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Georges River Data Compilation and Estuary Processes Study

For: Georges River Combined Councils' Committee

EXECUTIVE SUMMARY

Introduction

The Georges River Combined Councils' Committee (GRCCC), consisting of nine local councils within the Georges River catchment area, has recently established a sub-committee, the Georges River Estuary Management Committee, to formulate an Estuary Management Plan for the entire Georges River Estuary. The Estuary Management Plan is to be undertaken in accordance with the NSW Government's Estuary Management Manual under the NSW Estuary Management Policy Statement.

This report documents a combined Data Compilation and Estuary Processes Study for the Georges River Estuary. It identifies and collates key data and reports on the Georges River Estuary, encompassing relevant physical, ecological, social and economic, and land use planning activity characteristics – information that is generally applicable to relevant estuarine environments or management has also been included.

The report also maps the extents of and documents threats and pressures on estuarine and riparian vegetation, foreshore erosion, documents seawall assessments for the estuary, documents water quality, and existing gross pollutant traps and stormwater outlets in the study area. It also documents viable specific management actions for the parts of the estuary which are degraded or priorities for protection of significant value area.

The work presented herein has been carried out in accordance with the NSW Government Estuary Management Manual (1992), the NSW Estuary Management Policy, and the NSW Sea Level Rise Policy Statement.

Project Study Area

The Georges River Estuary stretches approximately 50 km and extends from its mouth at Botany Bay to the tidal limit at Liverpool Weir. The catchment area covers a significant portion of the Sydney Metropolitan area. The land surrounding the estuary has been highly modified with heavy urbanisation supporting a range of commercial, industrial and residential purposes, with many developments extending up to the foreshores. As such, this area has become a major source of pollution with metals, oils, grease, toxic organic compounds and high levels of nutrients entering the estuary from stormwater runoff. This has reduced water quality to such an extent that commercial fishing within the lower reaches has been banned and an oyster industry has collapsed from disease infestation. This is particularly significant given the international importance of the estuarine wetlands within the lower reaches of the estuary, in particular Towra Point Wetlands, which is an internationally recognised Ramsar site.

The project study area includes all the tributaries but does not include the Woronora River (as it is the subject of a separate Estuary Management Plan). It also includes the western foreshore of Botany Bay (Lady Robinsons Beach) and Towra Point.

Estuary and Catchment Characteristics

The Georges River Estuary is classified as a drowned river valley estuary. This kind of estuary is recognisable by a wide bedrock-flanked mouth, the presence of a submerged tidal delta such as Botany Bay and the absence of a sand barrier at its entrance.

Many changes in the bathymetry occurred since the first sounding of the Bay undertaken by Captain Cook in 1770. In particular, it is to be noted that several reclamation and dredging works occurred in the second half of the 20th century.

Botany Bay is a roughly circular depression reaching a diameter of 8km. The entrance of the bay is around 1km wide. The maximum depth in Botany Bay reaches 18m in its natural state but is now around 21m, due to the entrance channel dredging carried out in the 1970s. The average depth in the bay is about 4.5m and around 4m along the Georges River.

Soils and Topography

The topography is directly linked to the geology of each particular area. The study area elevation ranges between sea level at Botany Bay and approximately 75m in the west. Some gently undulating hills, narrow steep-sided valleys and gorges, broad valleys with floodplains or high exposed ridges with broad flat tops are noticeable along the Georges River. The Wianamatta shale geology in the upper reaches has influenced the gentle undulating slopes, low flat plains and broad valleys while the Hawkesbury sandstone has generated the dissected plateau west of the Illawarra Escarpment, narrow steep-sided sandstone valleys or gorges, high-exposed flat and broad ridges and moist gullies.

The soils in the northern half of the study area – derived from the Wianamatta Shales – have a high potential for erosion (SPCC, 1978). Sheet and gully erosion is often visible in shale-based areas. These soils have a high water retaining capacity but can be very dispersible, making the water turbid. These soils are the source of most siltation in the lower reaches of the Georges River.

Some skeletal stony sandy soils are found in the sandstone based areas. They are permeable and more porous than the Wianamatta shales and not dispersible. These soils are prone to water and wind erosion when the vegetation protecting them is disturbed.

Sedimentary Processes

During the last century, sedimentary processes changed considerably in the Georges River catchment area. These changes were both influenced by natural factors (e.g. natural variations in flood gradients and river flows, wind waves) and anthropogenic factors (e.g. dredging, reclamation, boat waves). The significant urbanisation increasing along the river had an important impact on the sediment processes due to increased urban runoff and vegetation removal. Developments along the Georges River changed the hydraulic character of the river, increasing erosion in the upper reaches and deposition in the lower reaches, making the latter siltier. The several dredging and reclamation works also significantly impacted the River behaviour and hence the sediment processes.

The Georges River Estuary can be split into three regions of bed sediments. These are:

- the main channel reach above Como Bridge which is mainly sandy
- the main channel reach below Como Bridge which is predominantly composed of clay and silt
- the large off-channel bay areas in the lower estuary where the major sediments are flocculent silts and clays

Overall longitudinal downstream fining of sand bed sediments illustrates a strong fluvial regime upstream of East Hills. Some occasional surface fine sediments are found at river bends.

A dominant flood tide (incoming tidal) sediment transport rate has been observed at several sites in the Georges River while the ebb transport (outgoing tide) is not significant (PBP, 1996).

In Botany Bay, ocean swell has moved sand in the direction of wave propagation across the bay, creating Lady Robinsons Beach. Breaking waves create longshore currents which lead to the generation of strong accretion at Dolls Point, westward sediment transport along Towra Point and a northward migration of sand along Lady Robinsons Beach.

Sediment Quality

The Georges River Estuary is intensively urbanised and industrialised and is important for boating and maritime activities. It has been a major repository for urban and industrial waste and is impacted by heavy metal loadings (e.g. copper, zinc, nickel, lead). Decrease in tidal flushing due to reclaimed areas and extensive urban discharge result in high values of some metals in the upper reaches of the river but additional excessive loadings from industrial and shipping activities probably accounts for some of the observed heavy metal loadings. Point sources (e.g. waste dumps, sewage overflows, and discharge from a polluted river) have elevated sediment heavy-metal concentrations up to 50 times above background in parts of Georges River Estuary.

The majority of estuarine areas have sediment heavy metal concentrations which are greatly in excess of background values with most elevated regions located at the upper reaches and bay ends, with the lower reaches and mouth areas approaching background values.

Dredging, Reclamation and Erosion

Many dredging works occurred in Botany Bay between 1948 and 1978 (SPCC, 1979) and all along the Georges River. Dredging has exacerbated erosion of river banks by steepening the sub-water-surface bank profile – hence making the riverbanks unstable. Dredging can also lead to decreased flow velocities in the river, which promotes accelerated sediment deposition. The major dredging occurring in the Georges River Catchment was at Moorebank and Chipping Norton Lakes.

Some dredging within Botany Bay has had an impact on the foreshore of the study area, more particularly along Towra Point and Lady Robinsons Beach. This dredging has been undertaken between 1948 and 1978 at Botany Bay entrance for the building of the Australian Oil Refinery jetty and offshore of Kyeemagh. These changes in depth changed the wave behaviour and direction within the bay which increased the sediment transport along the Towra Point coastline (SPCC, 1978). Some further dredging occurred in 1984-85 for the maintenance of the facilities at AOR and in 1992-94 at Botany Bay entrance.

The main areas where erosion occurs are in the upper reaches of the Georges River located in Wianamatta Shale geology, as lateral channel movement occurs more easily here than in sandstone. The impervious Wianamatta shales are covered by clay and clayey loams and some gully and sheet erosion makes the water turbid even at low discharge. Most silt in the lower reaches of the river comes from this area.

In shale areas, widths of the channel usually increase over time while in sandstone areas, widths mainly decrease over time. In both shale and sandstone, mean and maximum depths increase over time. Channel capacity increased by 60% in the uppermost reaches between 1959 and 1976 while in the lower reaches the rate of increase was only 3%. Reclamation of bank and mangrove/saltmarsh is largely responsible for width losses.

One main cause of erosion is dredging. This activity can have more or less impact on erosion depending on the depth of dredging and its distance from the banks. Some other causes of bank erosion include water in the soil profile causing a loss of bank coherence, passage of floods undermining the banks, wash from boats at high tide, wind waves, increasing tidal velocities due to increased storage at Chipping Norton ponds and lack of vegetation along banks. Erosion prone riverbank materials, presence of dispersive clay and change in flow regime at the Weir, Lake Moore inlet, river bend downstream of William Long Bridge and inlet to Chipping Norton Lake are also amongst the major mechanisms of erosion.

Inappropriate bank protection and channel modification may cause localised erosion (e.g. edge effects). Hence, controls, maintenance and management have to be undertaken.

Reclamations along the Georges River have increased erosion in the upper reaches and the eroded sediments are depositing in the lower reaches. Some reclaimed areas also reduced the tidal prism and generated siltation as a consequence of the lower tidal flush.

Hydrodynamics

The Georges River and its tributaries form a vertically well-mixed estuary with waters in the lower reaches having essentially marine salinities.

The tides in the Georges River area are semidiurnal with a diurnal inequality. This means that there are two high tides and two low tides each day and the two high or two low tides do not have the same amplitude. Tidal range is relatively constant along the River with differences in levels of less than 0.1m between the Liverpool Weir (mean spring range of 1.31m) and Botany Bay (mean spring range of 1.25m). A tidal lag is noticeable between the Georges River mouth and the Weir. This tidal delay is about 2.5 hours (SPCC, 1978).

Tidal flushing predominantly depends on the tidal prism, which is the volume of water in an estuary or inlet between mean high tide and mean low tide or the volume of water leaving an estuary at ebb tide. Between 1960 and 1980, the tidal prism of the Georges River upstream of Milperra increased from 700,000 m^3 to 1.6 million m^3 due to the lakes construction. This construction of the Chipping Norton Lake has reduced tidal range by approximately 0.2m in the upper reaches since 1960.

The lower reaches of the Georges River are relatively well flushed as they are well influenced by the tide. However, some areas within the estuary are subject to a lack of tidal ventilation and are called ‘dead water areas’. Most embayments of the lower reaches have a dead water area upstream in dry weather conditions.

Water Levels

During storms, the ocean water level and hence that along the river is elevated above the normal tide level. While these higher levels are infrequent and last only for short periods, they may exacerbate any storm damage on the foreshore. Elevated water levels allow larger waves to cross the offshore sand bars and reefs and break at higher levels on the beach, especially in places like Towra Point. Further, they may cause flooding of low lying areas and increase tail water control levels for river flood discharges in the upper reaches of the river.

A significant issue is the future rise in sea level resulting from climate change. A rising sea level may result in an increased potential for bank erosion along the river where there is no protection against erosion like a seawall or estuarine vegetation and increased inundation.

Currents

The principal drivers of currents are tides, floods, winds, waves breaking and wave orbital motion at the seabed.

Current speeds in both Botany Bay and Georges River are generally less than 1m/s. Dredging in Botany Bay have reduced currents in deep holes and the airport development within the Bay has disturbed the current patterns. The construction of the Lakes Scheme has affected the current velocities upstream of the lake and allowed some minor sediment transport which was non-existent previously.

Waves

Waves can be locally generated by wind. This phenomenon is more likely to occur within the upper reaches at the Chipping Norton lakes or Botany Bay where longer fetch (i.e. the length of water over which a given wind has blown) can be observed. These waves have a characteristic period ranging from 1 to 5 seconds and possess little energy.

Botany Bay is subject to ocean swells propagating through the entrance. The usual wave period for ocean swell waves is between 8 and 15 seconds. Wave heights within Botany Bay are generally less than 0.5m with only 10% of the waves exceeding 1m and rare occurrences of up to 2m in some locations. Wave diffraction can be observed around various obstacles such as the reclamations which were undertaken within the bay. Ocean swells are energetic and influenced by changes in bathymetry such as the dredging and reclamation which took place within Botany Bay, mostly between 1948 and 1978.

