulfides (pyrite) which when exposed to oxygen produce high concentrations of sulphuric acid and can also release heavy metals such as iron. Acid sulphate soils should not be disturbed by excavation, or lowering of groundwater, wherever this can be avoided.

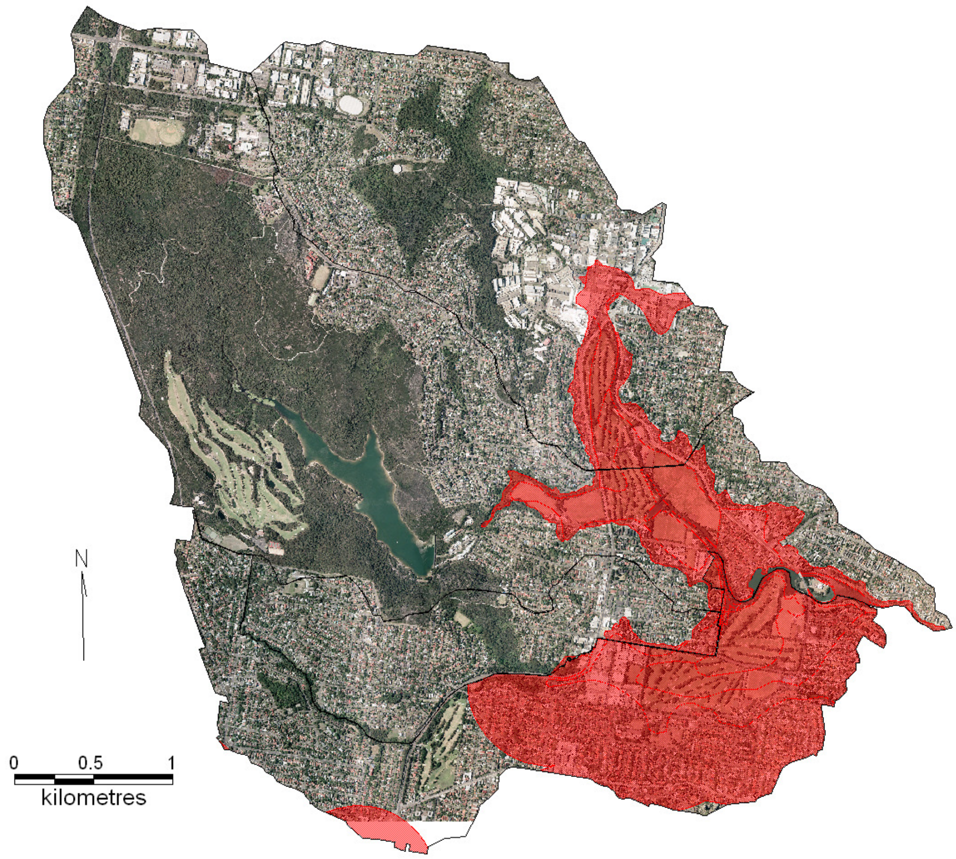


Figure 3: Acid Sulphate Soils in the Manly Lagoon Catchment (Warringah Council 2010 and Manly Council 2010).

2.4 Flora and Fauna

The Manly Lagoon Catchment is approximately 24% forested with a further 10% public open space. Large tracts of the forested catchment exist around and upstream of Manly Dam. Manly Dam was dammed in 1892 to provide freshwater to Manly, and the dam wall was raised in 1909 and in 1922 to 35.1 metres. The dam has a capacity of 1.7GL.

Manly Dam provides a template of typical vegetation communities found on Hawkesbury sandstone in broader Manly Lagoon Catchment, including sandstone heath, silvertop ash-brown stringybark forest and Duffy's Forest (Figure 4). While there are significant weeds in the catchment the following vegetation communities are present (Warringah Council 2010):

- **Bloodwood Scribbly Gum Woodland** – medium sized trees with sparse canopy cover. The dominant trees are Red Bloodwood and Broad-leaved Scribbly Gum, with Sandstone Stringybark and Silvertop Ash also occurring.
- **Silvertop Ash-Brown Stringybark Forest** – endangered vegetation community. Key trees include Silvertop Ash and Brown Stringybark, with Sydney Redgum, Red Bloodwood and Broad-leaved Scribbly Gum.
- **Peppermint-Angophora Forest** – open forest and woodland including Sydney Red Gum and Sydney Peppermint, as well as Red Bloodwood and Silvertop Ash.
- **Freshwater Lagoon Swamp** – consists of dense stands of reeds, sedges and other wetland plants, with a fringing zone of low trees and shrubs around freshwater lagoons.
- **Sandstone Heath** – varies from open heath to closed scrub. Shrub species include *Allocasuarina distyla, Angophora hispida, Banksia ericifolia, Epacris pulchella, Grevillea speciosa, Hakea teretifolia, Kunzea ambigua* and *Leptospermum squarrosum*.

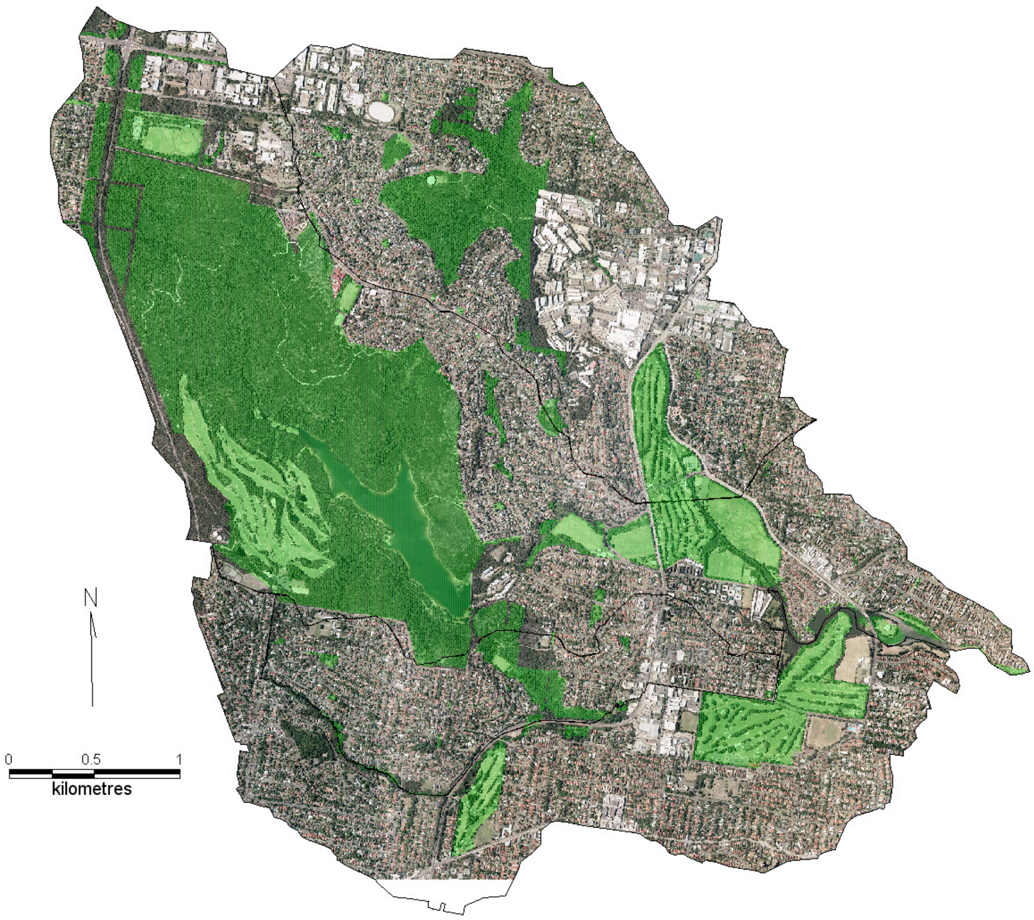


Figure 4: Manly Lagoon Catchment Open Space and Vegetated landuse (Warringah Council, 2010 and Manly Council, 2010).

2.5 Rainfall

The climate in the catchment is a temperate humid climate. Average annual rainfall is approximately 1200mm within the catchment. Rainfall stations within the catchment and close to the catchment are shown in the table below.

There are five daily rainfall stations within a few kilometres from the catchment that are available from the Bureau of Meteorology. Only two of these stations have data for more than 15 years. There are two pluviograph stations, which measure rainfall at six minute intervals, within 10km of the catchment. The statistics for these rainfall stations are shown in Table 2.

Table 2: Rainfall Stations in the vicinity of Manly Lagoon (BOM, 2010, MHL, 2010)

Station Number	Station Name	Station Type	Years of Data	Annual Average Rainfall (mm)
66088	Manly Dam	Daily	1906 - present	1204
66089	Manly North Bowling Club	Daily	1961 - 1987	1171
66062	Observatory Hill)	6 min	1929 – present	1215
66037	Sydney Airport	6 min	1890 - present	1086

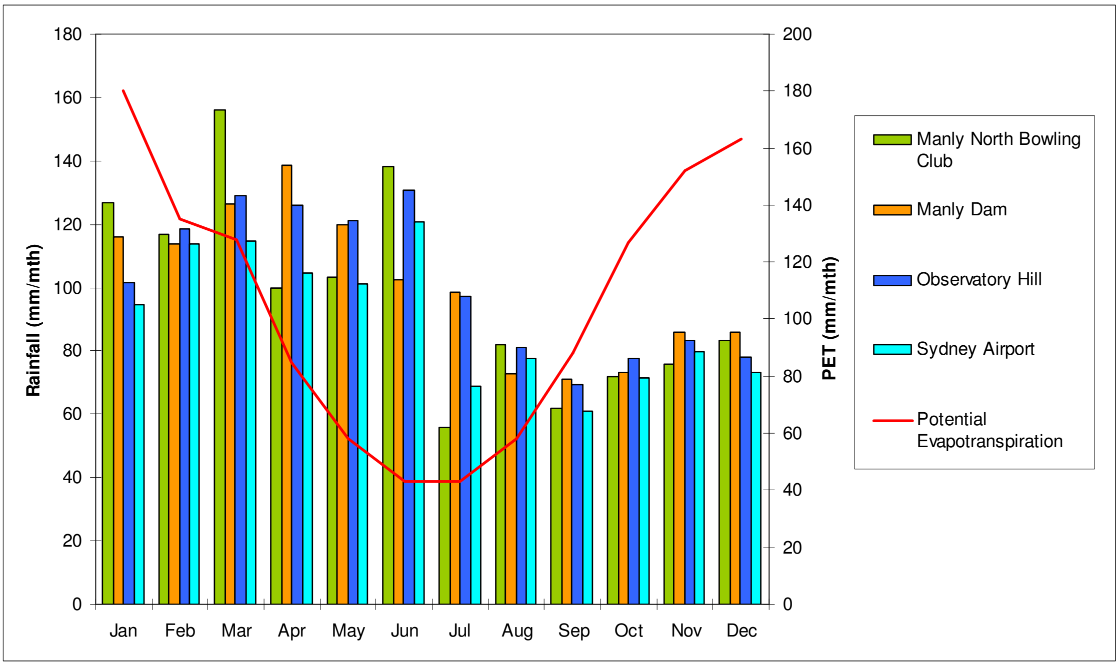


Figure 5: Mean rainfall statistics for rain gauges close to Manly Lagoon (Bureau of Meteorology, 2010).

As shown in Figure 5 the rainfall pattern at Manly Dam is similar to Sydney Observatory Hill (the closest pluviograph station with a long period of rainfall data) for all months of the year except January when there is approximately 20mm difference in rainfall between the stations. Sydney Observatory Hill will be used as the rainfall station for the modelling, as it has 6 minute data, as compared to the two local Manly rainfall gauges which only have daily rainfall data.

Potential evaporation (PET) data used for the catchment is based on data for Sydney from the Climactic Atlas of Australia (Bureau of Meteorology, 2008). This shows that PET is highest in the spring and summer months and that the greatest deficit between rainfall and PET is in the months from September to December.

3 Urban Catchment Analysis

As shown in Table 1, the Manly Lagoon catchment is 40% residential, 24% forested, 16% roads, 10% public open space and 9% commercial. To determine potential sediment loads from the catchment as a result of varying landuses and the influence of online structures such as Manly Dam and pollution traps, a subcatchment analysis has been undertaken.

The sub-catchment analysis seeks to more specifically identify landuse attributes such as imperviousness or residential development to discrete sub-catchments as compared to broader generalisations across the entire catchment. The sub-catchment analysis identified eight sub-catchments based on the three main creeks within the Manly Lagoon Catchment. The sub-catchments are shown in Figure 6, and include:

1. Brookvale Creek Catchment.
2. Manly Creek – includes Manly Dam Catchment upstream of Manly Dam and Manly Lagoon catchment downstream of the dam and Manly Plateau subcatchment.
3. Burnt Bridge Creek Catchment –
    a. North Burnt Bridge Creek Sub-Catchment and within the Warringah LGA
    b. West Burnt Bridge Creek Sub-Catchment
    c. South Burnt Bridge Creek Sub-Catchment
    d. Fairlight – upstream of Balgowlah Industrial Estate and Manly Golf Course.

The landuse breakdown is outlined in Table 3. Table 3 is based on a detailed assessment of Councils GIS and distinguishes between impervious areas and pervious areas for each of the major landuses. For example road area in Table 3 is slightly less that Table 1 as pervious (vegetated) areas have been removed.

Table 3: Manly Lagoon landuse breakdown by 3 sub-catchments

Catchment	Total Catchment Has	Roof Has	Roads (Imperv) Has	Other Impervious Has	Pervious (POS + other) Has	Forested Has	Open Water Has
Brookvale Creek	450.6	151.2	67.4	70.3	95.2	66.5	0.0
Manly Creek	912.3	142.9	83.8	163.4	141.2	339.7	41.3
Burnt Bridge Creek	445	140	80.6	92.7	105.3	26.6	0
Total	**1807.9**	**433.9**	**231.8**	**326.3**	**341.8**	**432.8**	**41.3**

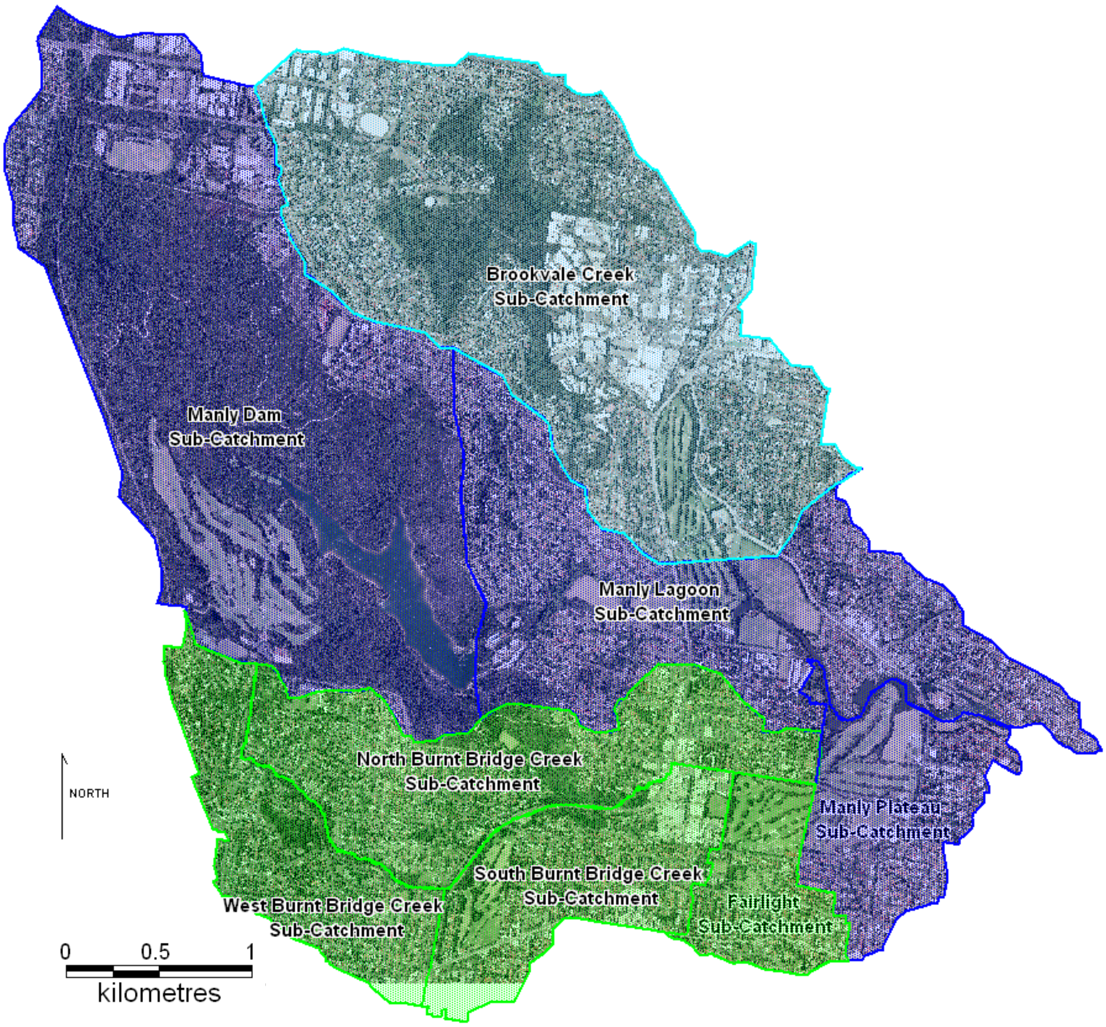


Figure 6: Manly Lagoon Sub-catchments (Warringah Council 2010, Manly Council 2010)

A review of the sub-catchment assessment of landuses as presented in Table 3, highlights some key considerations for modelling:

- Brookvale Creek (Warringah LGA) is the second largest sub-catchment and includes approximately 33% roof area (both industrial and residential) and approximately similar areas of roads, other impervious areas, pervious areas and forested areas.
- Manly Dam sub-catchment (Warringah LGA) is the largest catchment, however nearly two-thirds of the sub-catchment is forested or open water. Roofs, other impervious and pervious (including Wakehurst golf course) areas each comprise approximately 10% of the catchment.
- Manly Lagoon sub-catchment (Warringah LGA) is a large residential catchment with relatively similar amounts of roof, road, other impervious and pervious areas. Parts of the sub-catchment downstream of Manly Dam have been identified as forested.
- North Burnt Bridge Creek Sub-Catchment (Warringah LGA) is within the Warringah LGA and has a large residential catchment, and includes a forested area of Condover Reserve and industrial zone of the Balgowlah Industrial Estate.
- West Burnt Bridge Creek Sub-Catchment (Manly LGA) is more than 70% residential connected by roads (20%) with limited areas of open space and forest.

- South Burnt Bridge Creek Sub-Catchment (Manly LGA) is approximately 50% residential and equal amounts of road, open space and industrial. The industrial commercial area around Balgowlah Industrial Estate and the Stockland Mall on Sydney Road at Balgowlah.
- Fairlight sub-catchment (Manly LGA) is a predominately made up of residential landuse (45%) and Manly Golf Course (30%).
- Manly Plateau (Manly LGA) adjacent to Manly Lagoon is a combination of residential (40%) and open space (40%).

A breakdown of the impervious portion of each sub-catchment (Roads, Roofs, other impervious) is shown in Figure 7. Brookvale Creek sub-catchment is the largest catchment and also has the largest portion of impervious areas. Most of the catchments are dominated by roofs (50-60% roof area) with the remainder made of roads and other impervious.

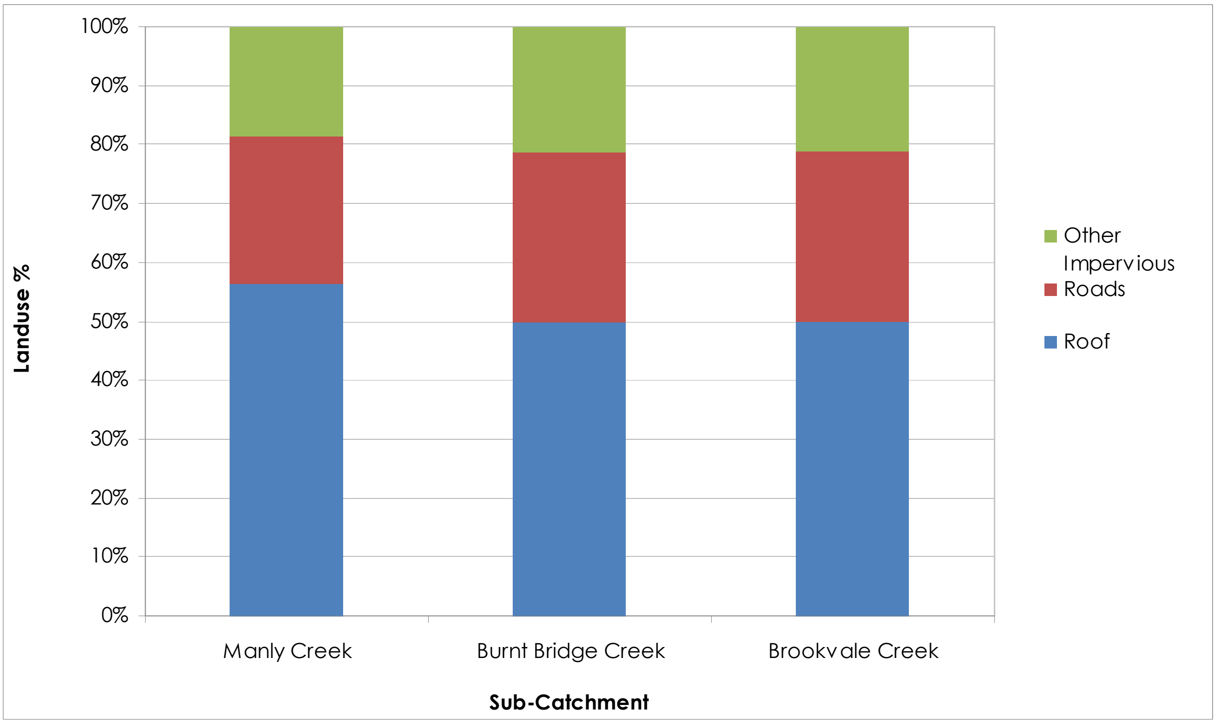


Figure 7: Breakdown of the impervious portion of each of the 3 Manly Lagoon Sub-catchments

The residential landuse within the Manly Lagoon Catchment is well established with little major redevelopment or infill development possible. As such most of the building works would be associated with alterations and additions to existing allotments, or potentially knock-downs and rebuilds associated with urban consolidation. There is a noticeable trend in the allotment size through the sub-catchments as shown in Figure 8. While all allotments throughout the catchment typically have a backyard with mature trees, suggesting the established nature of the houses, allotments in suburbs such as North Balgowlah have allotments which are twice the size of those closer to the coast. This means that while the roof area for the allotments maybe the same, the pervious area for allotments in these sub-catchments away from the coast is larger than near the coast.

Figure 8: Example of residential allotments in North Balgowlah (left) and Manly (right). North Balgowlah allotments are typically 800m² compared to allotments in Manly of 3-400m².

3.1 Stormwater Infrastructure

3.1.1 Stormwater Quality Elements

A series of stormwater treatment elements are located within the Manly Lagoon Catchment. These treatment elements include gross pollutant traps, booms, nets and wetlands (Table 4 and Figure 9). Monitoring and cleaning of these elements by Council from 2001-2006 has derived an annual removal rate. The largest system downstream of Warringah Mall has an average annual removal rate of 180tonnes/ year of sediment.

Table 4: Stormwater treatment elements in the catchment

ID Code	Catchment area	Location	Type	Sediment T/yr
03GO101	340	Brookvale Creek / Cnr Pittwater & Condamine	GPT	180.24
01GO26	70	Currie Rd. Forestville / Eastern end of road	GPT	19.15
15GO78	11.9	Riverview Pde. North Manly / Entrance to park	GPT	10.50
15GO79	16	Nolans Reserve. North Manly / In reserve	CDS	10.49
15GO24	23	Sloane Cr. Manly Vale / Millers Res	GPT	9.50
17GO86	1.9	Corymbia Crt. Oxford Heights, Adjacent to # 51	pit insert	8.02
15GO102	6.5	Aquatic Dr. Frenchs Forest / 300m west of Allambie Rd	CDS	5.65
04GO90	11	Eileen St. N.Balgowlah / Base of park	GPT	5.23
15GO103	0.5	Riverview Pde Boom	Boom	2.48
15TR3	8.9	Tamworth Pl rear #7 Allambie Hts	Trash rack	
15WO30 & 31	6.5	Cootamundra Drv. Allambie Hts. Opp. 18	wetland	
15TR32	4.7	Crn Churchill & Cootamundra Dve. Allambie Hts	Trash rack	
15TR4	5.2	Cootamundra Drv. Allambie Hts. Opp. Forbes Pl	Trash rack	
15TR9	1.4	Manning St Nth Balgowlah	Trash rack	
15W33	1.4	Manning St Nth Balgowlah	wetland	
15W1	9.7	Below Wakehurst Golf course	wetland	
15TR10	3.8	Aquatic Dr. Frenchs Forest	GPT	
9/MA08	8.7	Opp. 93 Clontarf St, North Balgowlah	Rocla GPT	24.51

8/MA09	20.0	Clontarf / Uranga Rd, North Balgowlah	Rocla GPT	19.62
13//MA01	6.2	Balgowlah Road, Opp. West St., Balgowlah	CDS	11.39
18/MA06	62.4	Keirle Park, Near Skate Ramp, Pittwater Rd, Manly	CDS	6.27
19//MA07	32.9	Hinkler Park, Pittwater Road, Opp. Aitken Ave, Manly	CDS	4.07
21//MA13	23.3	Manly West Park, Quirk Road, Balgowlah	Ecosol	17.32
20/MA14	40.0	Cemetery Ck, Manly Golf Course, Balgowlah Rd, Fairlight	Humegard	12.28
4/MA20	13.6	West of Koobilya St end, off Baringa Av., Seaforth	Net Tech	2.12
5/MA21	13.0	Opp. Koobilya St., Adj to 38 Baringa Av., Seaforth	Net Tech	1.54
6/MA22	25.5	Adj. to Kitchener St, Balgowlah	Net Tech	0.98
3/MA16	23.3	Manly West Park, near 1A Paton Pl, Fairlight	Net Tech	
1/MA15	50	Keirle Park, near Manly Golf Course, Fairlight	Litter Boom	0.1

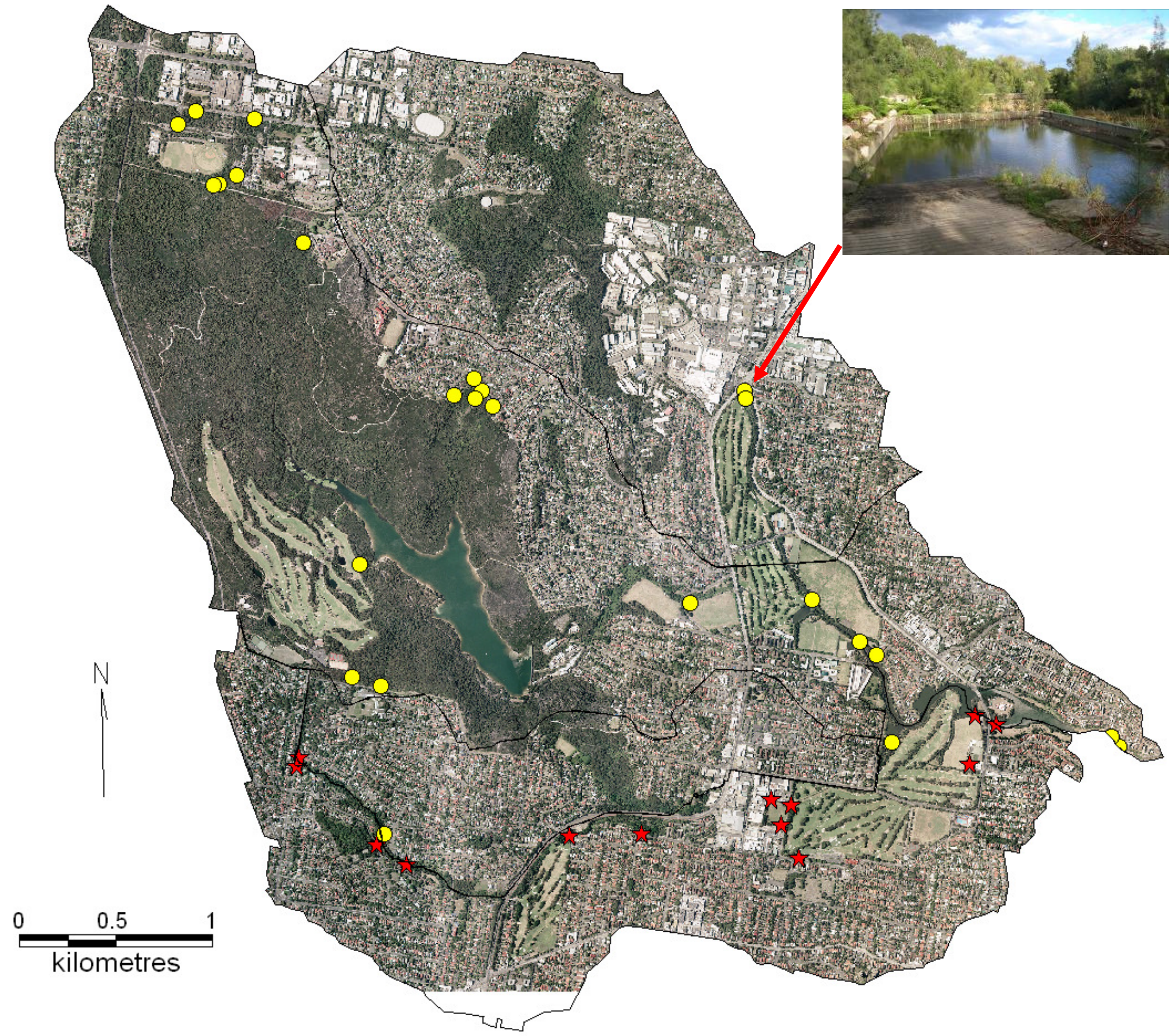


Figure 9: Stormwater Quality infrastructure in the Manly Lagoon Catchment (Manly Council infrastructure as red stars and Warringah Council as yellow dots). Inset Brookvale Creek Trash Rack and location (Cnr Pittwater & Condamine).