Before the development at the Bay entrance, Lady Robinsons Beach was frequently damaged during storms at Brighton le Sands. Dredging of the entrance channel reduced the wave climate along Lady Robinsons Beach. However, the works increased the wave heights along the southern shore. The change of wave climate created a westward longshore current along Towra Point generating a longshore sediment drift eroding the beach. Changes in direction of the wave induced a beach rotation of Towra Beach to realign with the new wave direction.

Flooding

The major floodplain area of the Georges River catchment is the urban area located between Liverpool and East Hills, along Cabramatta and Prospect Creeks. These areas are subject to the most significant damage as they are located in low-elevated and shale-dominated landscape being more impervious than the sandstone soils. The Cabramatta and Prospect Creeks areas are of special concern because they are expected to be fully urbanised which would increase the flows by 60% for Prospect Creek and 190% for Cabramatta Creek. This would cause increases in flood flows and significantly reduce response times. Around 30% of flood prone areas are residential and industrial/commercial developments and 70% are open spaces.

The largest flood events which have occurred within the past 30 years are the 1986 and 1988 floods. These events are assessed to be around a 1 in 20 year Annual Recurrence Interval (ARI) flood. More than 1000 residential properties were flooded by the 1988 flood along the Georges River, Cabramatta and Prospect Creeks.

The major flood which occurred within the last 100 years was the 1956 flood event but this flood is still relatively small in comparison to some other floods from the previous century. The most significant flood ever recorded occurred in 1873 and was 1m higher than the estimated 100 year ARI flood, while three other large floods equalling the 100 year ARI event were recorded at the end of the 19^{th} century.

Freshwater inflows are directly linked to rainfall and urbanisation. In highly urbanised areas, there is more impervious area which results in higher runoff flowing into the river after a storm rainfall event. Natural freshwater inflow from the uppermost reaches of the river is controlled by the Liverpool Weir. Freshwater inflows in the Georges River are generally low. In the higher reaches the water becomes brackish and reaches fresh conditions at the level of the weir. Under conditions of high freshwater flows, the Georges River may be stratified for up to two weeks.

Many significant developments were undertaken over the last 20 years within the Georges River catchment, which have an impact on the flood behaviour. These developments have involved filling of large tracts of flood-prone land, large scale excavation such as with the Chipping Norton Lake Scheme, removal of homes from the floodway and sand extraction activities at Moorebank.

Floodplain management options that have been adopted within the Georges River Estuary have included:

- Voluntary purchase of affected homes
- House raising
- Flood protection works
- Retarding basins, and
- Flood warning systems.

Water Quality

Water quality describes the suitability of a particular body of water for a specific use, but it can also generally indicate the relative health of a waterway.

Some of the more fundamental processes directly affecting water quality involve material transport into and out of the system via natural water flows (freshwater and marine), anthropogenic sources and sinks, and through the atmosphere. At the local scale, this transport is governed by physical processes of mixing, and advective/dispersive transport.

In the past, the Georges River has suffered from a number of poor management practices. Up until the 1970's and 1980's, extensive dredging activities along the river and the eventual construction of the Chipping Norton Lakes have altered the hydrodynamics of the river and have subsequently increased turbidity through increased bank instability.

Land reclamation activities up until the 1970's caused the destruction of many wetlands while also using waste as fill. This has partially been responsible for the collapse of an oyster, prawn and fish industry in the Georges River due to a loss in spawning habitats and degradation of water quality caused by leachate seepage into the river. Raw sewage, which is high in nutrients, pathogens and other pollutants was being discharged directly into the river from the Glenfield sewage treatment plant in the 1960's, causing widespread issues of eutrophication and poor water quality in the upper sections of the Georges River. This legacy of uncontrolled waste dumping also expanded to industrial wastes and chemicals being discarded into the river. While some areas of the river have recovered from past pollution, many of the toxic chemicals, heavy metals and pollutants still remain in the Georges River bound to riverbed sediments.

A number of point and diffuse sources continue to significantly contribute towards the degradation of water quality in the Georges River. The highly urbanised catchment areas surrounding the main river channel continue to grow in population density, exerting more pressure on the ageing stormwater and sewerage infrastructure, increasing the pollution and sediments washed off an expanding catchment area of paved surfaces. Sewage overflows discharging into the river are becoming more frequent with less intense rainfall due to ageing infrastructure and growing demand, while stormwater from urban catchments is contributing substantially to an increasing influx of gross pollutants, heavy metals and nutrients into the river. Recreational activities like dirt biking and four wheel driving along some sections of the river's foreshores continue to contribute to water turbidity indirectly, by destabilising soil structure and destroying foreshore vegetation which increases the risk of soil loss through erosion.

Despite all the above problems, there has been a recent concerted effort to manage the Georges River catchment in a more ecologically sustainable way and this has led to some recent improvements in water quality.

Water quality is multifaceted and encompasses physical, chemical and biological factors. In our report, a number of specific parameters were adopted from the ANZECC 2000 Water Quality Guidelines to help describe and define the state of the water in more detailed, concrete and measurable terms. The following parameters for water quality have been described in detail in the main body of the report, including water quality data analysis where available:

- Water temperature
- Salinity and stratification
- Dissolved Oxygen
- Turbidity
- Nutrients
- Chlorophyll-a
- Bacteria and pathogenic contamination
- Heavy metals
- Gross pollutants.

Foreshore Erosion and Structures

Some erosion occurs with various degrees of severity in various locations all along the Georges River foreshore. In general, most erosion occurs in the areas of the river underlain by Wianamatta Shales in the upper reaches while the lower reaches are located in sandstone or are highly urbanised and protected by seawalls. The study team visited the site over several days by land and boat to assess the severity of erosion and the seawall conditions along the Georges River foreshore. Foreshore erosion and the seawall assessment are mapped in Appendix 2.

Foreshore erosion along the Georges River is generally due to factors such as boat waves, tidal undercutting, floods and stormwater runoff. Erosion was rated as being light, moderate or high/severe.

Many seawalls have been constructed along the Georges River. Most of them are located in the lower reaches and all around Chipping Norton foreshore. Seawall conditions were rated as *Good*, *Fair* or *Poor*. Details of the seawall assessment can be found in the main report and in Appendix 2.

Erosion and seawall management should generally follow the guidelines given by DECCW (2009) for environmentally friendly seawall design. Response to erosion issues depends on the severity of the erosion, the height of the embankment and the land use directly behind the eroded area. Management actions for specific areas have been suggested and are illustrated on maps of the study area.

Stormwater outlets and GPTs were assessed during site visits both by boat and by land. However, these assets are often hidden by vegetation and not easily accessible. Hence, these devices have been mostly assessed using desktop work and study of maps from diverse reports and GIS data from the different Councils. Conditions of the stormwater and GPT assets were rated as *Good, Fair* or *Poor.*

Ecology

The ecology of the Georges River Estuary describes the terrestrial and aquatic ecosystems and the interaction of these. This covers the estuarine aquatic environments of Botany Bay, up the Georges River to Liverpool Weir and also the riparian edge environments of the river up to 50m landward from the high water mark, which is influenced by and contains habitat for, the flora and fauna associated with the river.

Several forms of estuarine vegetation were found to occur within the Georges River Estuary. These include:

- Seagrass,
- Mangroves,
- Saltmarsh,
- Swamp Oak Forest, and
- Estuarine Reedland

The occurrence of each of these communities has been found to be a result of past land use and management, water quality and sedimentation and prior occurrence. Changes to these vegetation zones occur primarily when hydrological and sediment regimes (freshwater input, tidal flushing etc.) are altered.

Modelling of successional change from 1951 to 2005 was undertaken within the current study. Saltmarsh, seagrass and saltmarsh with mangrove were found to have decreased significantly in abundance within the Estuary over this time, with mangroves experiencing an increase in occurrence. This trend has also been reflected in the estuarine vegetation patch sizes, with the fragmentation of most of the estuarine communities, with the exception of mangroves.

Of these three vegetation communities, saltmarsh is the most sensitive and least competitive in the succession process. In recent decades the invasion of saltmarsh from both swamp oak and mangroves, and resulting decline in this vegetation zone has been well documented (Keith 2004). This appears to be occurring within the Georges River Estuary as a result of changes in tidal and sedimentation patterns from anthropogenic influences.

Saltmarsh and seagrass areas were found to be particularly sensitive to anthropogenic influences within the study area and therefore are considered a priority for future conservation and management actions.

Thirty riparian vegetation communities were found to occur within the areas surrounding the river. Within the study area, Sutherland Shire had the greatest amount of remnant riparian vegetation of the Local Government Areas (LGA) investigated. The condition of the riparian vegetation was predominantly of a good quality with minimal invasive plant invasion. Areas that were more prone to invasive plant invasion and other threats such as erosion, were communities located in the upstream areas on more erodible soils, near stormwater outlets, close to urban areas and where rubbish collected due to the river flow direction.

Several of the estuarine vegetation communities that were found meet the description of endangered ecological communities under the *Threatened Species Conservation Act*

1995. In addition several of the riparian vegetation communities have been mapped as endangered ecological communities (DECCW 2009) and from preliminary investigations appear to meet the descriptions. Further, a number of threatened flora and fauna species were considered likely to occur within the habitat provided by these riparian and estuarine areas within the Georges River Estuary.

The wetlands of the study area are particularly important habitat for threatened and migratory bird species. This is particularly the case with the Towra Point wetlands which are important habitat for migratory birds and are subject to international treaties.

Further investigation on the occurrence, distribution and condition of threatened species and ecological communities was highlighted as an area to incorporate into future management for the study area. The management of habitat for these ecologically significant features has also been identified as a priority for future planning.

Specific management priorities and future investigation recommendations have been included for each of the LGAs for the study area including, where available, information on specific management locations within each of the council areas.

Human Usage Recreation and Impacts

The Georges River Estuary is surrounded by a variety of land uses. These land uses influence the health of the river system in different ways, with urban and industrial uses increasing pressure on the river ecosystem and degrading estuarine health.

The dominant land use surrounding the estuary is urban, which includes a mixture of residential and commercial land use. Threats from urban areas on estuary health include invasive plant invasion, pollution from diffuse (i.e. stormwater runoff) and point sources (i.e. overflows from sewage pipes), clearing, illegal dumping, vandalism and pest species. There is also a history of oyster farming within the estuary which has left relics of processing plants and other industry-related sites which may be causing land contamination and may be impacting on the estuary.

Several strategic documents for the planning of the estuary and catchment have been prepared. These, along with local planning instruments (through LEPs) will inform the future management of the study area significantly. The incorporation of findings of this study and the subsequent future management planning for the estuary will need to be considered for future strategic planning of the wider catchment.

The Georges River and its tributaries form part of the local environment for residents. The close proximity of the estuary to housing is likely to increase contact and connection by residents, potentially forming a connection to, and interest in the river environment. The estuary is used for a range of land and water based recreational activities. Popular water sports include boating, fishing, kayaking, canoeing, sailing and swimming. Land based sports undertaken in the area include walking, cycling, 4 wheel driving, quad and dirt biking, mountain biking, shore fishing and golf. There are also a range of sporting areas, including those for tennis, bowls and soccer adjacent to the river.

There are a number of areas of public open space within the river corridor. The Georges River National Park and Towra Point Nature Reserve are also popular for bird watching, with the former offering several tracks for bushwalking and bike riding and provides access for launching of water craft and areas for shore fishing.

A number of heritage sites, both aboriginal and European, have been identified as occurring with the Georges River Estuary study area. The Georges River Estuary has a rich history with the presence of a range of Aboriginal and cultural heritage sites recognised within the study area. The current study has highlighted that there is insufficient knowledge of both Aboriginal and historic heritage within the study area, to ensure that such features are managed into the future.