4 Stormwater Quality Modelling

Stormwater quality modelling allows simulation of key water quality processes in catchments and treatment systems and has become an important part of catchment management and urban stormwater quality planning and design.

A typical stormwater quality model allows the simulation of key stormwater pollutants such as suspended solids and nutrients. Stormwater quality models have been designed to simulate:

- Pollutant loads generated in the catchment
- Concentrations and loads in stormwater runoff
- Pollutant removal in stormwater treatment systems
- Loads exported to receiving waters

Receiving water quality models also exist, to simulate processes that occur within rivers, lakes and estuaries when there is a stormwater input.

Models can range from a simple spreadsheet to a software package.

4.1 Purpose of Stormwater Quality Modelling

Urban stormwater systems are complex and the properties of stormwater runoff are difficult to predict. Some of the key aspects to this complexity are:

- Urban catchments include multiple land uses and an extensive drainage network
- Every rainfall event is different (amount, duration, intensity, etc)
- Stormwater pollutant loads in stormwater are highly non-linear; pollutant loads depend partly on antecedent conditions but are also stochastic in nature
- There are typically a wide range of alternative management options
- Stormwater treatment performance depends on a large number of variables including the season, antecedent rainfall and individual storm pattern

Computer models can capture much of this complexity, and therefore allow complex catchments to be studied and management measures to be tested.

While the primary focus of stormwater quality modelling is on pollutant loads and the pollutant removal performance of treatment measures, stormwater quality models can contribute to analysis of other important issues:

- Life cycle costs of management measures
- Risk analysis
- Ecosystem response

4.2 Modelling Considerations

Key considerations in selecting an appropriate model and undertaking stormwater quality modelling are as follows:

- **Runoff quality and quantity**: stormwater quality models need to be able to make an accurate prediction of both stormwater quality and quantity. Estimation of pollutant loads requires knowledge of both pollutant concentrations in stormwater and total stormwater volumes.

- **Spatial and temporal scale**: stormwater quality models need to be able to simulate processes from the catchment scale to individual treatment systems. Within a treatment system, pollutant removal processes occur over short time periods (e.g. minutes to hours) and therefore the modelling timestep needs to be short enough to capture these processes. The total period of simulated needs to be long enough to capture a wide range of storm events and provide a representative result.

- **Data requirements**: stormwater quality modelling requires local rainfall data, catchment data, pollutant export data, treatment system performance data and calibration data. Local information should be used wherever possible, although local information may not be available in all cases.

4.3 Stormwater Quality Models

Australian Runoff Quality (Wong, 2006) identifies a number of types of stormwater quality models, according to their model structure and function. The range of options is outlined in Table 5. Some of the modelling packages most commonly used in Australia are:

- **MUSIC**: MUSIC is a planning and conceptual design tool. It can be used to estimate stormwater pollutant loads that will be generated in a catchment, predict the performance of stormwater treatment measures, develop a stormwater management strategy for a catchment and estimate life cycle costs for stormwater treatment systems.

- **XP-AQUALM**: XP-AQUALM is a planning tool. It allows assessment of the effects of land use changes and alternative catchment management practices. It can be used to estimate preliminary life cycle costs.

- **E2**: E2 is a whole-of-catchment planning tool. It is normally applied on a regional scale for pollutant load estimation and prioritisation of management actions. E2 is useful for understanding where pollutants originate in a catchment, how they are transported to receiving waters, and how pollutant loads are modified by management actions.

- **XP-SWMM**: XP-SWMM is a planning and conceptual design tool. It is a combined hydrology, hydraulics, wastewater and stormwater quality model and therefore has a wide range of applications.

- **AQUACYCLE**: Aquacycle is a planning tool. It allows urban water cycle scenario modelling, including water supply, wastewater and stormwater. Alternative water servicing schemes can be compared and their performance evaluated in terms of water volumes.

- **SWITCH**: SWITCH2 is a design tool for infiltration systems, rainwater tanks, grass swales, bioretention systems and sand filters.

At the planning stage, a tool that allows neighbourhood scale planning and conceptual design is ideal. MUSIC has become the most commonly applied model for this purpose in Australia. For this reason MUSIC will be used for modelling in this project. MUSIC is discussed in more detail in the following sections.

Table 5: Stormwater quality modelling options

Aspect	Options			Recommendation
Modelling period	***Event-based*** models simulate single rainfall events, normally design events	***Continuous simulation*** models simulate a long rainfall data series, which may cover months or years.		Continuous simulation is preferred, as it is better able to approximate the range of conditions which may be encountered in reality, and to simulate cumulative and long-term impacts on receiving waters.
Modelling approach	***Empirical*** models relate runoff quality and quantity directly to catchment and rainfall parameters, without modelling the various processes occurring. Sizing curves presented in the Practice Guide are essentially an empirical model	***Conceptual*** models use interlinked storage and process components to represent the system. Parameters usually need to be determined through calibration and verification. MUSIC is a conceptual model	***Process-based*** models use fundamental equations to represent the system. The model parameters have a direct physical meaning and can be measured in the field.	Empirical models are simple to use and require relatively little data input. Process based models are complex and require significant data input. For the purposes of sizing stormwater treatment measures as part of a WSUD Strategy, conceptual models represent a good balance between simplicity and accuracy.
Spatial resolution	***Spatially-lumped*** models use a single set of parameters to represent the whole catchment	***Distributed*** models divide the catchment into a series of smaller subcatchments, each having different properties.		Distributed models are able to represent heterogeneity within a catchment and provide a more accurate result. Most modelling packages allow the model set up to be either spatially lumped or distributed, and the model set up can be refined over time as more information is available to define the properties in a distributed set up.
Parameter type	***Deterministic*** models always produce the same results for a given set of input parameters	***Stochastic*** models contain one or more parameters with random behaviour, usually with a statistical distribution. Stochastic models may include both deterministic and probabilistic components. Stochastic models do not always produce the same results for a given set of input parameters		Stochastic models allow more realistic simulation of parameters such as pollutant concentrations in runoff, which are log-normally distributed when measured in the field.
Purpose	***Planning*** models are normally used to compare the outcomes of different management options for a catchment	***Design*** models are normally used to optimise the size and configuration of stormwater treatment measures for to achieve best practice pollutant removal performance	***Operational*** models are normally used to optimise the performance of stormwater drainage and wastewater networks once they are operational	All three types of models are important at different stages.

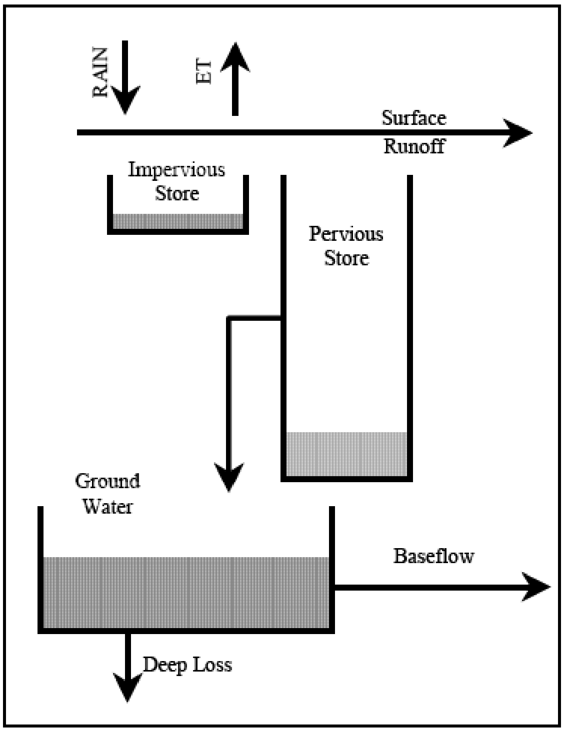
4.4 The MUSIC Model

MUSIC has been designed to help evaluate concept designs for stormwater management systems at the planning and conceptual design stage. It has been used throughout Australia, and has enough flexibility in the choice of parameters so that it can be adapted to local conditions anywhere. This section discusses the parameters included in the MUSIC model, the data available in Manly and in Sydney.

4.5 Rainfall-Runoff Simulation

MUSIC includes a rainfall-runoff model, which relies on the following parameters:

- **Rainfall data**: suitable rainfall data is available in the Sydney Region, with a range of 6-minute pluviograph rainfall data available as outlined in section 2.4.
- **Catchment data**: catchment data (area and impervious fraction) can be estimated for existing development using aerial imagery
- **Soil parameters**: pervious area losses are modelled in MUSIC with a soil storage model as shown in Figure 10. Several soil parameters need to be specified in the model. These can be estimated from field tests and can be refined in the model calibration process. The MUSIC User Guide also recommends some initial values suitable for Sydney.



Soil parameters:

- Rainfall Threshold (mm)
- Soil Capacity (mm)
- Initial Storage (%)
- Field Capacity
- Infiltration Capacity Coefficients a and b
- Initial Depth (mm)
- Daily Recharge Rate (%)
- Daily Baseflow Rate (%)
- Deep Seepage (%)

Figure 10: MUSIC rainfall runoff model and key parameters

4.6 Pollutant Load Simulation

MUSIC models pollutants using stochastically generated event mean concentrations (EMCs). An example of the MUSIC's pollutant data page is shown in Figure 11. Baseflow and stormflow EMCs are entered separately. The EMCs are log-normally distributed, therefore it is necessary to specify a mean and standard deviation for each pollutant. MUSIC is set up with default parameters for total suspended solids (TSS), total phosphorus (TP) and total nitrogen (TN). The *default* parameters are derived from a comprehensive review of stormwater quality monitored in urban catchments (Duncan 1999).

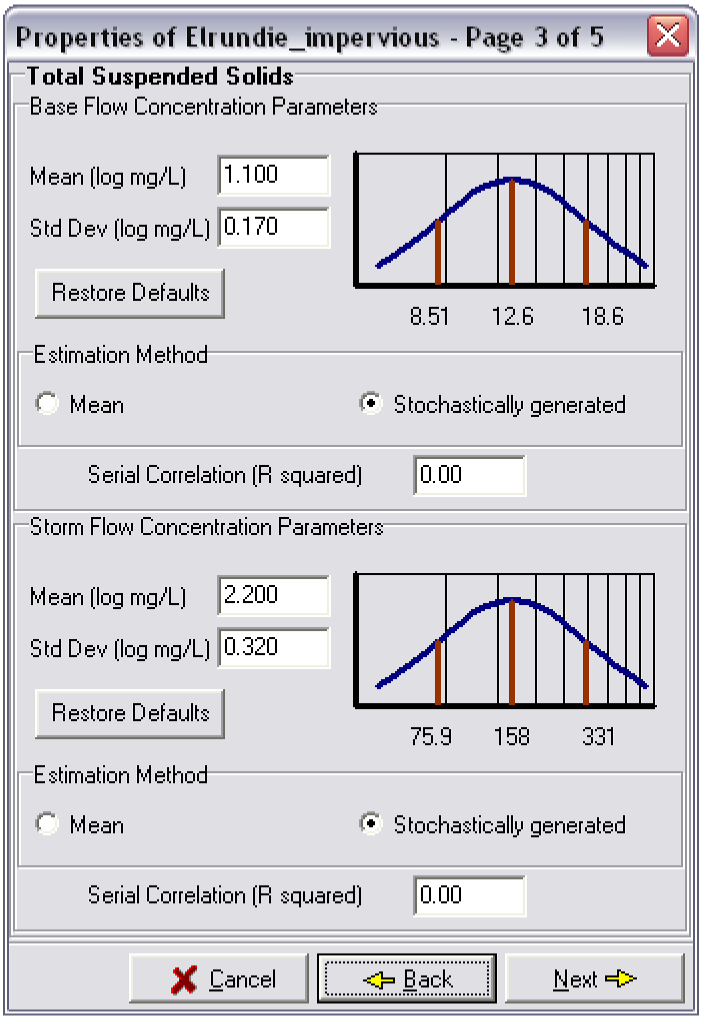


Figure 11: Example pollutant data in MUSIC

Australian Runoff Quality (Wong (Ed) 2006) includes a summary of the pollutant data from Duncan (1999) including:

- EMC mean and standard deviation values for additional pollutants, including metals, organic pollutants and pathogens.
- EMC mean and standard deviation values for a range of different catchment types, including roads, roofs, residential areas, commercial areas, industrial areas, rural and forested catchments (where data is available).

Further, some local monitoring has been undertaken in the Manly Region and in the broader Sydney region to measure pollutants from urban catchments. This is discussed in more detail in the following sections.