Issues for Consideration in the Estuary Management Study

This report has presented a comprehensive data compilation and estuary processes study of the Georges River Estuary. It has identified several issues for consideration in the Estuary Management Study phase of the estuary management process. In particular, the investigations have identified specific locations where individual management actions could be taken to enhance the local environment. These locations have been divided up in terms of:

- Local government area
- Severity of the problem (i.e. how severe is bank erosion in specific areas? What condition are local seawalls and stormwater devices in? What is the condition of local ecological communities?)
- What are the physical processes causing local degradation? Are these natural or anthropogenic?
- What management responses are possible or practical for particular locations?

It was found that many areas within the Georges River Estuary are suffering from environmental degradation. These areas as well as specific appropriate management responses are described in Appendix 2. This report has presented a summary of the local estuarine processes and management issues required to proceed with a comprehensive Estuary Management Study of the Georges River, the next stage of the NSW Estuary Management Process.

Conclusions

Hydrodynamics and sedimentary processes have been significantly influenced by human factors within the Georges River catchment and have been subject to important changes over the last decades. Tides, wave and wind climates have been detailed as well as sediment transport. Flood mapping was provided for the study area.

Poor water quality is a significant issue within the Georges River due to the urbanisation along the river generating runoff, sewer discharges and other pollution sources. ANZECC guidelines are regularly exceeded in several areas.

Foreshore erosion, seawalls and stormwater outlets were observed, assessed, mapped and some possible solutions were provided to improve the foreshore condition. However, the river is currently stabilising and adjusting to a new equilibrium in response to the several dredging and reclamation works which occurred in the river channel – in particular the construction of the Chipping Norton Lakes. Therefore, erosion in the Georges River is likely to continue in the upper reaches and erosion problems in some areas will continue.

Anthropogenic factors have contributed to degraded health of the estuarine and riparian vegetation within the Georges River Estuary and surrounding area. Water quality and other factors such as direct disturbance, clearing, sedimentation and erosion, directly influences the occurrence and successional stages of estuarine vegetation communities by changing the tidal influence and sedimentary processes of the estuary. However, large areas of high quality estuarine vegetation occur throughout the estuary, particularly within Towra Point Nature Reserve and the Georges River National Park.

Recommendations for closing data gaps, future work and potential management options for the Georges River Estuary have been identified for the various processes operating within the study area.

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1 INTRODUCTION

This report has been commissioned by the Georges River Combined Councils Committee and documents a Data Compilation and Estuary Processes Study for the Georges River Estuary. It identifies and collates key data and reports on the Georges River Estuary, encompassing relevant physical, ecological, social and economic, and land use planning activity characteristics.

The extents of threats and pressures on estuarine and riparian vegetation have been documented and mapped. Foreshore erosion, seawall assessments for the estuary, water quality, and existing gross pollutant traps and stormwater outlets have also been mapped and documented. The report documents viable specific management actions for the parts of the estuary which are degraded and also provides priorities for protection of significant value areas.

The work presented herein has been carried out in accordance with the NSW Government Estuary Management Manual (1992), the NSW Estuary Management Policy, and the NSW Sea Level Rise Policy Statement.

1.1 Background

The Georges River Combined Councils Committee (GRCCC), consisting of nine local councils within the Georges River catchment area, has recently established a sub-committee, the Georges River Estuary Management Committee, to formulate an Estuary Management Plan for the entire Georges River estuary. The Estuary Management Plan is to be undertaken in accordance with the NSW Government's Estuary Management Manual under the NSW Estuary Management Policy.

The primary goal of the policy is to achieve the integrated, balanced, responsible and ecologically sustainable use of the State's estuaries. The objectives of the policy are to protect and restore estuarine habitats and ecosystems, and to prepare and implement a balanced, long-term management plan for the sustainable use and ecological improvement of estuaries.

1.1.1 The NSW Estuary Management Process

The Estuary Management Process is described in the State Government's Estuary Management Manual (1992) and consists of seven steps illustrated in Figure 1.1.

For Georges River, the Estuary Management Process has begun and the GRCCC has formed an Estuary Management Committee. The NSW Estuary Management Process is shown in Figure 1.1.

The purpose of this project is to prepare a Data Compilation and Processes Study, which incorporates Stage 2 and 3 of the Estuary Management Process. The first stage in this two-staged study includes assembling, compiling and interpreting existing data, which provides a basis for assessing the type and scope of data that may need to be collected in future studies and programs. This study reviews the data and qualitatively assesses the relevance of this data for the production of an Estuary Process Study for both the lower and upper reaches of the estuary (upstream and downstream of Salt Pan Creek).

The Georges River estuary is subject to a variety of pressures that may threaten its existing economic, social and environmental values, and the development of an estuary management plan for the Georges River Estuary is seen as a positive approach to addressing these issues.

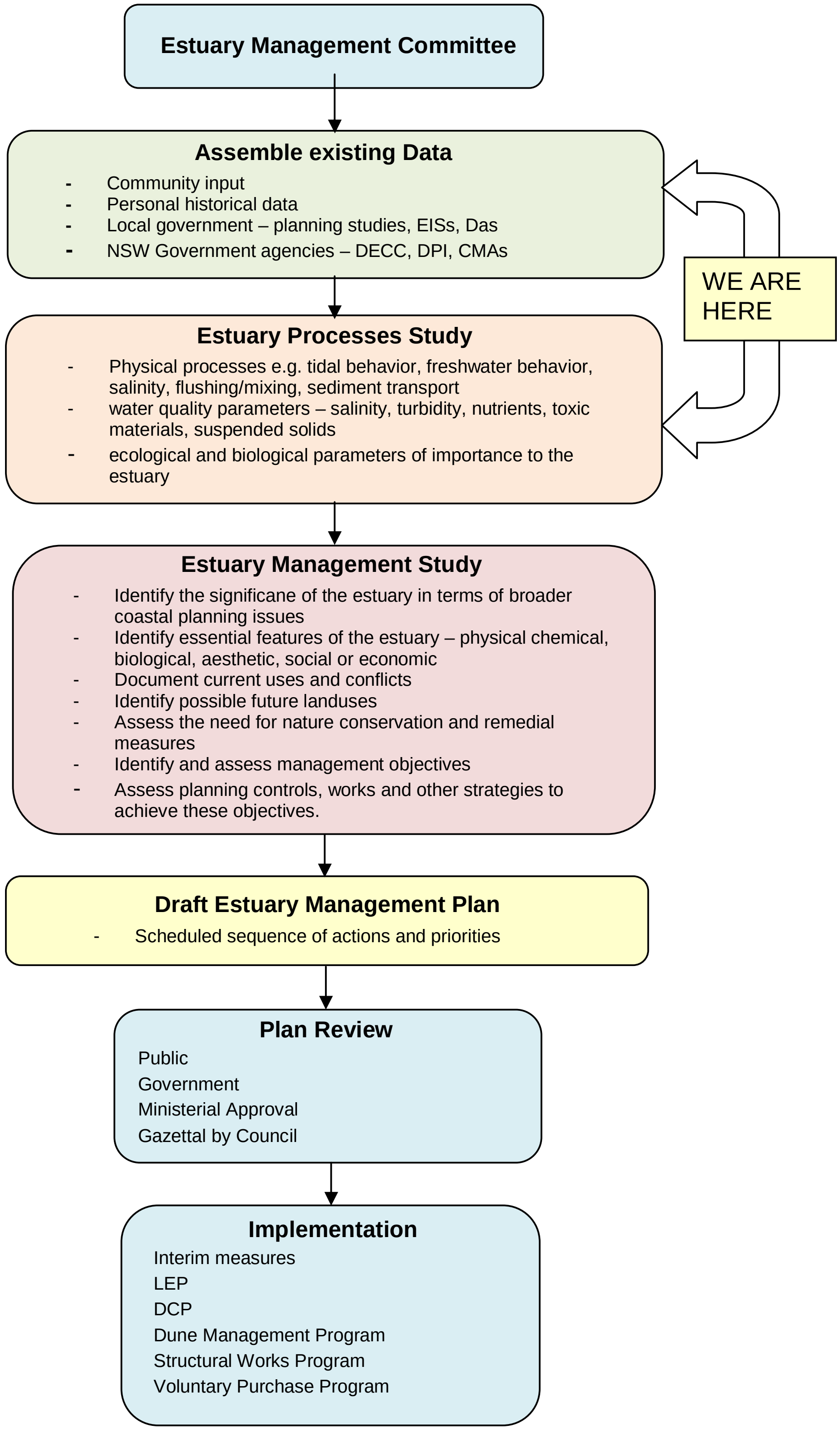

Figure 1.1 – The NSW Estuary Management Process (NSW Government, 1992)

1.2 Study Area

The Georges River Estuary is a significant estuary in size and population with over four million people living within the catchment. It stretches approximately 50 km inland from Botany Bay. Its catchment area incorporates the upper reaches, which includes the area from Liverpool Weir to Salt Pan Creek, and the lower reaches, extending from Salt Pan Creek to Botany Bay. The land surrounding the estuary has been highly modified with heavy urbanisation supporting a range of commercial, industrial and residential landuse, with many developments extending up to the foreshores. As such, this area has become a major source of pollution with metals, oils, grease, toxic organic compounds and high levels of nutrients entering the estuary from stormwater runoff. This has reduced water quality to such an extent that commercial fishing within the lower reaches has been banned and an oyster industry has collapsed from disease infestation. This is particularly significant given the international importance of the estuarine wetlands within the lower reaches of the estuary, in particular Towra Point Wetlands, which is an internationally recognised Ramsar site.

The Georges River extends from its mouth at Botany Bay to the tidal limit at Liverpool Weir, and its catchment area covers a significant portion of the Sydney Metropolitan area. The extent of the study area is shown in Figure 1.2.

Major estuarine tributaries include:

- Prospect Creek
- Williams Creek
- Tudera Creek
- Salt Pan Creek
- Little Salt Pan Creek
- Boggywell Creek
- Woronora River
- Forbes Creek

The project study area includes all the tributaries and Scarborough Ponds that drains into Botany Bay through Lady Robinsons Beach, but does not include the Woronora River (as it is the subject of a separate Estuary Management Plan). It also includes the western foreshore of Botany Bay (Lady Robinsons Beach) and Towra Point.

DATE	08/12/2009	COORDINATE SYSTEM	GDA 94 Zone 56
FIG NO.	1.2	FIGURE TITLE	Extent of the Study Area
PROJECT NO.	3001765	PROJECT TITLE	Georges River Data Compilation and Estuary Processes Study
CREATED BY	M.GLATZ	LOCATION	I:\projects\3001765 - Georges River Estuary Process Study\009DATA\GIS\Mapinfo Workspaces

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The Estuary Management Process has begun in some of the Georges River's estuarine tributaries, been completed in some, but has not commenced in others. Bankstown Council has completed Estuary Management Plans for Little Salt Pan Creek and Kelso Creek. Kogarah Council has completed the Kogarah Bay and Oatley Bay Management Plan.

In addition, the GRCCC have recently finalised a Management and Implementation Plan for the Georges River. Other work has been completed for the Botany Bay Coastal Catchments Initiative, which also includes information relevant to the Data Compilation and Processes Study.

The Georges River Estuary has been assessed as being in an extensively modified condition, under the Australia-wide National Land and Water Resources Audit (2002). Management issues within the Georges River Estuary include:

- Stormwater pollution from rural and urban runoff, including roads, sewer overflows, land and sediment contamination;

- Contaminants in bottom sediments resulting in commercial fishing bans in the estuary's lower reaches (ANZECC ISQG high level exceeded for lead, copper and zinc);

- Modified river flows due to increased runoff from impervious areas, the influence of Woronora Dam, removal of upland swamps, groundwater extraction and past dredging.