4.7 Manly Lagoon Model Setup

A model was set up with the 8 subcatchments and the details outlined in section 3. An image of the catchment is shown below. No routing was used. Routing and other time delays do not have any significant impact on total loads to receiving waters. A screen shot of the MUSIC model developed is shown in Figure 12

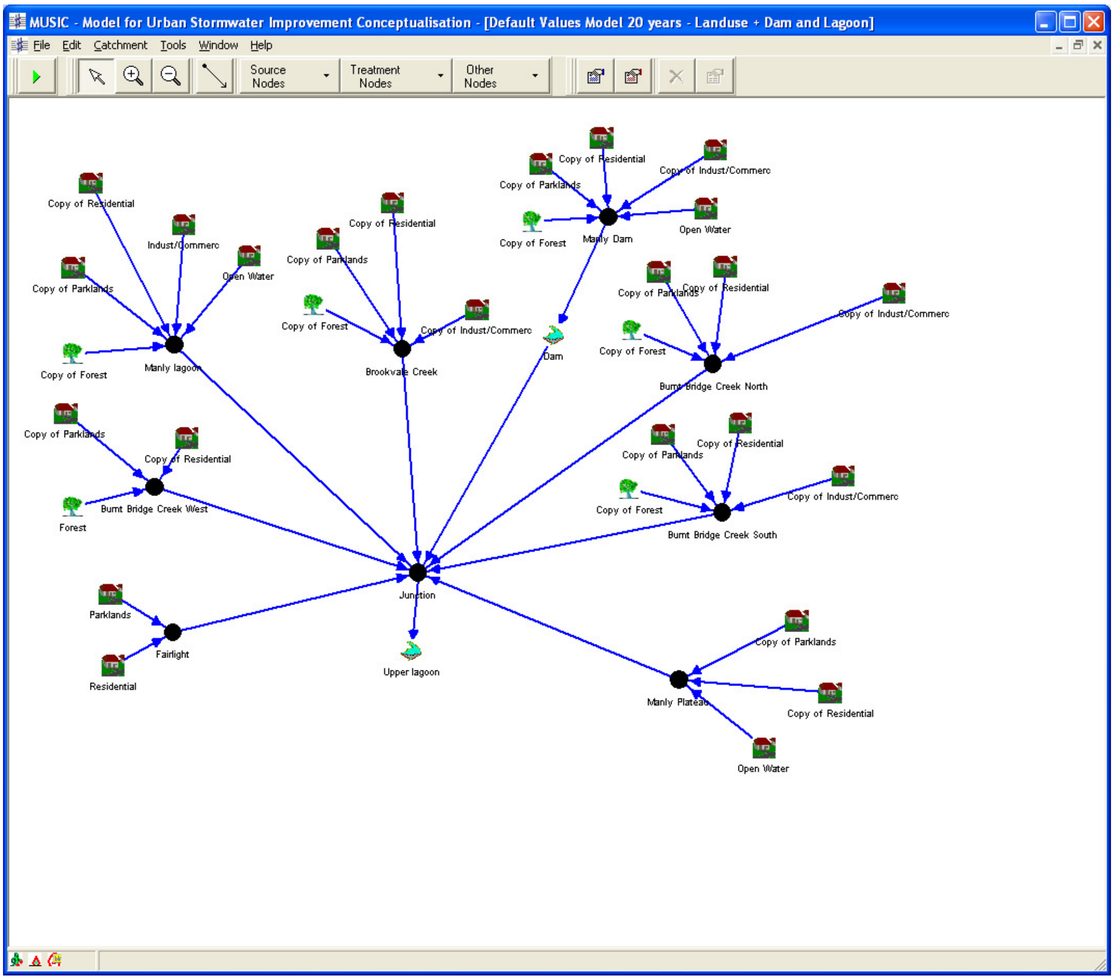


Figure 12: Screen Shot of MUSIC Model developed

4.8 Model Calibration

Wherever possible, MUSIC should be calibrated to local conditions using local data. Elements of the model that should be calibrated are:

1. **The rainfall-runoff model**, which can be calibrated by modifying the soil parameters to reflect local values. It is assumed that the catchment area and impervious fraction are known. MUSIC should be calibrated to observed flow data over a given period. This is discussed in

2. **Pollutant parameters** can be calibrated where data is available. MUSIC results would need to be calibrated against continuous monitoring of pollutant loads

from urban catchment/s (i.e. concentration and flow data would be required) over a given period. Total loads could be used as a check.

4.8.1 Rainfall Runoff (Soil) Parameters

No flow data currently exists for flows entering the Manly Lagoon. Therefore calibration of rainfall runoff parameters is not possible in this study. To determine the rainfall runoff parameters the following will be undertaken:

- Adoption of standard rainfall runoff parameter based on soil characteristics
- Assessment of runoff volumes sensitivity to the selection of soil parameters

The current draft NSW MUSIC modelling guidelines recommend the following rainfall runoff parameters for NSW soil types as shown in Table 6

Table 6: MUSIC Soil Parameters 1 (DECCWA, 2010, *Draft*)

Dominant Soil Description	0.5m root zone		1.0m root zone	
	SSC*	FC*	SSC*	FC*
Sand	175	74	350	144
Loamy sand	139	69	279	134
Clayey sand	107	75	214	145
Sandy loam	98	70	195	135
Loam	97	79	194	154
Silty clay loam	100	87	200	167
Sandy clay loam	108	73	217	138
Clay loam	119	99	238	189
Clay loam (sandy)	133	89	267	169
Silty clay loam	88	70	175	133
Sandy clay	142	94	283	179
Silty clay	54	51	108	96
Clays	93	68	187	127

Where SSC = soil store capacity and FC = Field Capacity

Table 7: MUSIC Soil Parameters 1 (DECCWA, 2010, *Draft*)

	MUSIC rainfall-runoff parameters				
Dominant soil description	Inf "a" (mm/d)	Inf "b"	DRR (%)	DBR (%)	DSR (%)
Sand, loamy sand	360	0.5	100%	50%	0%
Clayey sand, sandy loam, loam, silty clay loam, sandy clay loam	250	1.3	60%	45%	0%
Clay loam, clay loam (sandy), silty clay loam, sandy clay, silty clay	180	3.0	25%	25%	0%
Clays	135	4.0	10%	10%	0%

Where DRR = Daily Recharge Rate and DBR = Daily Baseflow Rate, DSR = Daily Seepage Rate

Based on the known geology (dominated by Hawkesbury sandstone) and soils (shallow sandy loams and sandy clays) in the catchment the soil parameter shave been based on shallow sandy loams. Thus the following pervious soil parameters were adopted:

- Soil Store Capacity (0.5m root zone): 98mm

- Field Capacity (0.5 m root zone): 70mm
- Infiltration coefficient a: 250
- Infiltration coefficient b: 1.3
- Recharge Rate: 60%
- Baseflow rate: 45%
- Seepage Rate: 0%

All impervious surfaces assumed a 1mm initial loss.

Based on these a MUSIC model was set up with the above parameters. Modelling undertaken showed that:

- 10,640 ML/yr (70%) of runoff in the catchment was estimated to originate from impervious surfaces
- 4,560 ML/yr (30%) of runoff in the catchment was estimated to originate from pervious surfaces (including forested and urban pervious)

This indicates that flows from the catchment are dominated by the impervious area in the catchment which is expected in urban areas.

5 Local Pollutant Concentrations

5.1 Urban Stormwater Quality - General

As discussed in the section above pollutant load generation is estimated in MUSIC using event mean concentrations based on land use.

Various authorities (Sydney Metro CMA, Department of Environment, Conservation and Water, Healthy Waterways Partnership) recommend using general event mean concentrations adopted in Australian Runoff Quality (ARQ) (Institute of Engineers, 2006) where suitable local catchment monitoring is not available.

Table 8: Typical Pollutant Concentrations (Sydney Metro CMA, 2007)

Constituent	Land Use						
	Parkland	Airport	Industrial	Commercial	Urban	Bushland	Rural
Event Mean Concentrations (mg/L)							
Total Organic Carbon	8	33	33	33	19	8	8
Total Phosphorus	0.08	0.25	0.25	0.25	0.25	0.08	0.08
Total Nitrogen	0.9	2.0	2.0	2.0	2.0	0.9	2.0
Total Suspended Solids	40	140	140	140	140	40	90
Biochemical Oxygen Demand	6.2	20	20	20	18	6.2	6.2
Faecal Coliforms (cfu/100mL)	600	4000	4000	4000	20000	600	600
Dry Weather Concentrations (mg/L)							
Total Organic Carbon	8	8	8	8	8	8	8
Total Phosphorus	0.03	0.14	0.14	0.14	0.14	0.03	0.03
Total Nitrogen	0.3	1.3	1.3	1.3	1.3	0.3	0.9
Total Suspended Solids	6	16	16	16	16	6	14
Biochemical Oxygen Demand	0	0	0	0	0	0	0
Faecal Coliforms (cfu/100mL)	100	350	350	350	2500	100	100

A comprehensive review of stormwater quality in urban catchments was undertaken by Duncan (1999). Duncan reviewed over 500 literature studies on stormwater runoff quality from both Australia and overseas to determine typical pollutant concentrations for various land uses. The study compiled these values into a mean with a standard deviation.

This review forms the basis for the *default* values of event mean concentrations in MUSIC. Table 8 presents the recommended model defaults for various land use categories. Note that TN is consistent across each urban land use as TN is substantially influenced by atmospheric deposition.

Baseflow in MUSIC is rainfall that has infiltrated into the soil and enters waterways via groundwater flows. Default baseflow concentrations have also been developed based on data from ARQ for the respective catchment types. Typically in urban areas base flow concentrations have little influence on the overall loads generated from the catchment and generate only a very small fraction of the sediment loads.

It is important to note that the concentrations of TP and TN are influenced by rainfall. In a study by Cattell and White (1989), concentrations of TP and TN in Sydney rainfall data have been measured at 51 µg/L (SD 58µg/L) and 1.4 mg/L (SD 2 mg/L) respectively. Thus high proportions of TP and TN, i.e. 20% and 53% of the total default concentrations for urban areas, are directly deposited in rainfall itself. These contributions are relatively independent of physical location and landuse within an urban environment due to the dependence on large scale atmospheric processes.

5.1.1 Pollutant Hotspots

Pollutant hotspots may exist within the catchment. The preferred approach for identification of pollutant hotspots is to undertake monitoring within the catchment as has been undertaken for Balgowlah Industrial Estate. Typically pollutant hotspots can be initially targeted by land use (e.g. industrial or commercial land uses) as well as anecdotal observations from residents, council staff, etc.

There are a number of potential pollutant hotspots within the catchment that were identified. Particular areas identified as being potential pollutant hot spots within the catchment include:

- Manly Golf Course and Warringah Golf Course
- Major arterial roads
- Industrial areas

The golf courses are a potential pollutant hotspot because of its use of fertiliser, pesticides and herbicides. Numerous studies have shown the impact that golf courses can have on water quality due to the high concentrations of nutrients in turf runoff (see for example Kunimatsu et al, 1999 and Gross et al 1990). Furthermore the use of herbicides and pesticides can also have an impact on aquatic health.

Major arterial roads and highways have been shown to be significant sources of pollutants, including sediment, hydrocarbons and heavy metals (Ellis and Mitchell, 2006). Pittwater Road and Condamine St are both major arterial road, with large numbers of daily vehicle movements.

Hotspot monitoring has been undertaken in the catchment at a number of locations including industrial estates and this is discussed in more detail in the following section.

5.2 Urban Stormwater Quality – Local

5.2.1 Wet weather stormwater quality

The general values of pollutant event mean concentrations adopted have been compared to local runoff quality data. A large number of relevant studies were found in academic literature and provided by Warringah Council for assessment.

A number of water quality studies have been undertaken of monitoring stormwater quality within the lagoon catchment including:

- Monitoring of Balgowlah Industrial Estate (Smith, 2002)
- Monitoring of Balgowlah Industrial Estate and Cemetery Creek (Galloway, 2005)
- Warringah Runoff Study (UWS, 2007)
- Monitoring of Roof runoff at Manly Vale (Cheah et al, 2009)
- Monitoring of local road catchment runoff (Ball and Rankin, 2010)

- Monitoring of Burnt Bridge Creek Main Stream flows (Manly Council, 2009-10)
- Monitoring of Sydney Road Catchment (Balgowlah Golf Course) (Manly Council, 2009-10)

A range of other studies were also investigated due to their relatively close location to the Manly Lagoon Catchment. These studies included:

- Annandale runoff study (Birch, 2004)
- Centennial Park runoff study (Ball, 2004)
- Chiswick runoff study (Birch and Matthai, 2009)
- Drummoyne runoff study (Kandasamy et al, 2008)
- Erskineville runoff study (Manly Hydraulics Lab, 2004)
- Little Sirius Cove Mosman (Manly Hydraulics Lab, 2002)
- Riverwood Runoff study (Birch et al 2004)

These local pollutant concentration values are shown in Table 10.

The EMC values for pollutants reported within the catchment are in the range of:

- 23 mg/L to 117 mg/L for TSS with an average of 56mg/L (excluding pre intervention in Balgowlah)
- 0.05 mg/L to 0.38 mg/L for TP with an average of 0.16 mg/L (excluding pre intervention in Balgowlah)
- 0.7 mg/L to 2.3 mg/L for TN with an average of 1.48 mg/L (excluding pre intervention in Balgowlah)

The EMC values for pollutants reported within near vicinity to the catchment are in the range of:

- 14.4 mg/L to 192 mg/L for TSS (Average of 85mg/L)
- 0.14 mg/L to 0.5 mg/L for TP (Average of 0.28 mg/L)
- 1.47 mg/L to 4.38 mg/L for TN (Average of 2.6 mg/L)

This shows that the reported values inside the catchment are lower than reported values for other areas in Sydney. TSS is 67% of the average value for other catchments in Sydney while TP and TN are 56% lower. This is shown in Figure 13.

Furthermore the Manly Lagoon catchment is significantly lower than typical urban values. TSS is 67% of the average value for other catchments in Sydney while TP and TN are 56% lower.

While the local Sydney runoff studies are broadly consistent with general reported literature values (as discussed in section 5.1) for TN and TP, TSS is significantly lower (60% of the general TSS EMC) than the general urban values.

Manly Lagoon has slightly lower reported EMCs for TN and TP (approximately 70% of the general urban EMC value) and a much lower then the general reported urban values (40% of the general urban EMC value).

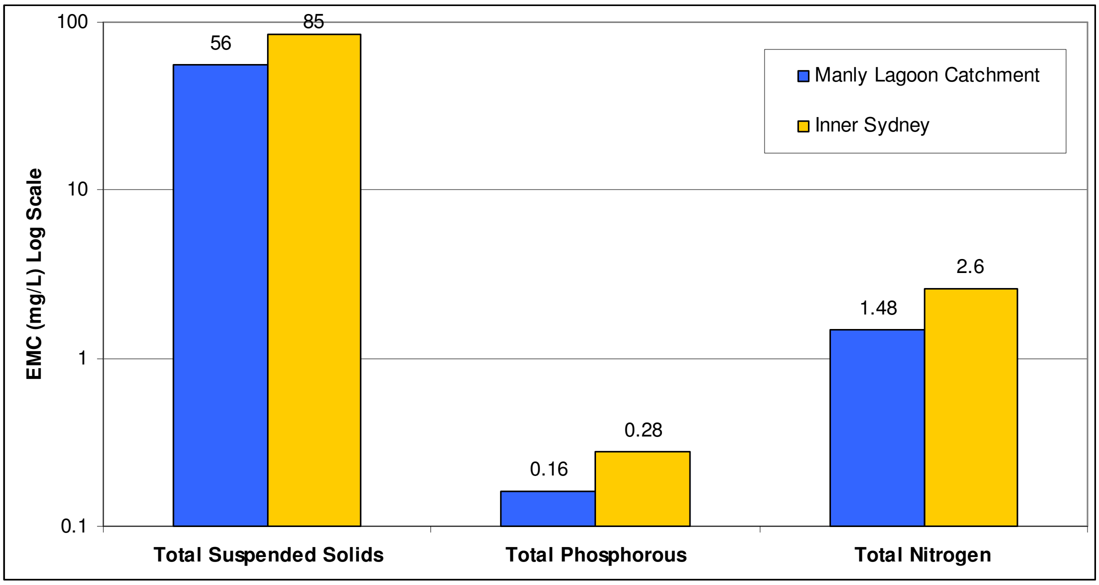


Figure 13: Event Mean Concentrations for Manly Lagoon Catchment compared to inner Sydney

Monitoring of water quality of Burnt Bridge Creek has also been undertaken in 2010 by Manly Council. Seven events were sampled in Burnt Bridge Creek at 5 minute intervals with every second sample sent to the laboratory for analysis. The summary results for these events are shown in Table 9.

No flow monitoring was undertaken for this sampling so EMCs were not possible to determine and the results cannot be compared to other local monitoring data. However the water quality data from this sampling shows that the average event concentrations are similar to the local EMCs providing further confidence in the local data ((for example average event means of TSS 62 mg/L compared to EMCs of 56 mg/L, TN 2.0 mg/L compared to 1.48 mg/L and TP 0.26 mg/L compared to 0.14mg/L).

Table 9: Burnt Bridge Creek Average Pollutant Concentrations

	Conductivity (us/cm)	TSS (mg/l)	FC CFU/100ml	Enterococci /100ml	TN (mg/l)	TP (mg/l)	Cu (ug/l)	Pb (ug/l)	Zn (ug/l)
Storm1	98	234		16750	3.3	0.23	37	62	169
Storm2	143	8			0.5	0.05	14	6	66
Storm3	130	23	28200	9000	3.6	0.45	49	68	259
Storm4	162	21	96667	34750	1.0	0.06	24	13	79
Storm5	118	12			1.0	0.31	13	9	57
Storm6	112	75	40667	26417	2.6	0.44	34	39	148
Storm 7			8748	12117					
Average	**127**	**62**	**43570**	**19807**	**2.00**	**0.26**	**29**	**33**	**130**

5.2.2 Dry Weather / Baseflow stormwater quality

Base flow in MUSIC is rainfall that has infiltrated into the soil and enters waterways via groundwater flows. The base flow concentrations have also been established based on data from ARQ for the respective catchment types. However it should be noted that the catchment is predominantly developed (approximately 75%) and the base flow concentrations have relatively small influence on the overall water quality and pollutant loads into Manly Lagoon.

As most of the studies were monitoring urban channels, drains, roofs, etc there were typically no or little baseflows available to monitor. The only study that reported on baseflow values was the Warringah Runoff Study. Baseflow values for this study are shown in Table 11.

These values have been adopted in the model.

Table 10 EMC for Wet Weather Events for Various Local Catchment Studies

Site	Catchment Area Has	Land Use	TSS mg/L	TP mg/L	TN mg/L	Faecal Coliforms #/100mL	Notes
Smith St Manly	0.65	Local Road and Residences	23	0.22	NA	NA	Runoff from permeable pavements
UNSW WRL Manly Vale	0.005	Corrugated Roof	29.2	NA	NA	NA	Monitored Colourbond Roof
Balgowlah Ind - Before Interventior	13	Industrial	297	0.87	3.0	28,000	
Balgowlah Ind - After Intervention	13	Industrial	117	0.38	1.7	32,000	
Balgowlah Ind - recent data	13	Industrial	69	0.43	2.2		
WSS1 - Frenchs Forest	14	Industrial/Commercial	NA	0.05	1.7	9,200	
WSS2 - Fr. Forest + Allambie Hts	50	Mixed	NA	0.06	1.6	4,450	
WSS3- Allambie Heights	8	Residential	NA	0.14	1.4	5,400	
WSS4 - Wakehurst Golf Course	24	Golf Course	NA	0.17	1	870	
WSS5 - Wakehurst Golf Course	7	Forest	NA	0.21	2.3	790	
WSS6 - Alambie Heights	15	Mixed	NA	0.06	0.7	3,500	
Cemetary Creek	NA	Mixed	65	0.4	2.6	3,500	
Chiswick	60	Residential	95	0.17	2.3	283,789	
Annandale	6	Residential	42	0.25	2.14	68,894	
Riverwood	48	Residential	87.5	0.14	4.38	68,383	
Drummoyne	6	Resid and Commerc	14.4	0.21	2.2	57,814	Monitored downstream of surcharge pit
Erskineville	15	Residential	73	0.38	1.47	182,011	
Little Sirius Cove, Mosman	11	Residential	192	0.5	3.3	13,478	
Centennial Park	60	Residential	91	0.33	NA	NA	

Notes:

1. *Rows highlighted in blue are studies undertaken in the catchment. Those in white are taken in catchments in Sydney in relatively close proximity to the Manly Lagoon catchment*
2. *NA (Not Available:) indicates that this parameter was not monitored in this study*

Table 11 EMC for Dry Weather for Local Catchment Studies

Site	Catchment Area Has	Land Use	TSS mg/L	TP mg/L	TN mg/L	Faecal Coliforms #/100mL	Notes
WSS1 - Frenchs Forest	14	Industrial/Commercial		0.11	1.6	11	
WSS2 - Fr. Forest + Allambie Hts	50	Mixed		0	19.2	33	Downstream of former landfill
WSS3- Allambie Hieghts	8	Residential		0.01	2	4	
WSS4 - Wakehurst Golf Course	24	Golf Course		0.04	0.7	40	
WSS6 - Alambie Heights	15	Industrial/Residential		0.05	0.6	170	

5.3 MUSIC Model Pollutant Values Adopted

The MUSIC model was run with three scenarios for pollutant load values.

1. By Landuse Zone: Utilising generic EMCs based on land zone (residential, commercial, industrial etc) as outlined in Table 8 and discussed in section 5.2. This model was run to determine the default range of overall pollutant loads that would be expected from the catchment.

2. By Landuse type: Utilising generic EMCs based on land use type (roads, roofs) as outlined in Table 8 and discussed in section 5.2. This model was run to determine the percentage of pollutants from different surface types within the catchment. The EMCs adopted are summarised in Table 12.

3. Local Pollutant Data: Utilising local pollutant loads as outlined in Table 10 and Table 11. The averages and standard deviations of these values were taken to determine the input values into MUSIC to determine pollutant concentrations based on local data. The summary of these results are shown in Table 13. Note that due to the lack of local data for TSS in some cases generic values for TSS had to be used. It should be noted that local data could not be used to determine sediment contributions from land use (road, roof, etc) as there was not sufficient local data on pollutants generated from the individual land use (e.g. there have been no specific studies on road quality data and there is only one study on roof water quality but it only measured TSS)

Table 12: EMC and Standard Deviations for Land Use (based on Duncan 1999)

	Total Suspended Solids (mg/L)	Total Phosphorous (mg/L)	Total Nitrogen (mg/L)
Roads - Mean	270	0.25	2.2
Roads - SD	90.6-804	0.0794-0.794	0.98 – 4.91
Roofs - Mean	20	0.13	2
Roofs - SD	4.7-84.9	0.05-0.29	0.682
Other Hardstand - Mean	140	0.25	2
Other Hardstand - SD	39.6-494	0.08-0.8	0.68-5.86

Table 13: EMC and Standard Deviations Based on Local Monitoring

	Total Suspended Solids (mg/L)	Total Phosphorous (mg/L)	Total Nitrogen (mg/L)
Residential - Mean	86.3	0.27	2.5
Residential - SD	53-140	0.13 - 0.543	1.7-3.6
Comm/Ind- Mean	65.8	0.174	1.58
Comm/Ind- SD	37-117	0.07-0.41	1-2.51
Parklands - Mean	39.8	0.17	1
Parklands - SD	11-141	0.05-0.5	0.34-2.9
Forest- Mean	40	0.21	2.29
Forest - SD	25.1-63.1	0.126-0.348	1.32-3.98

6 Sewer Overflow Data

Sewer overflows occur from the sewer system when the capacity of the sewer pipe or pumping station is exceeded and the sewer discharges untreated wastewater to the stormwater system. Wet weather sewer overflows occur because of rainfall entering the system through cracks in pits and pipes or illegal connections of stormwater runoff to the sewer system. Dry weather overflows occur predominantly due to blockages of pits and pipes which cause the sewer system to discharge flows into the stormwater system.

Sewer overflows from the sewer system have been modelled by Sydney Water under the Sewer Overflow Licensing Project (SOLP) and the Sewer Catchment Asset Management Plan (SCAMPs) programs. The SOLP program modelled only the trunk sewer system while the SCAMPs program is modelling the whole of Sydney Water sewer systems. Data is not currently publicly available for the SCAMPs program.

The SOLP project monitored the dry weather sewage quality and wet weather overflow quality and this data is summarised in Table 14. The lower pollutant concentrations found during wet weather are due to the dilution of sewage with stormwater.

Table 14 Typical Sydney Wastewater Quality (Sydney Water, 1997)

Constituent	Dry Weather Sewage	Wet Weather Overflow
Suspended Solids mg/L	300	90
Biological Oxygen Demand mg/L	275	80
Nitrogen mg/L	55	20
Phosphorus mg/L	12	4
Faecal Coliforms cfu/100mL	10,000,000	1,000,000

Sydney Water have provided sewer overflow data for the Manly Lagoon catchment. It should be noted that these overflow volumes are expected to reduce in the near future due to the works that are being undertaken in the catchment to reduce sewer overflow frequency. Table 15 shows a list of all of Sydney Water's sewer overflows in the Manly Lagoon catchment. The table shows the predicted events per 10 years that these overflows are activated due to wet weather ingress into the sewer system and the predicted sewer overflow volumes based on these events.

It should be noted that while Sydney Water was able to provide all the predicted frequency of events it was not able to provide all the predicted volumes (for 8 overflow locations in total). Those volumes shown in italics are estimated volumes. These volumes have been roughly estimated based on the data provided by taking the average volume per event and using this figure to estimate the loads for those overflows which do not have data.

These estimated values contribute 44% of the total sewer overflow volume thus there is a relatively *high* degree of uncertainty over the total sewer overflow volumes predicted.

Table 15 Sewer Overflow Frequency and Volumes

Overflow Asset Number	Suburb	Events/10 years	Volume/10 years
SNNA1OF02	ALLAMBIE	0	-
SNNA1OF03	ALLAMBIE HEIGHTS	5	549
SMBH3OF05	ALLAMBIE HEIGHTS	5	291
SNBH3OF04	ALLAMBIE HEIGHTS	4	32
SNNA1OF05	ALLAMBIE HEIGHTS	0	-
SMBH3OF01	BROOKVALE	30	44,147
SMWI4OF02	BROOKVALE	9	657
SNNA1OF07	BROOKVALE	0	-
SMSC5OF01	BROOKVALE	19	60,113
SNNA1OF06	BROOKVALE	4	186
SMWI4OF01	BROOKVALE	23	3,822
SNWI4OF03	BROOKVALE	6	680
SMSC5OF03	CURL CURL	3	41
SMGL3OF01	MANLY VALE	13	28,129
SNGL3OF02	MANLY VALE	2	202
OF1223410	CURL CURL	17	3,106
OF1396759	NORTH MANLY	0	-
OF1219500	NORTH MANLY	0	-
SP140OF01	FAIRLIGHT	0	-
SMQU1OF01	HARBORD	58	*34,227*
SP100OF01	HARBORD	0	-
SN037OF01	MANLY	0	-
SMAS4OF01	MANLY	17	*10,032*
SP035OF02	MANLY	0	-
SNAS4OF02	MANLY	0	-
SP306OF01	MANLY	2	*1,180*
SP116OF01	MANLY	7	*4,131*
SP117OF01	MANLY	4	*2,360*
MOF1393912	HARBORD	91	*53,701*
MOF1356937	MANLY	3	*1,770*
MOF1225074	MANLY	10	*5,901*
MOF1354269	MANLY	0	-
SNBB5OF03	SEAFORTH	0	-
SNBB5OF02		0	-
SNBB5OF01	BALGOWLAH	0	-
TOTAL			**255,258**

7 Sediment Loads

7.1 Sediment loads generated from stormwater runoff

The total sediment loads generated from the stormwater runoff in the catchment are shown in Figure 14. This graph shows an estimated range of sediment loads based on land zoning sediment concentration values. The figure shows that the predicted range of sediment generated from the catchment an annual average basis is:

- Mean: 3,470 tonnes/year
- Upper Estimate: 12,320 tonnes/year
- Lower Estimate: 980 tonnes/year
- Local Values Estimate: 1,100 tonnes/year

This shows that the estimated pollutants generated from the locally monitored values is at the lower range of estimates predicted for typical urban land zoning. The locally monitored values are approximately 50% less than those predicted for the general values.

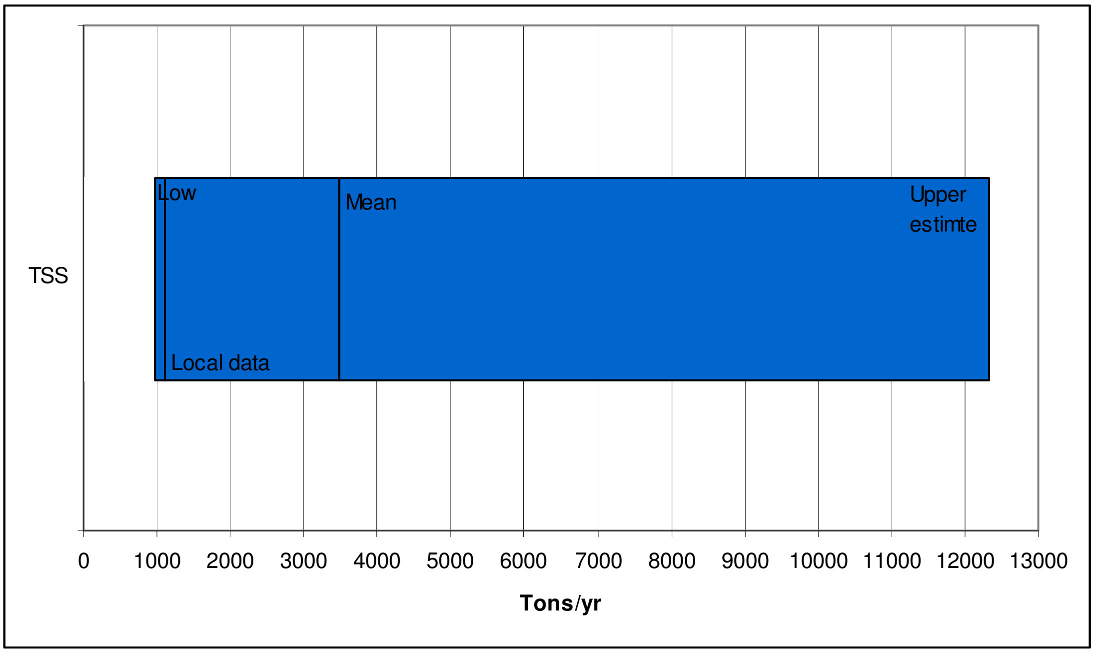
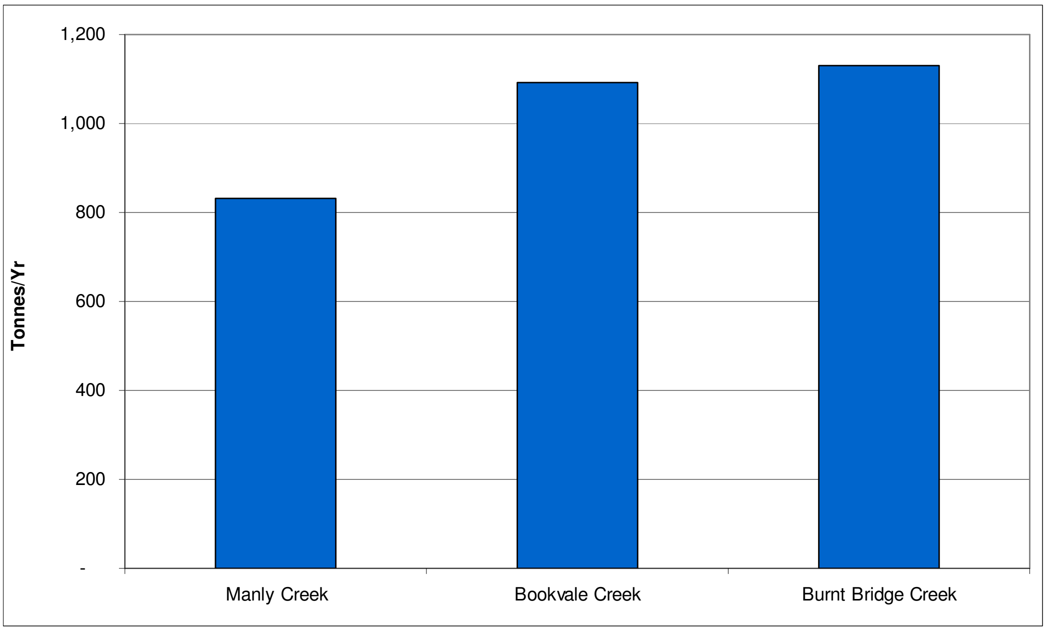