1.3 Scope of this Report

This report documents a combined Data Compilation and Estuary Processes Study for the Georges River Estuary. It identifies and collates all key data and reports that may exist on the Georges River estuary, encompassing the relevant principal physical, ecological, social and economic, and land use planning activity characteristics – some information that is generally applicable to relevant estuarine environments or management has also be included.

The report also maps the extents of and documents threats and pressures on estuarine and riparian vegetation, foreshore erosion, documents seawall assessments for the estuary, documents water quality, and documents existing gross pollutant traps and stormwater outlets in the study area.

It also documents viable specific management actions for the parts of the estuary which are degraded.

The work presented herein has been carried out in accordance with the NSW Government Estuary Management Manual (1992), the NSW Estuary Management Policy, and the NSW Sea Level Rise Policy.

Data and information for this study has been obtained from the following agencies and Councils:

- DECCW – Parramatta and Wollongong offices, and Goulburn Street and Hurstville libraries

- NSW Maritime (provided the vessel used for the project fieldwork)

- Sydney Metro CMA
- Industry and Investment NSW (I&I NSW)
- Rockdale Council
- Kogarah Council
- Hurstville Council
- Bankstown Council
- Sutherland Shire Council
- Liverpool Council
- Fairfield Council

2 ESTUARY AND CATCHMENT CHARACTERISTICS

The Georges River estuary is classified as a drowned river valley estuary characterised by channels which deepen and widen in the seawards direction.

In this section of the report, a basic conceptual model of the estuary and a diagrammatic representation of the evolutionary stages of a drowned river valley estuary are presented.

Physical characteristics of the study area are described, including:

- Climate;
- Bathymetry and topography; and
- Geology and soils.

2.1 Estuary Classification and Basic Description

The Georges River estuary is classified as a drowned river valley estuary (Estuary Management Manual, 1992). A conceptual model of a drowned river valley estuary is provided in Figure 2.1. This kind of estuary is recognisable by a wide bedrock-flanked mouth, the presence of submerged tidal delta such as Botany Bay and the absence of a sub-aerial sand barrier at its entrance. The upper catchment sediments have reclaimed the upper reaches to form extensive floodplains with tidal river channels (for example, from Picnic Point upstream). From this point downstream, the basic form of the original drowned river valley remains as a steep sided and deep muddy basin, which deepens and widens in the seawards direction. The size and depth of the relict drowned valley is dependent upon the dimensions of the parent valley and the relative sediment supply from the upper catchment. The typical evolution of such an estuary is illustrated in Figure 2.2.

Georges River is a drowned river valley estuary in the younger stages of evolution, characterised by channels which deepen and widen in the seawards direction. The landward narrowing of the channel promotes tidal amplification through the concentration of flows. As the channel shallows, tidal resonance also helps to maintain a high tidal range. Drowned river valley estuaries display no initial attenuation but often exhibit amplification of the ocean tidal range. In such estuaries, the tidal range is only attenuated in the upstream reaches where the cumulative dissipative effects of bed friction dampen tidal flows.

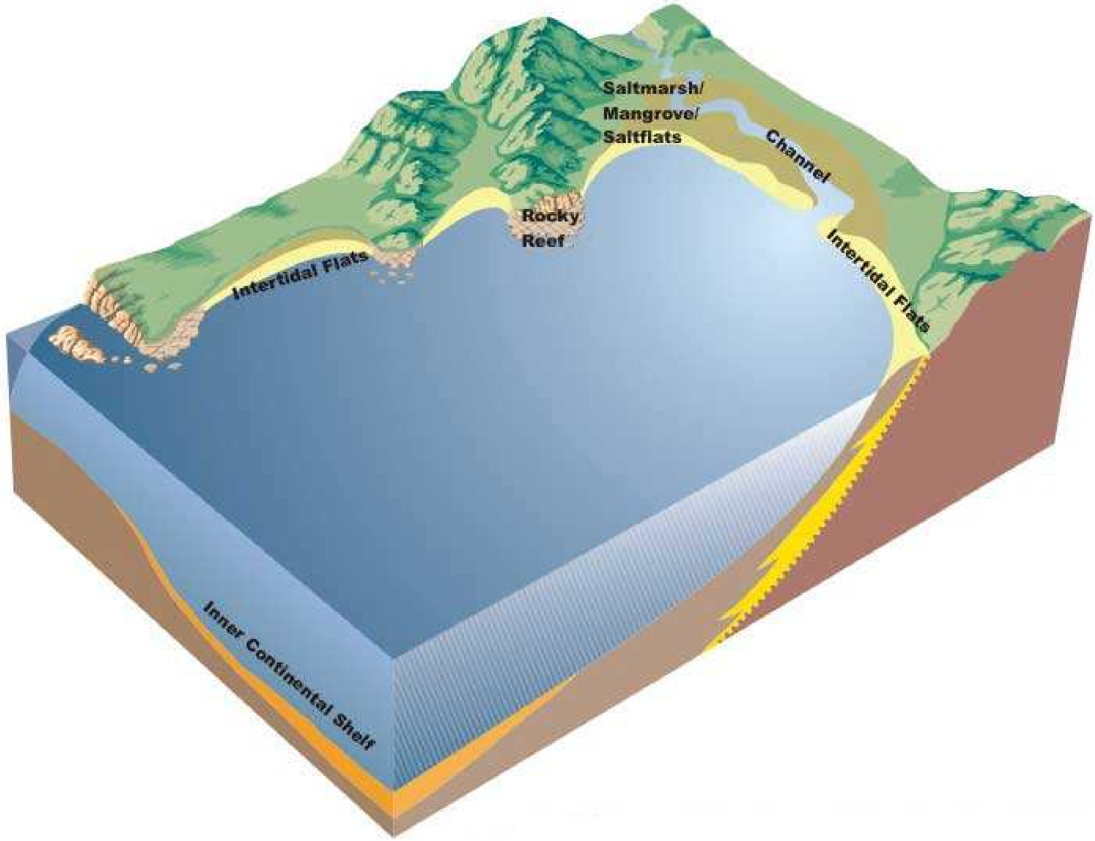


Figure 2.1 – Conceptual model of sediment transport within a drowned river valley (adapted from Ozcoast and OzEstuaries, www.ozcoasts.org.au)

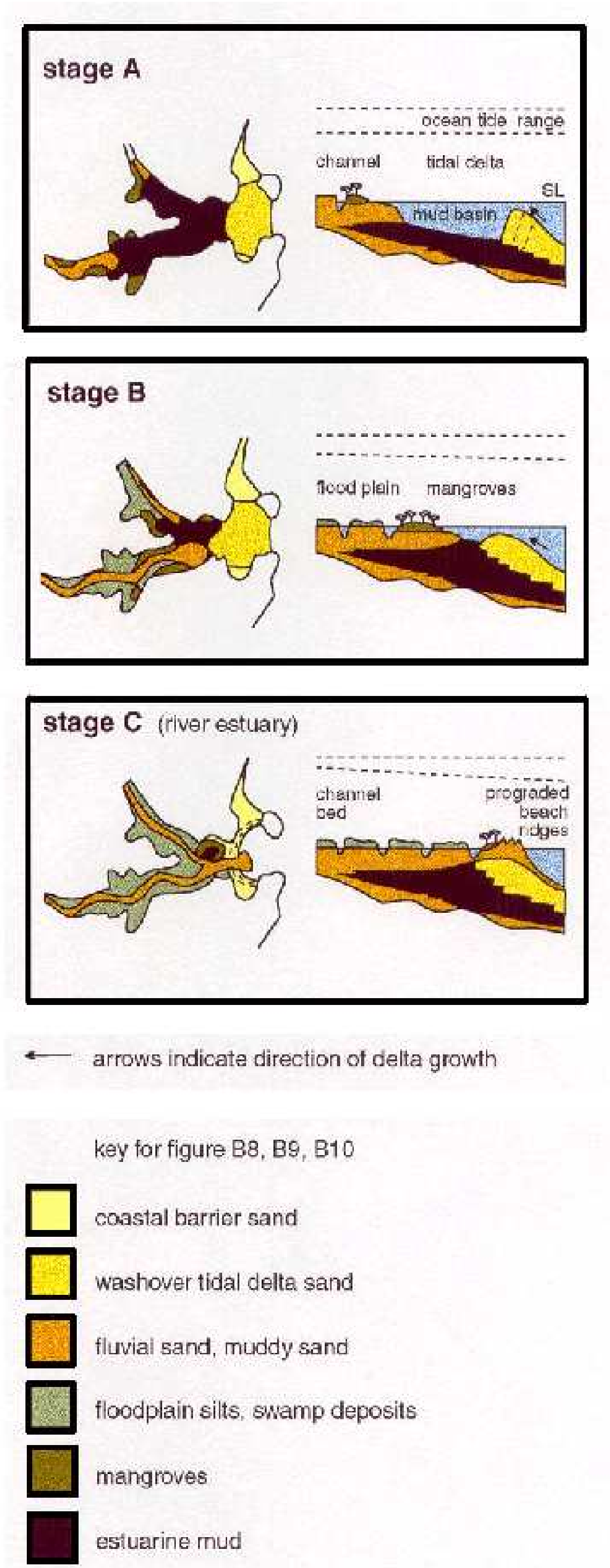


Figure 2.2 –Typical evolution of a drowned river valley estuary (Estuary Management Manual, 1992)

2.2 Climate

The study area is subject to a temperate climate influenced by the Pacific Ocean up to the lower reaches of the Georges River. The winters are relatively warm, but not as hot as the summer season. These climates rarely see frost or snow. The summers are warm and there is no dry season.

A summary of the average monthly minimum and maximum temperature, monthly rainfall and number of rainy day and the monthly 9am and 3pm wind speed is shown in Table 2.1. The data is sourced from the Bureau of Meteorology weather station located at Sydney Airport.

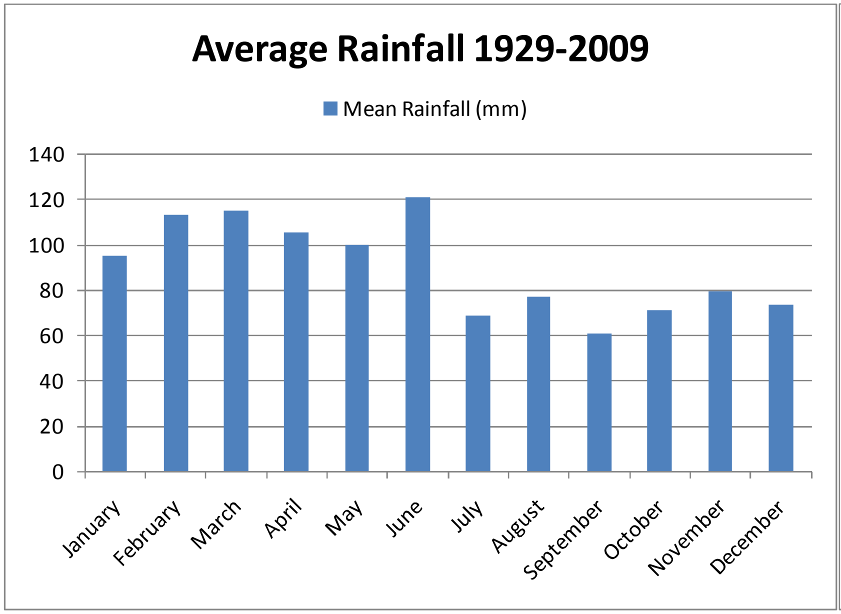
Mean monthly rainfall from the data of the Bureau of Meteorology measured at Sydney Airport between September 1929 and November 2009 are illustrated in Figure 2.3. The annual average rainfall is 1085.2mm.

Temperature data have been available since April 1939. Mean summer and winter temperature in the lower reaches ranges from 17-27°C and from 5-17℃ respectively. Daily maximum temperatures exceed 30℃ on around 22 days per year and the minimum temperature rarely drops below 2℃. Extreme tempera tures recorded are 45.2℃ and -0.1℃. Monthly minimum and maximum temperature are illustrated in Figure 2.3. In the upper reaches, the maritime influence diminishes and the temperature can be 2-4℃ more or less than in the lower reaches, with more frequent winter frosts.