Figure 14: Total Sediment Loads Generated



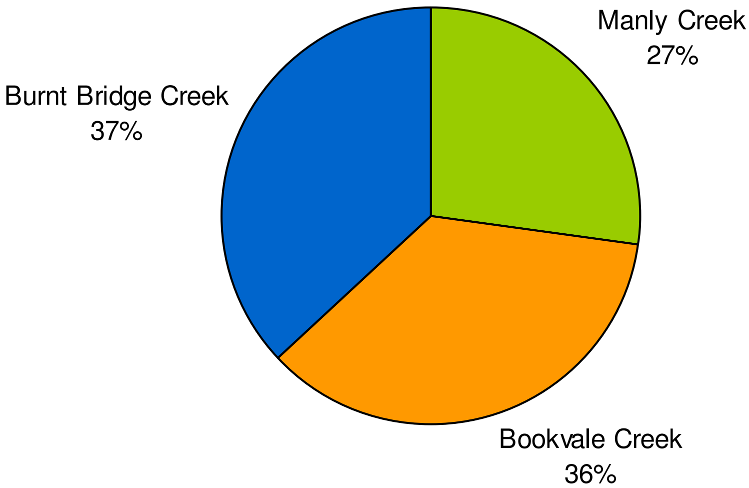
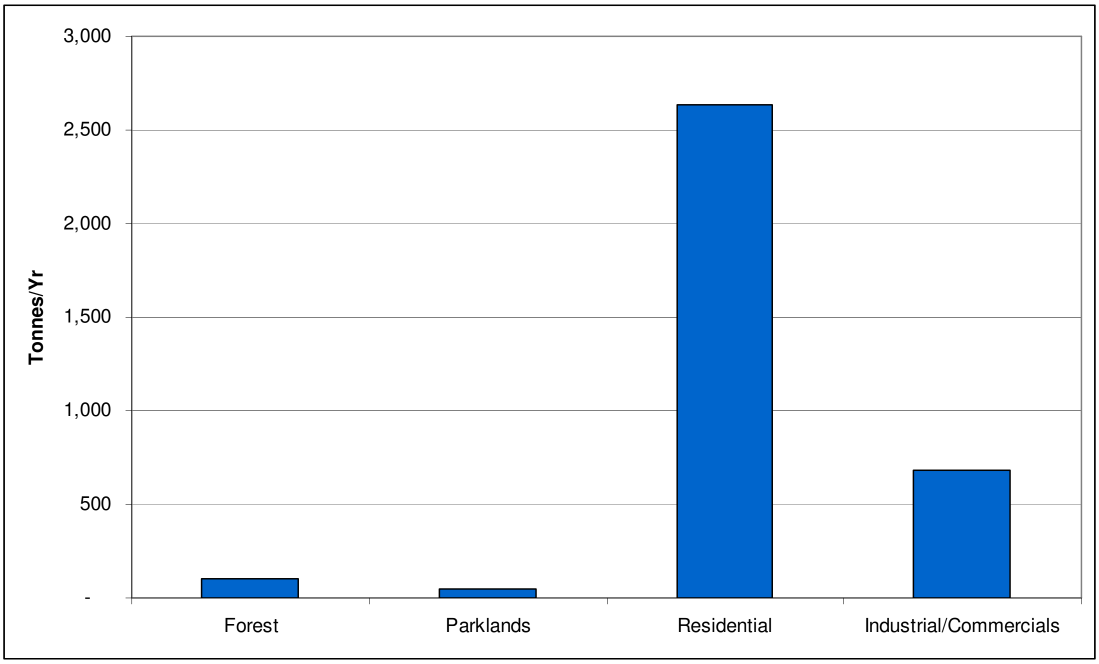


Figure 15: Total Sediment Loads – For 3 Sub-catchments

Figure 15 shows that the dominant catchments generating sediment within the Manly Lagoon catchment are Burnt Bridge Creek (combined contribution of 30% and 21% of the total catchment area) and Brookvale Creek 32% (25% of the total catchment area). These two catchments contribute approximately two thirds of the total sediment generated from stormwater runoff in the catchment.



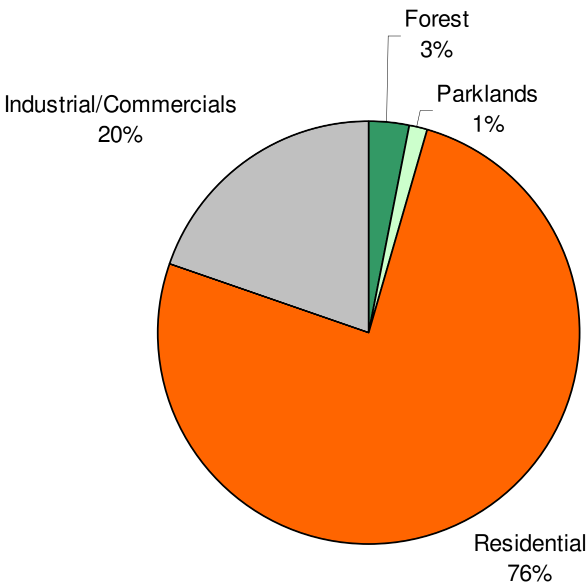


Figure 16: Total Sediment Loads – By Land Zoning

Figure 16 shows that residential dwellings is the dominant source of sediment in stormwater runoff. Residential areas are estimated to generate 75% of the total sediment loads. Residential areas are approximately 50% of the total land zoning within the Manly Lagoon Catchment. Industrial and commercial areas are estimated to contribute 20% to the total sediment generated in the catchment (11% of the total catchment area). It is noted that residential land zoning includes roads, roofs, etc.

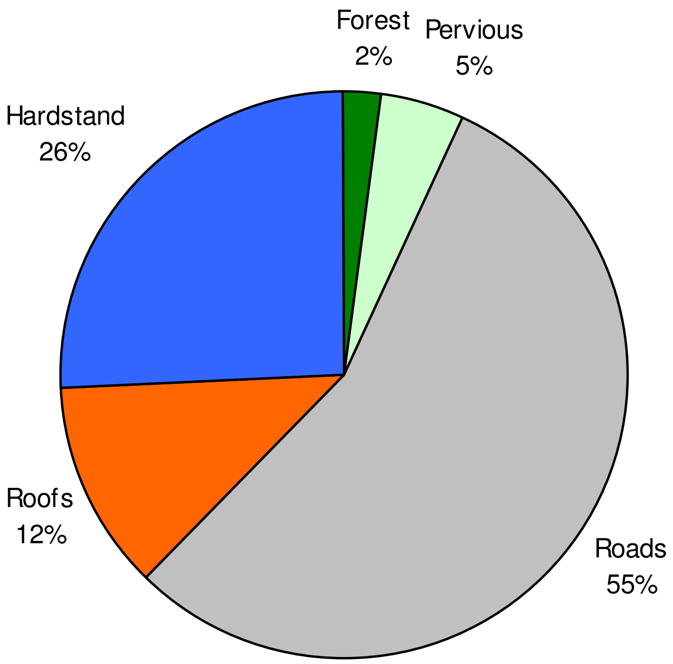


Figure 17: Total Sediment Loads – By Land Use

Figure 17 shows that roads are the dominant source of sediment in stormwater runoff. Roads are estimated to generate 55% of the total sediment loads. Roads are approximately 16% of the total land use within the Manly Lagoon Catchment. Roofs typically contribute less sediment in urban areas due to the significantly lower concentrations of sediment in roof runoff.

7.2 Sediment Loads Trapped by Manly Dam and Manly Lagoon

A basic MUSIC model was set up to estimate the amount of loads that were trapped by Manly Dam and Manly Lagoon. These models were used to determine general orders of magnitude of sediment removal. They are very indicative estimates as the exact details of the operation of Manly Dam and Manly Lagoon are not known in detail (including releases from Manly Dam, detailed bathymetry downstream of Pittwater Rd and tidal operation of Manly Lagoon). Thus these estimates of pollutant removal from the Dam and Lagoon should be considered orders of magnitude estimate for discussion purposes.

Preliminary modelling estimated that Manly Dam removed:

- 85% of sediment generated from the Manly Dam Catchment
- 420 tonnes/yr of sediment on an annual average basis

Preliminary modelling estimated that Manly Lagoon removed:

- 65% of sediment generated from the Manly Lagoon Catchment
- 2000 tonnes/yr of sediment on an annual average basis

Based on this ball park estimate the amount of sediment that is being deposited on the surface of the Manly Lagoon (assuming it was evenly distributed over the whole of the Lagoon area) is approximately 1cm/year on an annual average basis assuming the sediment density is 1.6 tonne/m^3.

7.3 Sediment Loads from Sewer Overflows

Based on the values discussed in section 5.4 the total predicted loads from sewer overflow of sediment (on an annual average basis) into the Manly Lagoon Catchment are 2,300 tonnes per year. It should be noted that there is a relatively high degree of uncertainty over the total sewer overflow volumes (see section 5.4 for more details).

Based on this data provided by Sydney Water and stormwater modelling the relative contributions of loads from sewer overflows and stormwater to Manly Lagoon has been estimated as shown in Table 16.

Table 16 Estimated Sources of Pollutant Loads

Pollutant	Stormwater Contribution Tonnes/yr (%)	Sewer Overflow Contribution Tonnes/yr (%)
Total Suspended Solids	3,500 (>99%)	2.3 (<1%)

8 Pollutant Loads

8.1 Total Phosphorous

The total phosphorous loads generated from the stormwater runoff in the catchment are shown in Figure 18. This graph shows an estimated range of phosphorous loads based on land zoning phosphorous concentration values. The figure shows that the predicted range of phosphorous generated from the catchment an annual average basis is:

- Mean: 5,690 kg/year
- Upper Estimate: 20,000 kg/year
- Lower Estimate: 1,800 kg/year
- Local Values Estimate: 4,000 tonnes/year

This shows that the estimated pollutants generated from the locally monitored values is relatively close to the estimates predicted for typical urban land zoning. The locally monitored values are approximately 20% less than those predicted for the mean general values.

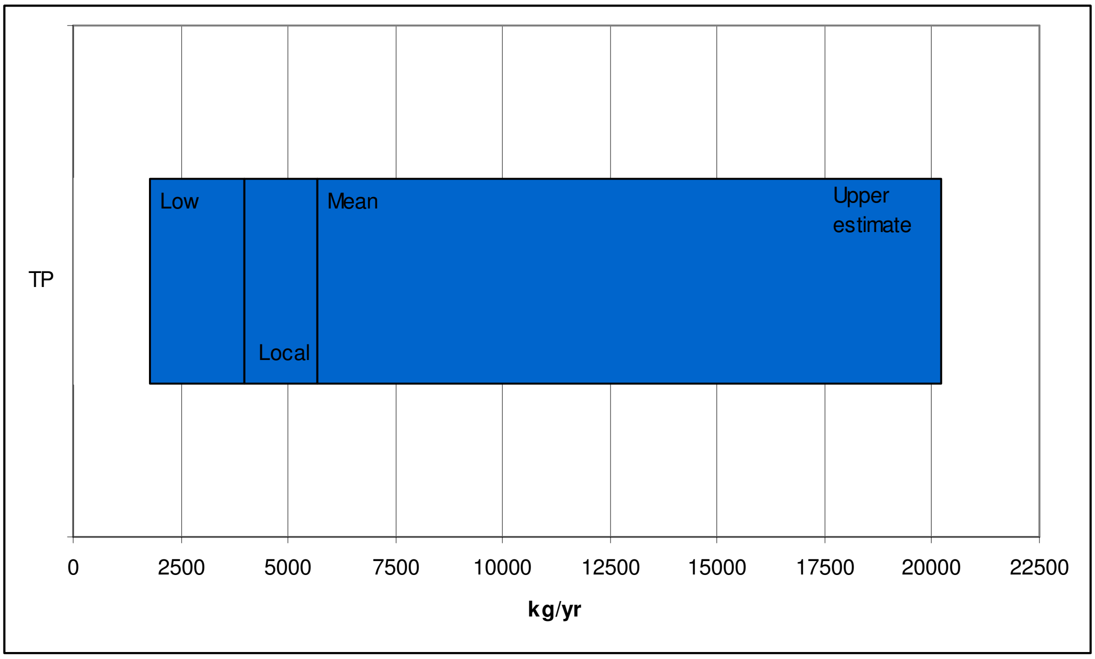
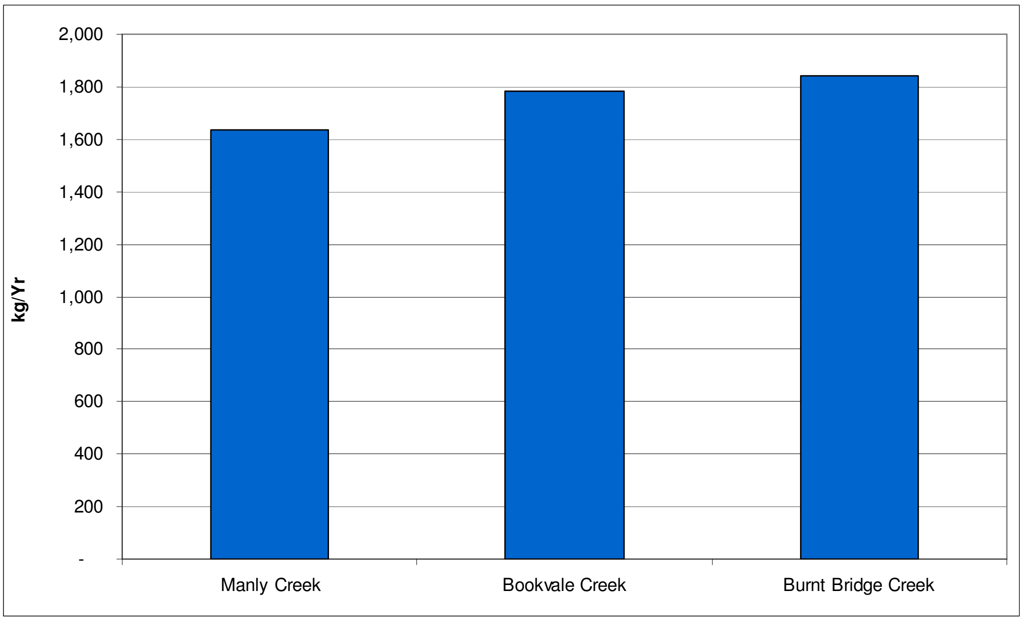