During summer, dominant wind directions are north-east and east while during winter, they are west and south. Some local land winds generate the westerly winter wind and influence the temperature at night while the southerly winds are generated by low-pressure systems further south and are often generated by cold fronts. Seasonal wind roses showing the average wind speeds and directions at 9am and 3pm at Sydney Airport have been provided in Figure 2.4 and 2.5. Data available for the determination of the wind roses are from 1939 to 2004.

Table 2.1 – Climate Summary for Sydney Airport

Rainfall (1929-2009)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean Rainfall (mm)	95.3	113.3	115.4	105.6	100.0	120.9	68.9	77.4	61.2	71.4	79.8	73.6	**1085.2**
Mean number of days of rain ≥ 1 mm	8.1	8.6	9.2	8.3	8.6	8.7	6.6	6.9	6.8	7.8	8.3	7.8	**95.7**
Temperature (1939-2009)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean maximum temperature (°C)	26.4	26.3	25.2	22.9	20.0	17.6	17.0	18.3	20.5	22.5	24.0	25.7	**22.2**
Mean minimum temperature (°C)	18.7	19.0	17.4	14.1	10.9	8.5	7.1	8.1	10.3	13.1	15.3	17.4	**13.3**
Wind speed (1939-2009)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean 9am wind speed (km/h)	14.4	13.7	12.8	12.9	12.5	13.3	13.2	14.3	15.4	16.3	16.0	14.7	**14.1**
Mean 3pm wind speed (km/h)	24.1	22.9	20.9	19.3	17.0	17.7	18.1	20.7	23.1	24.6	25.3	25.1	**21.6**



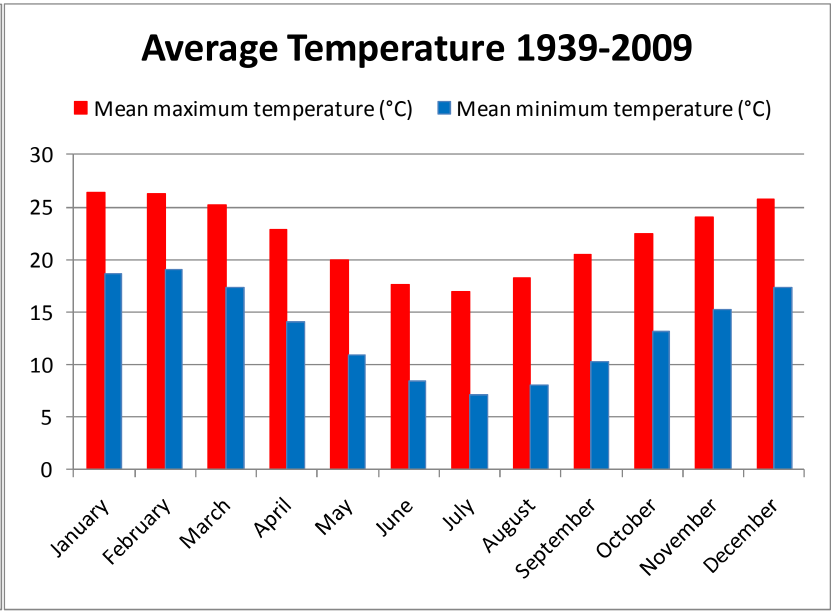


Figure 2.3 – Monthly rainfall and monthly temperature at Sydney Airport

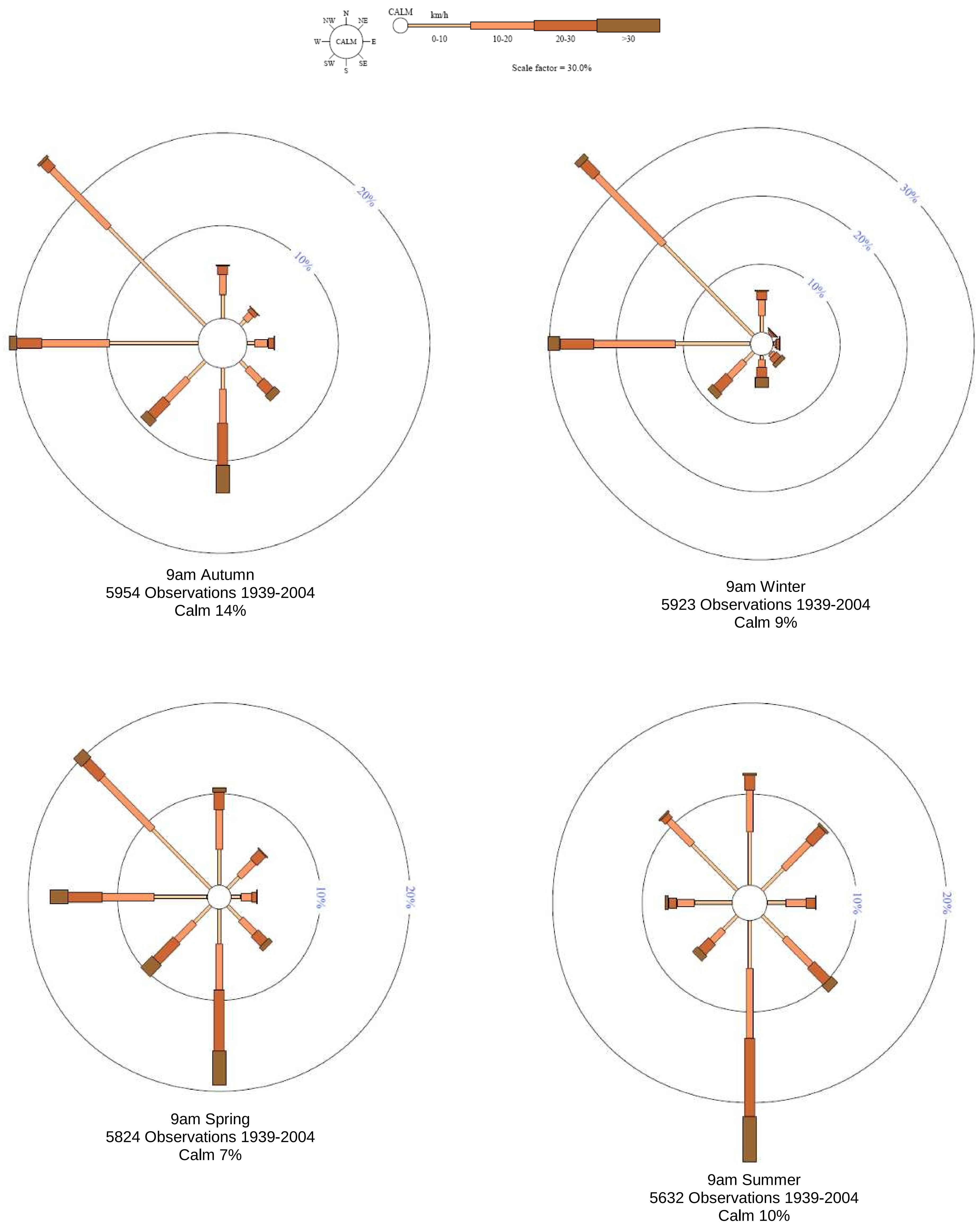
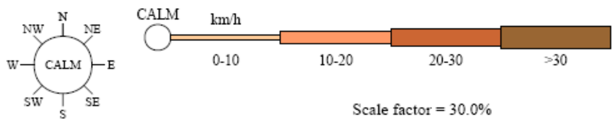
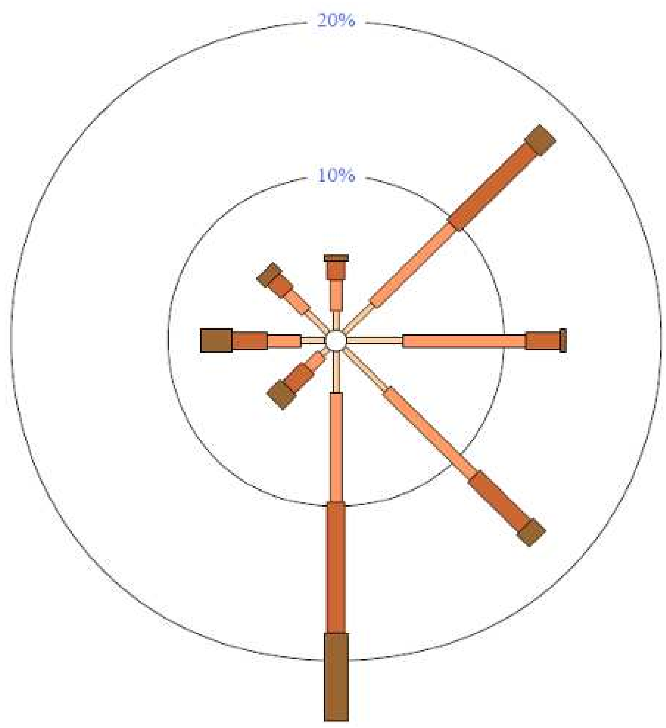
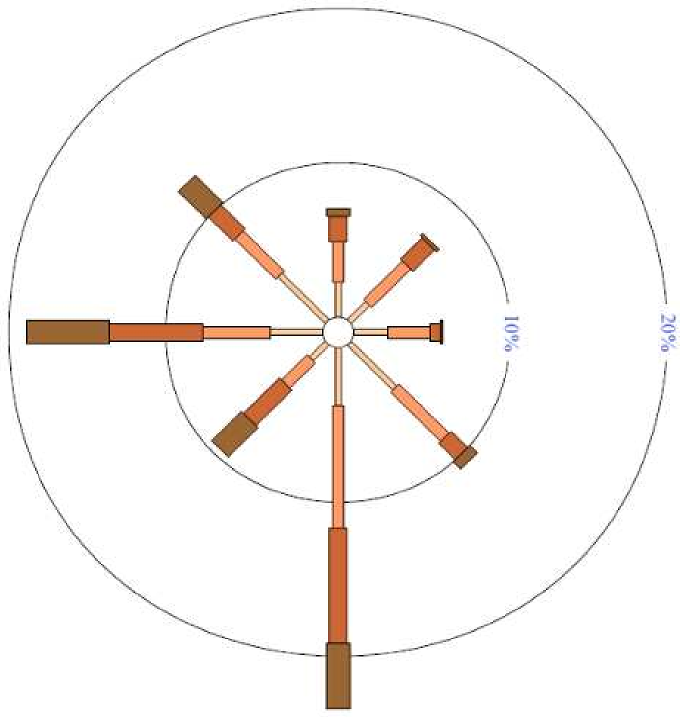


Figure 2.4 – Wind roses at Sydney Airport at 9am for each season (Bureau of Meteorology)