Figure 18: Total Phosphorous Loads Generated



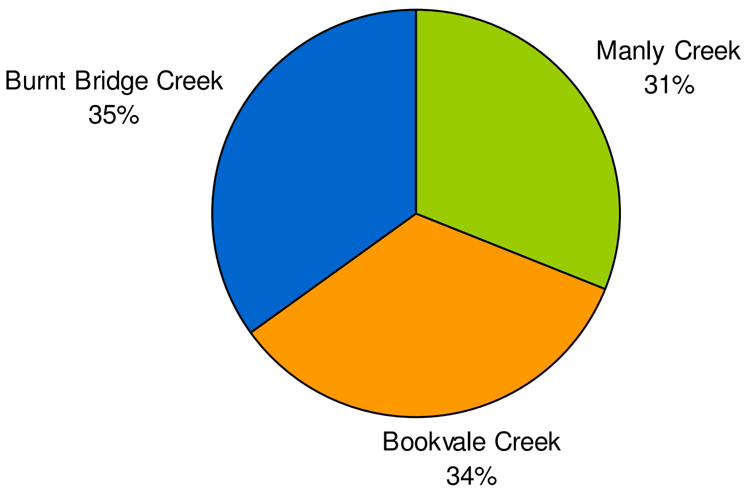
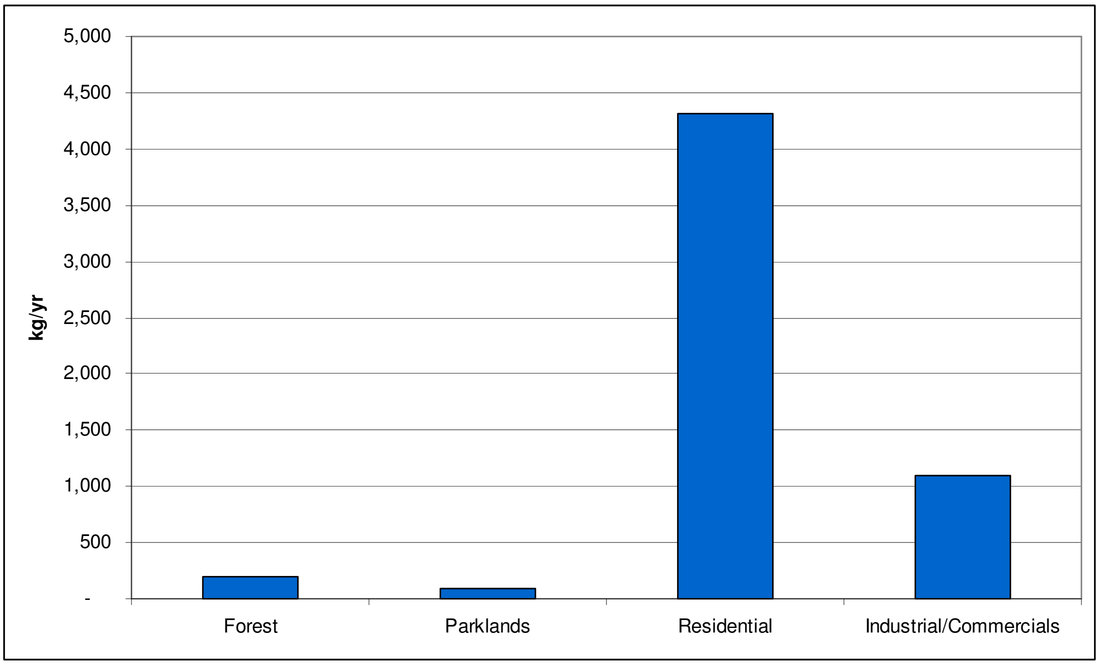


Figure 19: Total Phosphorous Loads – For 3 Sub-catchments

Figure 19 shows that the dominant catchments generating phosphorous within the Manly Lagoon catchment are Burnt Bridge Creek (combined contribution of 28% and 21% of the total catchment area) and Brookvale Creek 32% (25% of the total catchment area). Similar to that predicted for sediment, these two catchments contribute approximately two thirds of the total phosphorous generated from stormwater runoff in the catchment. This is expected because the majority of phosphorous in stormwater runoff is particulate phosphate and thus is strongly correlated to sediment loads.



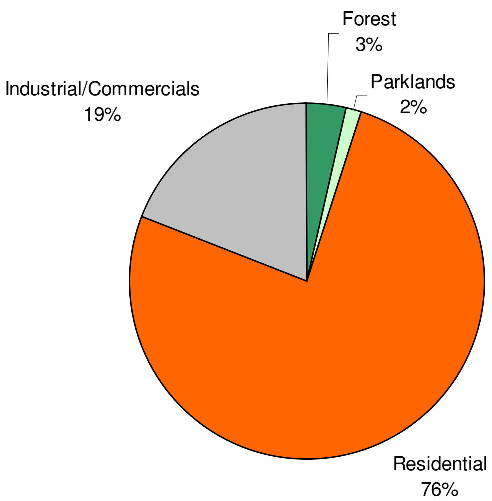


Figure 20: Total Phosphorus Loads – By Land Zoning

Figure 20 shows that residential dwellings is the dominant source of phosphorous in stormwater runoff. Residential areas are estimated to generate 76% of the total phosphorous loads. Residential areas are approximately 50% of the total land zoning within the Manly Lagoon Catchment. Industrial and commercial areas are estimated to contribute 19% to the total phosphorous generated in the catchment (11% of the total catchment area)

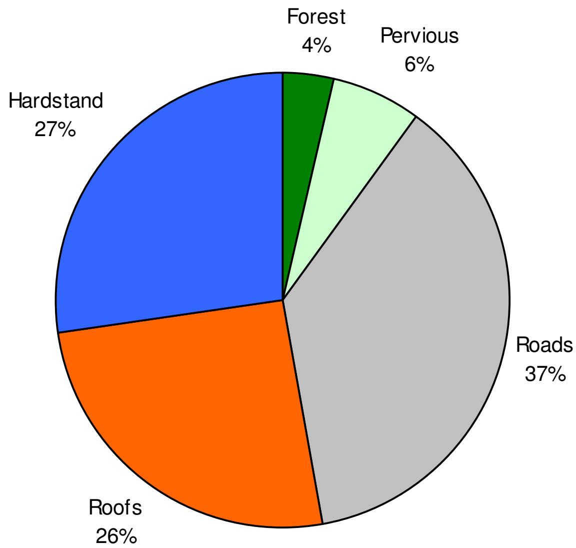


Figure 21: Total Phosphorous Loads – By Land Use

Figure 21 shows that while roads are the dominant source of phosphorous in stormwater runoff it is not as dominant as sediment generation. Roads are estimated to generate 37% of the total sediment loads. Roofs and other hardstand also provide significant phosphorous loads (approximately 25%).

8.1.1 Phosphorous loads trapped by Manly Dam and Manly Lagoon

As discussed in section 6.2 a MUSIC model was set up to estimate the amount of pollutant loads that were trapped by Manly Dam and Manly Lagoon. Preliminary modelling estimated that Manly Dam removed:

- 50% of phosphorous generated from the Manly Dam Catchment
- 430 kg/yr of phosphorous on an annual average basis

Preliminary modelling estimated that Manly Lagoon removed:

- 40% of phosphorous generated from the Manly Lagoon Catchment
- 2,400 tonnes/yr of phosphorous on an annual average basis

8.2 Total Nitrogen

The total nitrogen loads generated from the stormwater runoff in the catchment are shown in Figure 22. This graph shows an estimated range of nitrogen loads based on land zoning nitrogen concentration values. The figure shows that the predicted range of nitrogen generated from the catchment an annual average basis is:

- Mean: 41,930 kg/year

- Upper Estimate:148,760 kg/year
- Lower Estimate: 14,540 kg/year
- Local Values Estimate: 33,830 tonnes/year

This shows that the estimated pollutants generated from the locally monitored values is relatively close to the estimates predicted for typical urban land zoning. The locally monitored values are approximately 25% less than those predicted for the mean general values.

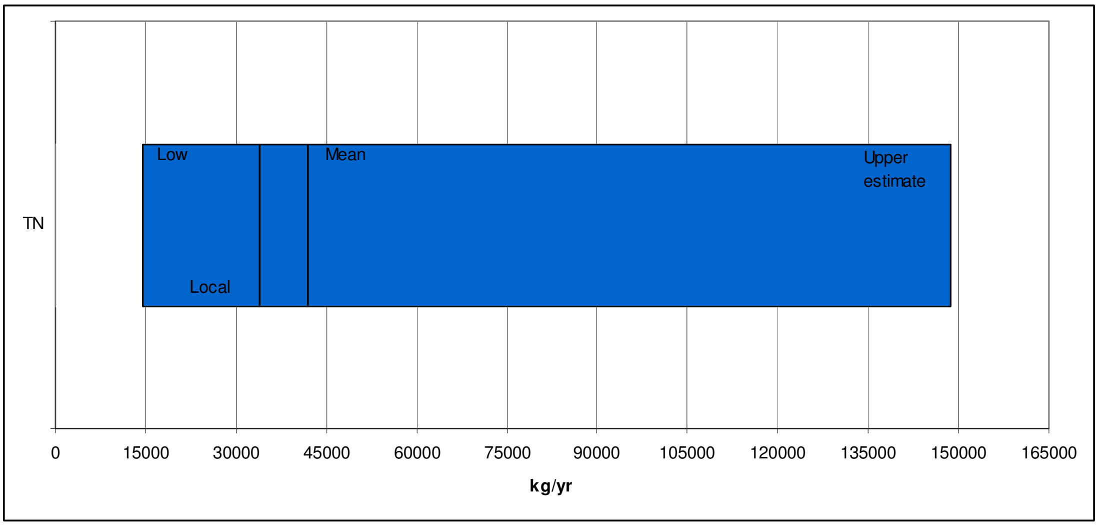
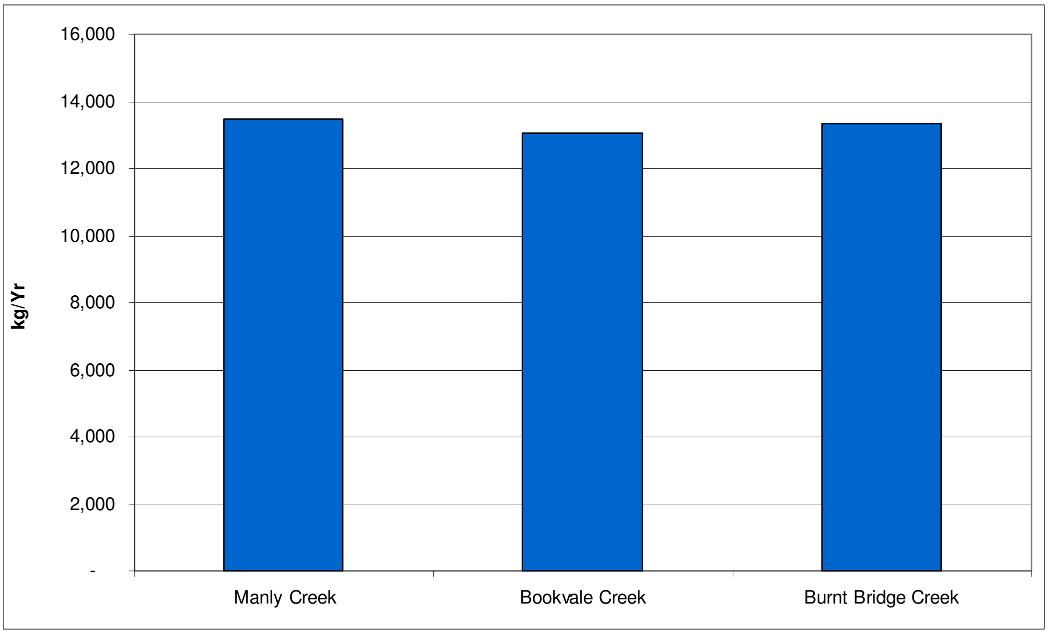


Figure 22: Total nitrogen Loads Generated



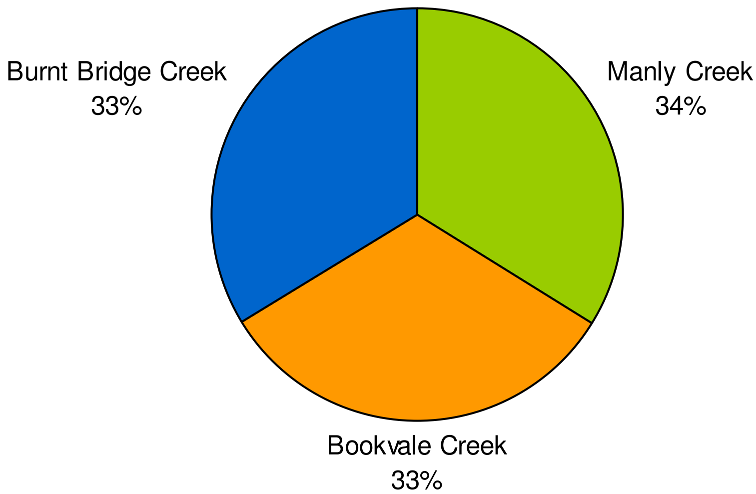
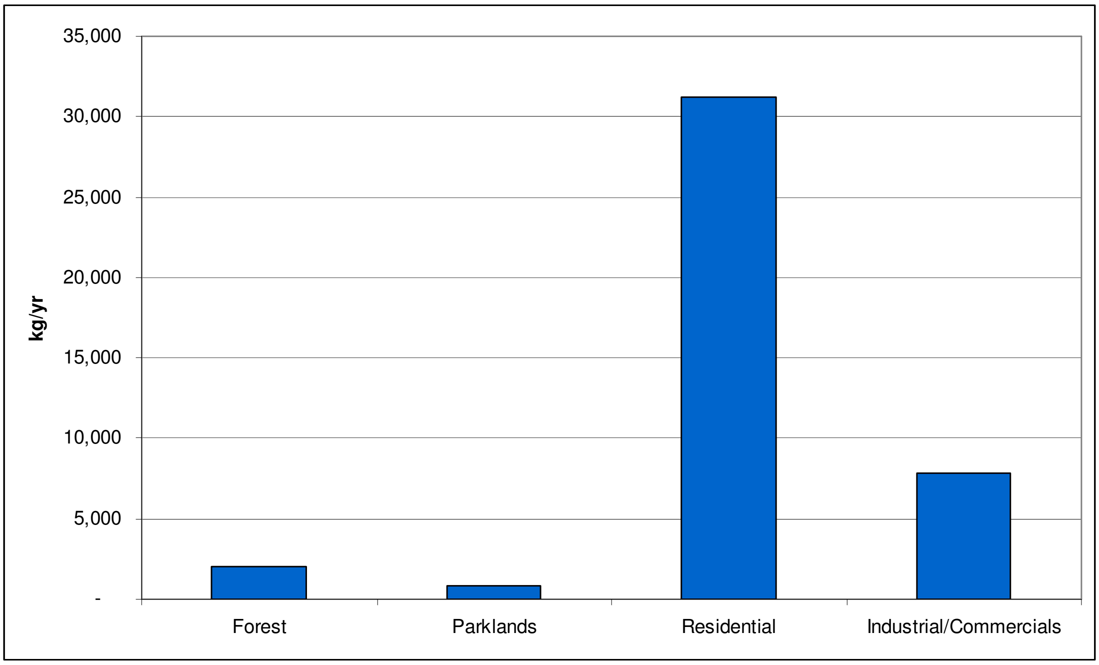


Figure 23: Total nitrogen Loads – For 3 Sub-catchments

Figure 23 shows that the dominant catchments generating nitrogen within the Manly Lagoon catchment are Burnt Bridge Creek (combined contribution of 28% and 21% of the total catchment area) and Brookvale Creek 32% (25% of the total catchment area). Similar to that predicted for sediment, these two catchments contribute approximately two thirds of the total nitrogen generated from stormwater runoff in the catchment.