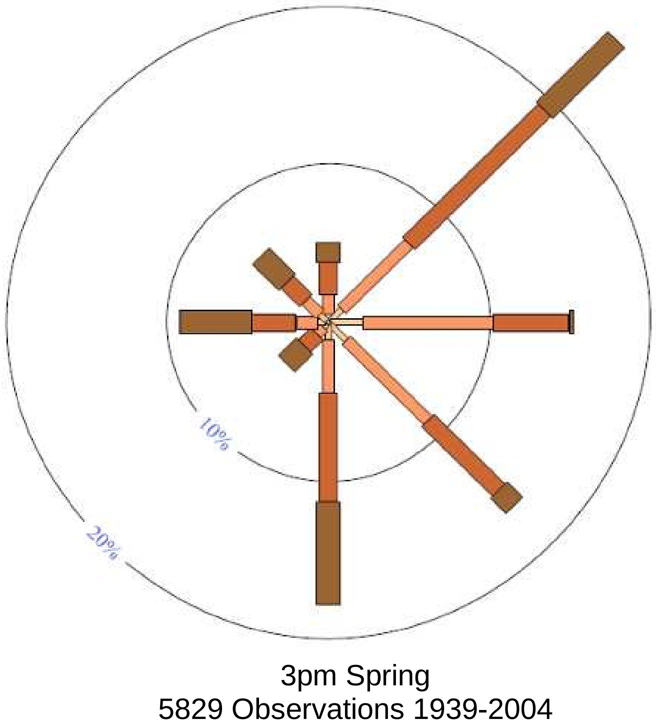




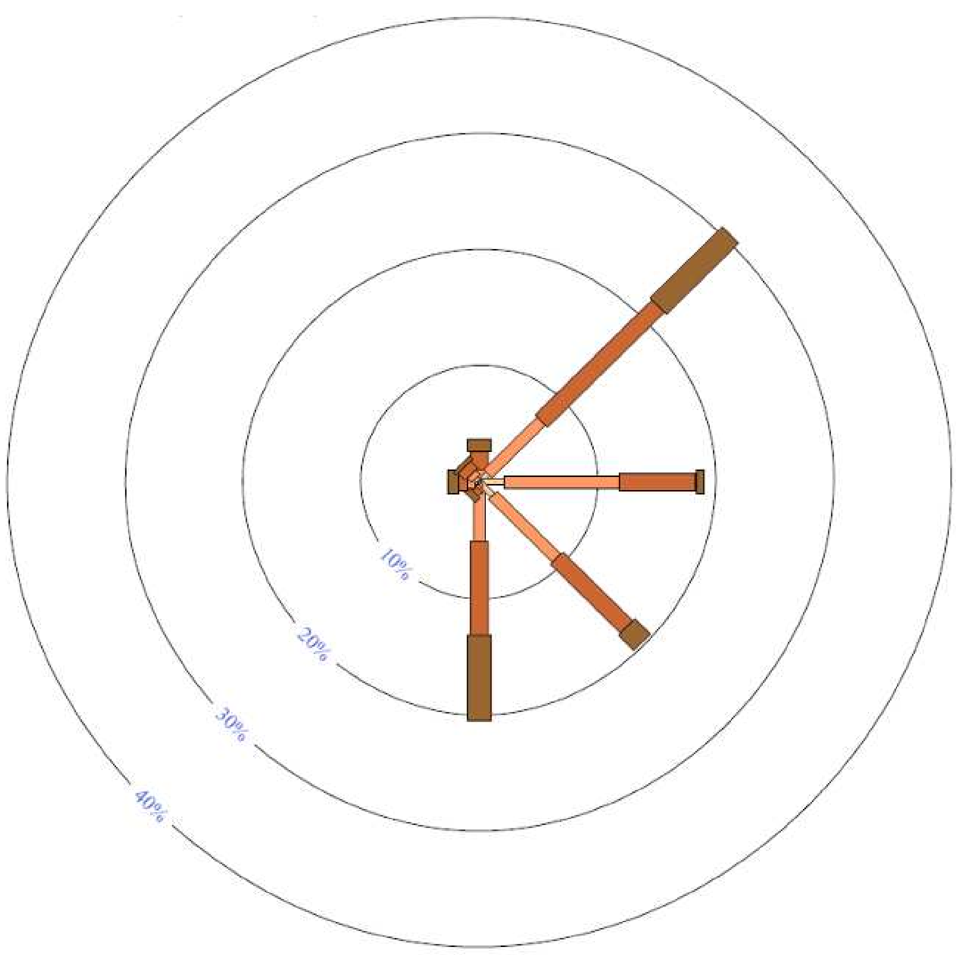
3pm Autumn
5654 Observations 1939-2004
Calm 14%



3pm Winter
5953 Observations 1939-2004
Calm 5%



3pm Spring
5829 Observations 1939-2004
Calm 1%



3pm Summer
5656 Observations 1939-2004
Calm 1%

Figure 2.5 – Wind roses at Sydney Airport at 3pm for each season (Bureau of Meteorology)

2.3 Bathymetry/ Topography

A map of the bathymetry and topography in the Georges River catchment created using 25m-grid data is provided on Figure 2.6. (Data from Brian Sanderson's website http://www.zonediet.com.au/bathymetry/BOTANY_GEORGES/Botany_Georges.html)

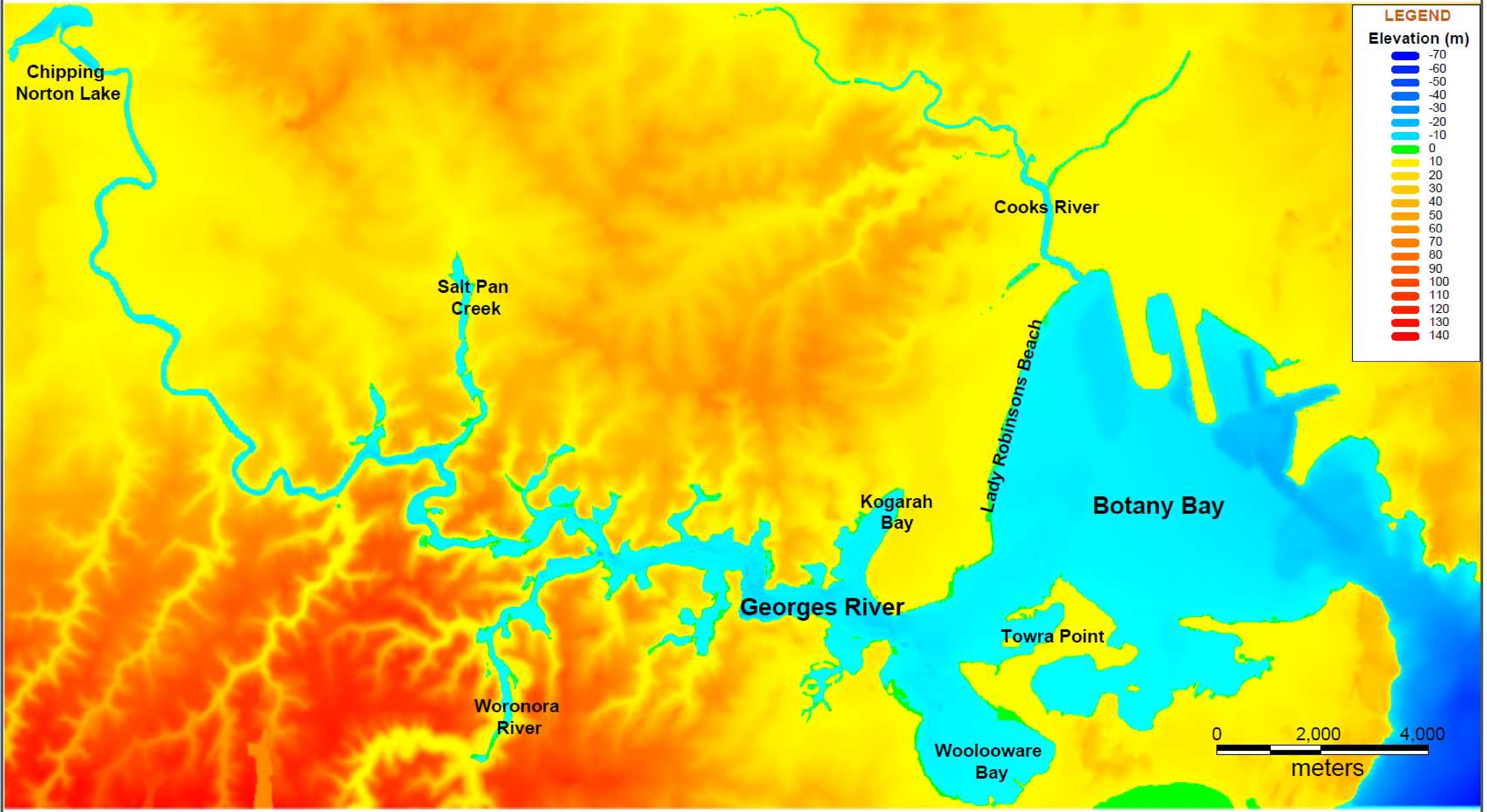
Many changes in the bathymetry occurred since the first sounding of the Bay undertaken by Captain Cook in 1770. In particular, it is to be noted that several reclamation and dredging works occurred in the second half of the 20th century (see section 3.3).

Botany Bay is a roughly circular depression reaching a diameter of 8km. The entrance of the bay is around 1km wide. The maximum depth in Botany Bay reaches 18m (from the Indian Spring Low Water datum) in its natural state but is now around 21m, due to the entrance channel dredging carried out in the 1970s. The average depth in the bay is about 4.5m and around 4m along the Georges River.

The topography is directly linked to the geology of the particular area. The study area elevation is comprised between sea level at Botany Bay and approximately 75m in the west. Some gently undulating hills, narrow steep-sided valleys and gorges, broad valleys with floodplains or high exposed ridges with broad flat tops are noticeable along the Georges River. The Wianamatta shale geology in the upper reaches has influenced the gentle undulating slopes, low flat plains and broad valleys while the Hawkesbury sandstone has generated the dissected plateau west of the Illawarra Escarpment, narrow steep-sided sandstone valleys or gorges, high-exposed flat and broad ridges and moist gullies.

The source of the Georges River is located above the Illawarra Escarpment around 3km south-east of Appin at an elevation of about 350m and flows towards north up to Liverpool, then flows south-east at Chipping Norton and then in an easterly direction between Picnic Point and Botany Bay. The total length of the River is around 100km and the study area includes the tidal section of the river between Liverpool Weir and Botany Bay which has a length of around 46km.

Within the past 6000 years, the Georges River ebb delta has migrated several times leaving relict channels and levees. Amongst these abandoned levees and spit is the Towra Peninsula which was further eroded and transformed by waves. Woolooware, Weeney and Quibrays bays are other relict channels which have been partially filled over time.



DATE 08/12/2009	**COORDINATE SYSTEM** GDA 94 Zone 56	**FIG NO.** 2.6	**FIGURE TITLE** Topography and Bathymetry of the Georges River
PROJECT NO. 3001765	**PROJECT TITLE** Georges River Data Compilation and Estuary Processes Study	**CREATED BY** M. Glatz	**LOCATION** I:\projects\3001765 - Georges River Estuary Process Study\009DATA\GIS\Mapinfo Workspaces

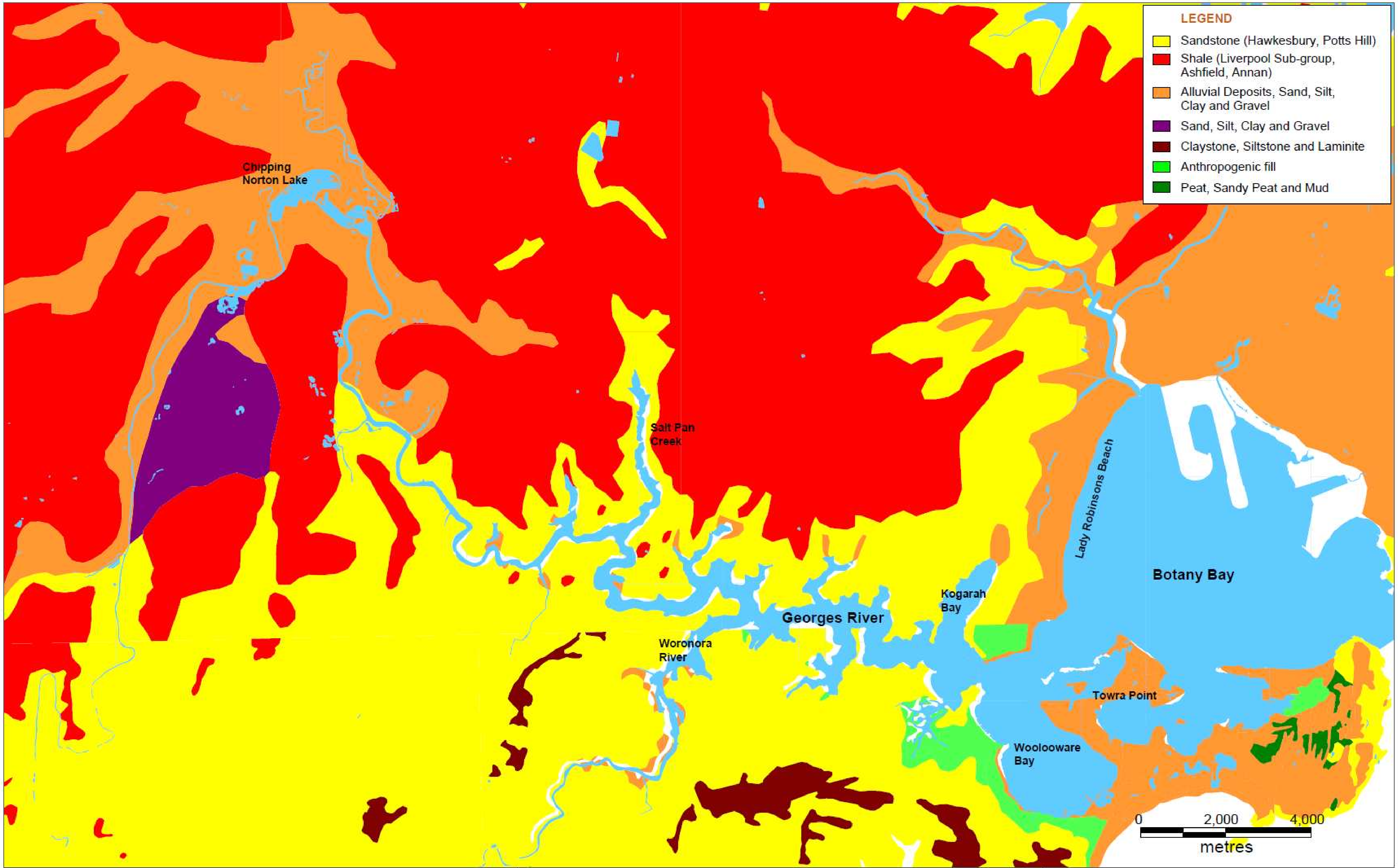
2.4 Geology and Soils

The Sydney Basin comprises Permian and Triassic sediments which overlay and are circled by Palaeozoic rocks. The most recent sediments are Wianamatta Shales, followed by Hawkesbury Sandstones while the deepest are the Narrabeen siltstones and sandstones and hence these ones form the deepest layer. Quaternary sediments are present as alluvium along the River and the main creeks.

The soils in the northern half of the study area – i.e. derived from the Wianamatta Shales – have a high potential for erosion (SPCC, 1978). Sheet and gully erosion is often visible in shale-based areas. These soils have a high water retaining capacity but can be very dispersible, making the water turbid. These soils are at the origin of most siltation in the lower reaches of the Georges River.

Some skeletal stony sandy soils are found in the sandstone based areas. They are permeable and more porous than the Wianamatta shales and not dispersible. These soils are prone to water and wind erosion when the vegetation protecting them is disturbed.

A map of the geology and soils of the Georges River catchment is provided on Figure 2.7.



DATE	08/12/2009	COORDINATE SYSTEM	GDA 94 Zone 56	FIG NO.	2.7	FIGURE TITLE	Geology and Soils in the Georges River Catchment
PROJECT NO.	3001765	PROJECT TITLE	Georges River Data Compilation and Estuary Processes Study	CREATED BY	M.GLATZ	LOCATION	I:\projects\3001765 - Georges River Estuary Process Study\009DATA\GIS\Mapinfo Workspaces

3 SEDIMENTARY PROCESSES

During the last century, sedimentary processes changed considerably in the Georges River catchment area. These changes were influenced both by natural factors (e.g. natural variations in flood gradients and river flows, wind waves) and anthropogenic factors (e.g. dredging, reclamation, boat waves). The significant urbanisation increasing along the river had an important impact on the sediment processes due to increased urban runoff and vegetation removal. Development along the Georges River changed the hydraulic character of the river, increasing erosion in the upper reaches and deposition in the lower reaches, making the latter siltier. Dredging and reclamation works also significantly impacted the river behaviour and hence the sedimentary processes.

This section studies the sediment quality and behaviour, erosion, accretion and their causes and consequences, changes in sediment processes either natural or human-related and the reclamation/dredging works which occurred within the Georges River Catchment.

3.1 Sediments in the Georges River catchment

The majority of the Georges River foreshores in the study area consist of Quaternary deposits – predominantly mid Holocene to mid Pliocene deposits of medium grained clay and silt (Department of Commerce, 2003). The Georges River Estuary can be split into three regions of bed sediments (WRL, 1967). These are:

- the main channel reach above Como Bridge which is mainly sandy
- the main channel reach below Como Bridge which is predominantly composed of clay and silt
- the large off-channel bay areas in the lower estuary where the major sediments are flocculent silts and clays

Overall longitudinal downstream fining of sand bed sediments illustrates a strong fluvial regime upstream of East Hills. Some occasional surface fine sediments are found at river bends (PBP, 1996).

There is a veneer of fine surface sediment overlaying medium to coarse sands between Liverpool Weir and Lake Moore. This thin layer of fine sediment indicates a low tidal influence (low flow and low tidal velocities). The Warwick Farm reach is composed of medium to coarse sands. Chipping Norton Lake comprises medium to coarse sand where no sand extraction occurred and bed sediments within the ponds themselves are predominantly mud with a fine-grained sand fraction reflecting the extensive widening and deepening of the channel. Between Prospect Creek and Milperra Bridge there are medium to fine sands with a low mud fraction showing a tidal influence (PBP, 1996). From Milperra Bridge to Kelso Park, the grain size distribution varies between sands and muds. Between Kelso Park and East Hills, there typically are medium grained sediments with small mud fractions and a high degree of sorting which indicates sediment mobility under the action of tidal flows.

Some previous studies (SPCC, 1978) measured detailed sediment compositions in different locations within the Georges River catchment. For example, Woolooware Bay sediments are uniformly very silty (50-70% silt-clay). Quibray and Weeney Bays are mainly sandy with some large silty pockets. The area between Captain Cooks Bridge and Dolls Point is also silty with substantial amount of shell debris in some areas. The area between Como Bridge and Alfords Point has 50-70% silt-clay content while Woronora River has around 45% silt-clay content. The sediments in the Lower Georges River are mainly silts and silty sands (60-90% silt-clay).

3.2 Sediment Transport

A dominant flood tide sediment transport rate has been observed in the Georges River and in particular at Milperra while the ebb transport was not significant (estimated annual sediment transport at Milperra in 1977-79 of 500 m^3/yr for the flood tide versus 50 m^3/yr for the ebb tide). The same observation has been made directly upstream of Heron Park site and at East Hills with rates of 2500 m^3/yr versus 1000 m^3/yr (PBP, 1996).

In Botany Bay, ocean swell has moved sand in the direction of wave propagation across the bay, creating Lady Robinsons Beach. Breaking waves create longshore currents which generate strong accretion at Dolls Point, westward sediment transport along Towra Point and a northward migration of sand along Lady Robinsons Beach (see Figure 3.1).

3.3 Sediment Quality/ Contamination

The Georges River estuary serves the intensively urbanised and industrialised city core and is important for boating and maritime activities. It has been a major repository for urban and industrial waste and is heavily impacted by anthropogenic metalliferous loadings (e.g. copper, zinc, nickel, lead). Decrease in tidal flushing due to reclaimed areas and extensive urban discharge result in high values in the upper reaches of the river but additional excessive loadings from industrial and shipping activities probably accounts for most of the metal values in bay ends. Point sources (e.g. waste dumps, sewage overflows, and discharge from a polluted river) elevated sediment heavy-metal concentrations up to 50 times above background in Georges River estuary (Birch *et al.* 1996). Significant concentration of chromium, strontium, yttrium, nickel, copper and arsenic have been measured at the Georges River mouth as illustrated in Figure 3.2 (BBCCI, 2008). Concentrations of heavy metals were also measured in the Scarborough Ponds and high concentrations of zinc, arsenic and lead were observed (see Figure 3.3).

Salt Pan Creek also exhibits high zinc and lead concentrations related to a waste dump at the head of the Creek and to sewage overflow which is activated at times of flooding (Birch, 1993).

The majority of estuarine areas have sediment heavy metal concentrations which are greatly in excess of background values with most elevated regions located at the upper reaches and bay ends, with the lower reaches and mouth areas approaching background values.

Polycyclic Aromatic Hydrocarbons (PAH) concentrations in sediments have been studied in the Georges River and are very high in comparison to other Australian estuaries. PAH concentration is correlated with silt and clay concentration as well as flocculation. Main source of PAH are combustion products from road-runoff, stormwater drains, sewage, marinas and other boating activities or air particles (Brown & Maher, 1992).

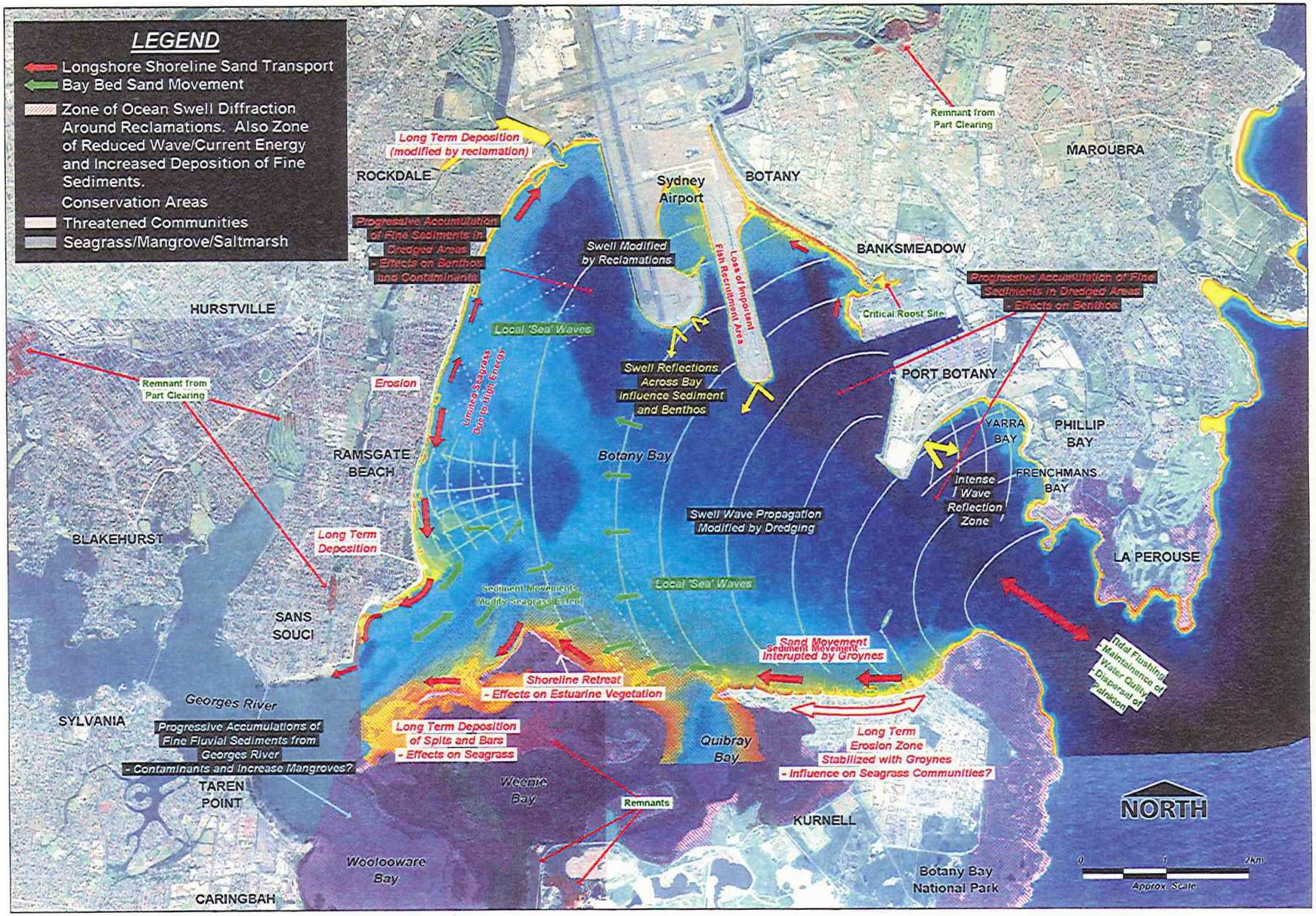


Figure 3.1 – Botany Bay sediment transport (WBM, 2003)