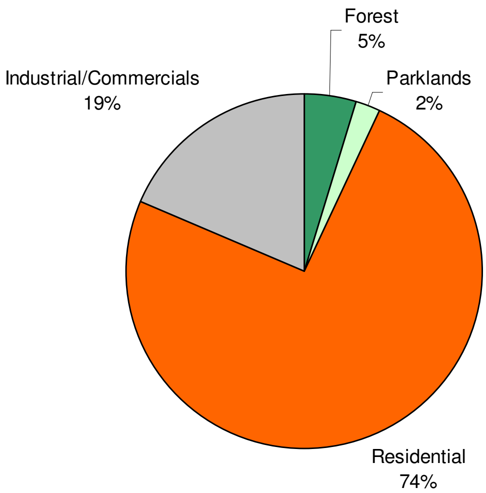


Figure 24: Total nitrogen Loads – By Land Zoning

Figure 24 shows that residential land zonings are the dominant source of nitrogen in stormwater runoff. Residential areas are estimated to generate 74% of the total nitrogen loads. Residential areas are approximately 50% of the total land zoning within the Manly Lagoon Catchment. Industrial and commercial areas are estimated to contribute 19% to the total nitrogen generated in the catchment (11% of the total catchment area)

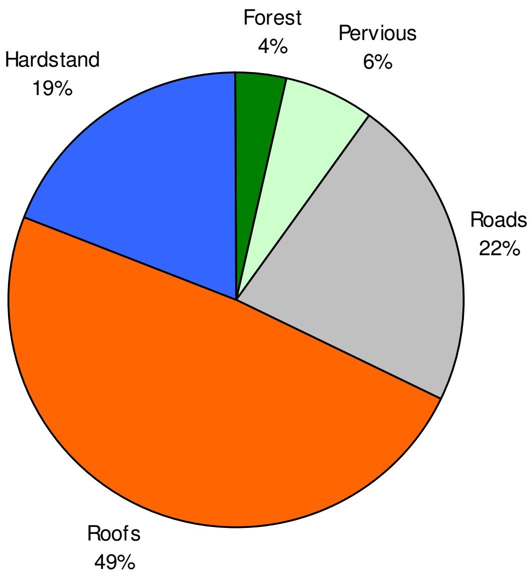


Figure 25: Total nitrogen Loads – By Land Use

Figure 25 shows that roofs are the dominant source of nitrogen in stormwater runoff. This is because a roof runoff concentrations for nitrogen are similar to he concentrations for surface level runoff (e.g. roads). This is typically because nitrogen concentrations are strongly influence by concentration of nitrogen in rainfall and thus have greater independence from the surface type. Roofs are estimated to generate 49% of the total nitrogen loads and roofs are approximately 24% of the catchment area.

8.2.1 Nitrogen loads trapped by Manly Dam and Manly Lagoon

As discussed in section 6.2 a MUSIC model was set up to estimate the amount of pollutant loads that were trapped by Manly Dam and Manly Lagoon. Preliminary modelling estimated that Manly Dam removed:

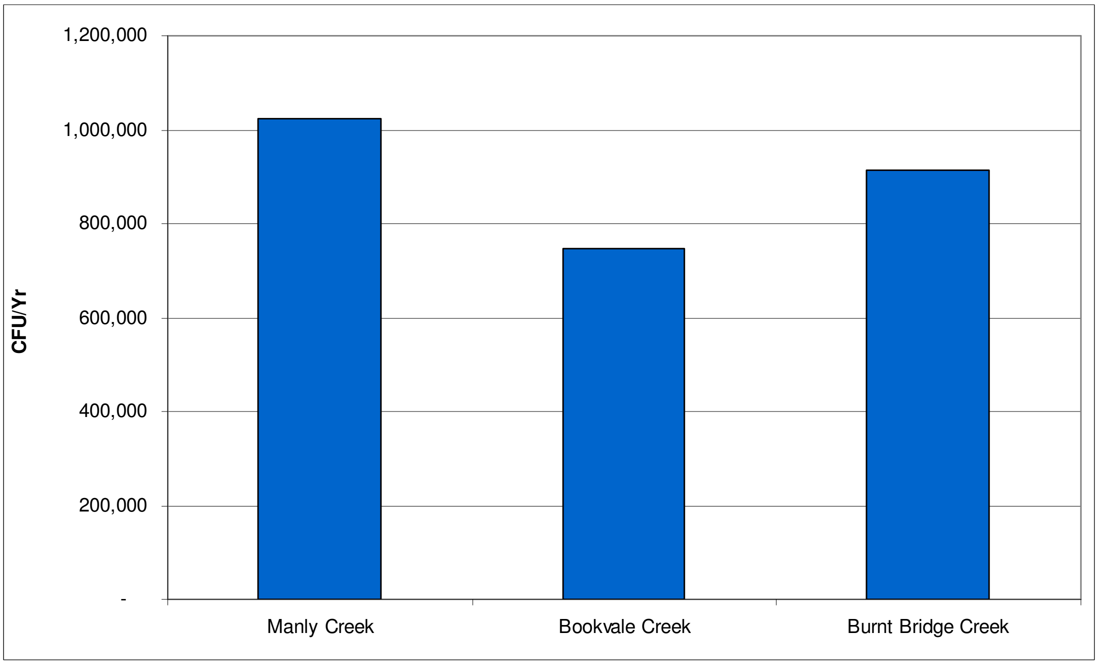
- 30% of nitrogen generated from the Manly Dam Catchment
- 2,050 kg/yr of nitrogen on an annual average basis

Preliminary modelling estimated that Manly Lagoon removed:

- 20% of nitrogen generated from the Manly Lagoon catchment
- 7,900 kg/yr of nitrogen on an annual average basis

8.3 Faecal Coliforms

The total predicted faecal coliform loads generated from the stormwater runoff in the catchment are 2.7×10^{14} CFU/yr.



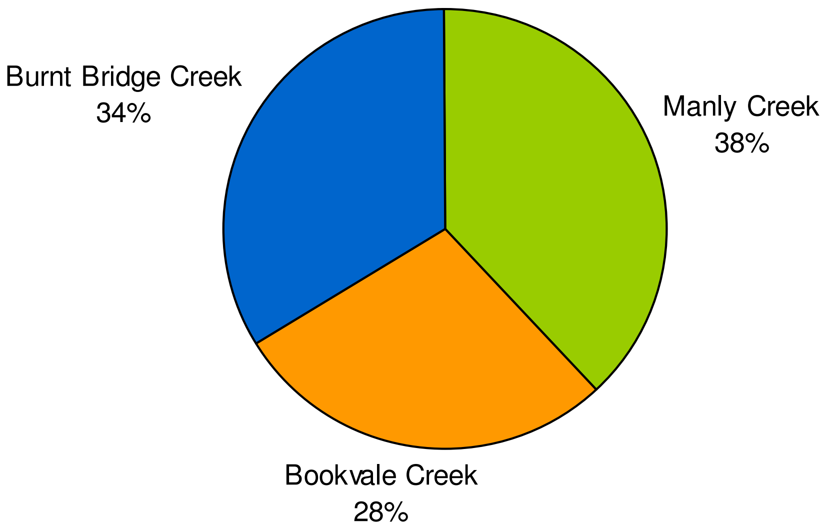
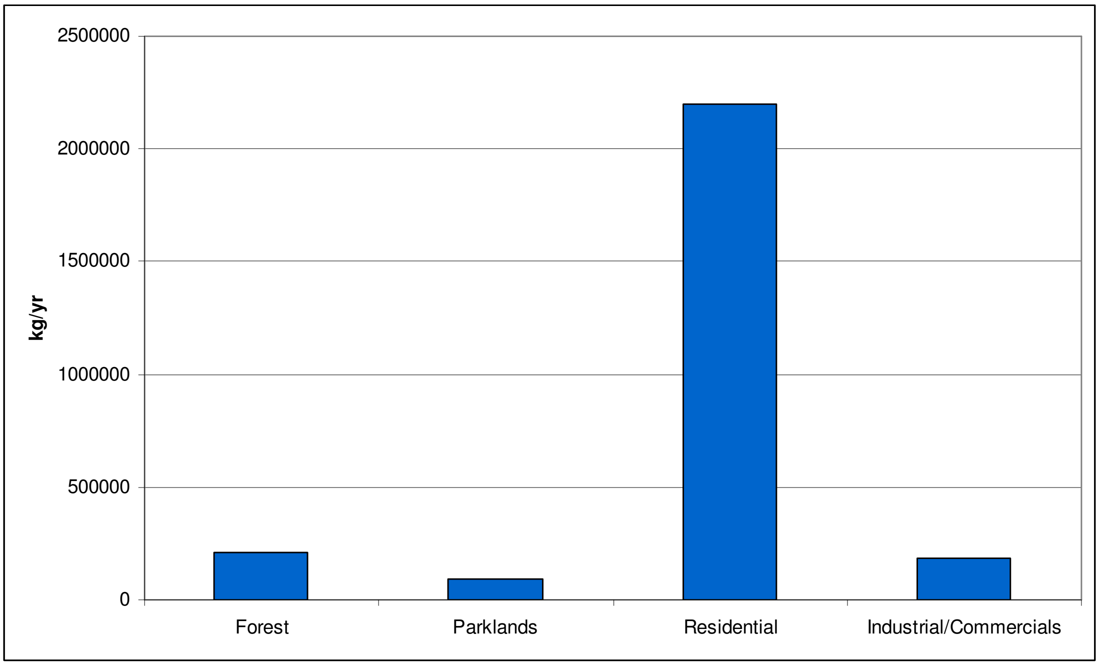


Figure 26: Total faecal coliform Loads – By Catchment

Figure 26 shows that the dominant catchments generating faecal coliforms within the Manly Lagoon catchment are Burnt Bridge Creek (combined contribution of 30% and 21% of the total catchment area) and Brookvale Creek 28% (25% of the total catchment area). Similar to that predicted for sediment, these two catchments contribute approximately two thirds of the total faecal coliforms generated from stormwater runoff in the catchment.



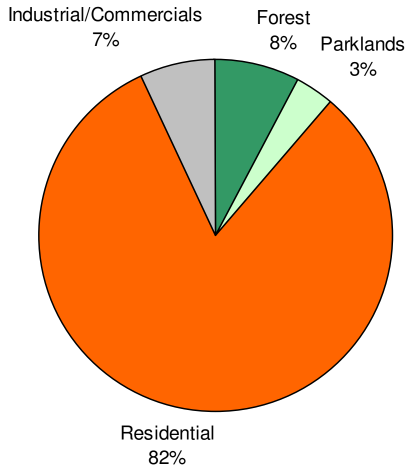


Figure 27: Total faecal coliform Loads – By Land Zoning

Figure 27 shows that residential land zonings are the dominant source of faecal coliforms in stormwater runoff. Residential areas are estimated to generate 82% of the total faecal coliform loads. Residential areas dominate pathogen loads because the majority of sewer volumes in urban areas come from residential land uses.

8.4 Sewer Overflow Contributions

Based on the data provided by Sydney Water and stormwater modelling the relative contributions of loads from sewer overflows and stormwater to Manly Lagoon has been estimated as shown in Table 16.

Table 17 Estimated Sources of Pollutant Loads

Pollutant	**Stormwater Contribution Kg/yr (%)**	**Sewer Overflow Contribution Tonnes/yr (%)**
Phosphorus	5,690 (98%)	102 (2%)
Nitrogen	41,930 (98%)	511 (2%)
Faecal Coliforms (CFU/yr)	2.7×10^{14} (>99%)	2.6×10^{8} (< 1%)

9 Conclusions

9.1 Source of pollutants (Sediment, TN, TP)

The dominant source of pollutants (sediment, phosphorous and nitrogen) in the Manly Lagoon catchment is diffuse urban stormwater pollution. Stormwater is the overwhelming source of pollutant loads into the lagoon (more than 95% for suspended sediment, phosphorous and nitrogen), rather than sewer overflows.

Impervious areas dominate the sources of pollutants entering Manly Lagoon. Impervious surfaces account for more than 90% of the sources entering Manly Lagoon. Roads surfaces dominate the source of sediment loads while roof surfaces dominate the source of nitrogen loads. This is dominated by rainfall contributions to nitrogen. Phosphorous is evenly distributed between roofs and roads and other impervious surfaces.

The dominant source of pollutants by land zoning is residential areas. This is strongly related to the dominant impervious land zoning in the catchment being residential.

Faecal coliforms according to the current modelling show that stormwater dominates the faecal coliform loads (several orders of magnitude larger than the volumes from sewer overflows). However these results should be taken with caution, as the modelling has not taken into account the source of faecal coliforms in stormwater. However it does generally indicate that stormwater may be a significant source of faecal coliforms into Manly Lagoon independent of sewer overflows.

9.2 Stormwater quality improvement as a means to improve Manly Lagoon Environmental Condition

All future works to improve the environmental condition in Manly Lagoon by both Manly and Warringah Councils should focus on stormwater quality improvement (Sediment and pollution loads in the catchment, using gross pollutant traps, nets, booms, street sweeping, biofiltration, wetlands, catchment and stormwater education, water sensitive urban design, stormwater interception, treatment and reuse, aquifer recharge and infiltration). This should be applied rather than end-of-point dredging of the Lagoon.

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