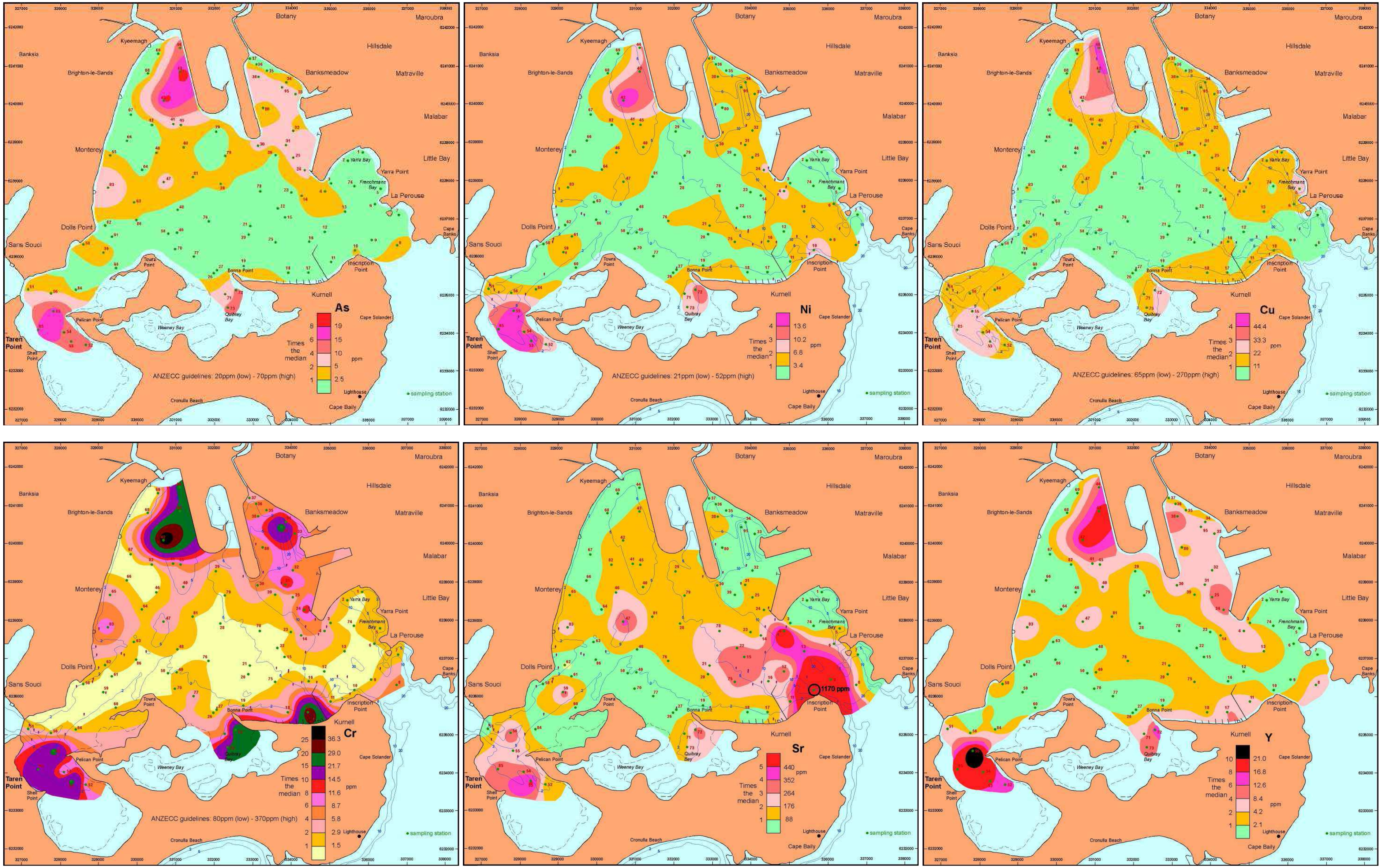


Figure 3.2 – Elevated heavy metal concentrations in Botany Bay (BBCCI, 2008)

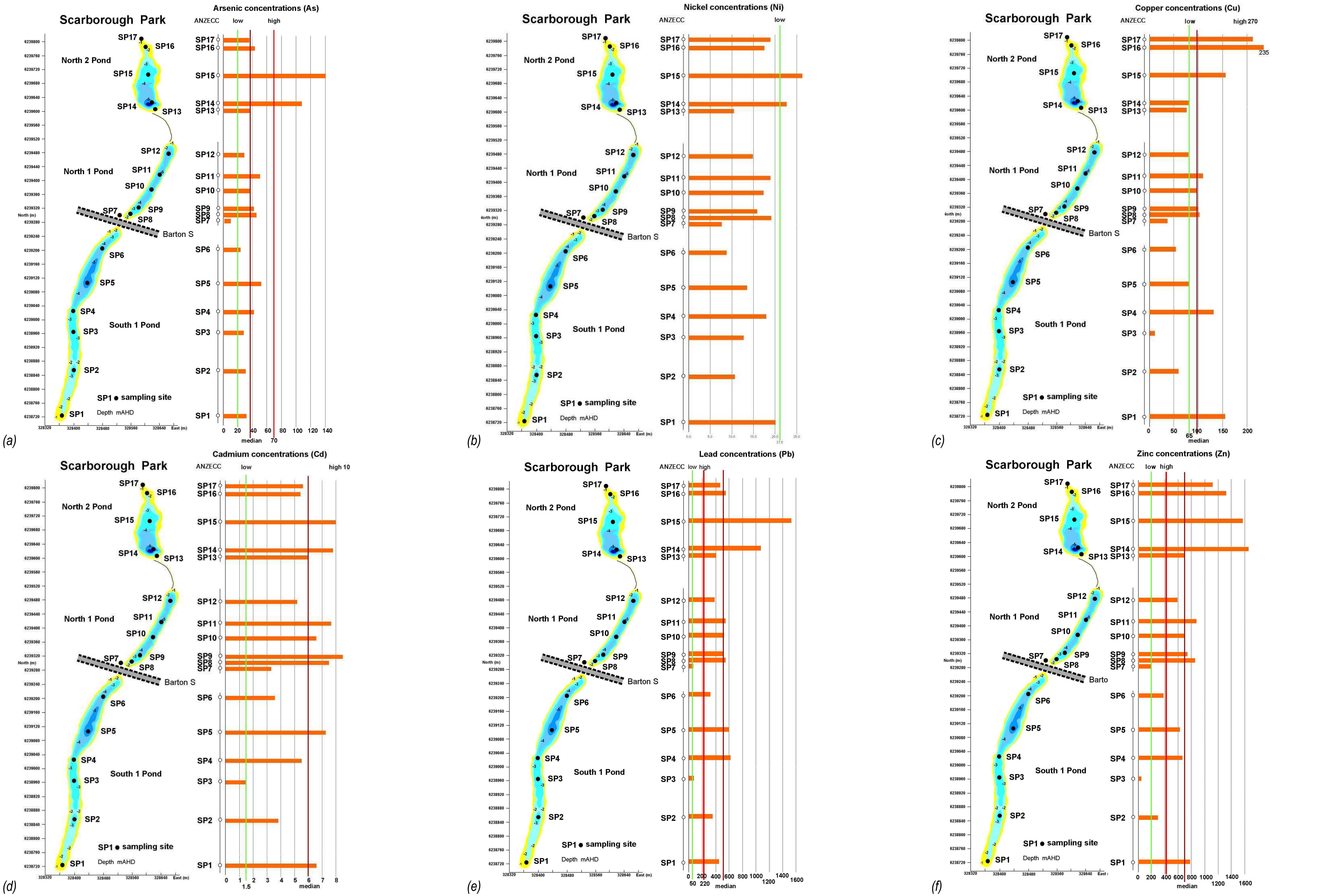

Scarborough Park
Arsenic concentrations (As)
Nickel concentrations (Ni)
Copper concentrations (Cu)
Cadmium concentrations (Cd)
Lead concentrations (Pb)
Zinc concentrations (Zn)
North 2 Pond
North 1 Pond
South 1 Pond
Barton S
SP1 ● sampling site
Depth mAHD
ANZECC
low
high
median
(a)
(b)
(c)
(d)
(e)
(f)

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Figure 3.3 –Concentrations of Arsenic (a), Nickel (b), Copper (c), Cadmium (d), Lead (e) and Zinc (f) in the Scarborough Ponds (BBCCI, 2008)

3.4 Dredging/ Reclamation

Many dredging works occurred in Botany Bay between 1948 and 1978 (SPCC, 1979) and all along the Georges River. Dredging has exacerbated erosion of river banks by steepening the sub-water-surface bank profile – hence making the riverbanks unstable. Dredging can also lead to decreased flow velocities in the River, which promotes accelerated sediment deposition.

The major dredging occurring in the Georges River Catchment was at Moorebank and Chipping Norton Lakes. Chipping Norton Lakes were originally the result of illegal dredging and unregulated extraction activities between the 1950s and 1977. The average removal depth was 9.5m and 7.5m for the north and south pond of the lake respectively, representing a total volume of 2.5 million cubic metres. The increased tidal flow due to the creation of Lakes allowed minor tidal reworking of bed sediments in the upper estuary and a flood tide bed sediment movement was generated from East Hills to Chipping Norton where pre-lake conditions did not allow mobilisation of sediments under tidal flow. This sediment transport intensity was based on bed form analysis and was predicted to reduce with distance upstream. In post-lake conditions the fluvial sediment transport has increased immediately upstream of Chipping Norton Lake, is nil through the lake and similar to pre-lake conditions downstream of the lake. Construction of the Lake has changed the balance between potential bed-scour, in-stream sediment transport capacity and natural sediment load over the full range of floods. As the sediments are held by the lake, sediment supply in downstream areas would be compensated by river bed and bank erosion or by the flood tides moving sediment back upstream.

Upstream of Salt Pan Creek, construction sand was extracted. Deep areas around Riverland Golf Course were dredged prior to 1980 and have not yet recovered. Deep areas between the Lake outlets near Wildlife Island have been created by sand extraction operations. Deep areas around Milperra Bridge and the River bend as well as the ones upstream of Chipping Norton Lakes to Liverpool Weir are likely to erode due to flood scour. Dredging too close to the river banks has caused slumping and significant erosion issues and scouring of the bed. A bed scour depth ranging from 3 to 9 m has been predicted between Liverpool Weir and East Hills (NSW Department of Commerce, 2003). East Hills upwards, the width of the channel had increased by between 5 and 154 feet in 1973. Maps of the areas dredged along the Georges River between 1959 and 1974 are provided in Figure 3.4.

Some dredging within Botany Bay has an impact on the foreshore of the study area, more particularly along Towra Point and Lady Robinsons Beach. This dredging has been undertaken between 1948 and 1978 at Botany Bay entrance for the building of the Australian Oil Refinery jetty and offshore of Kyeemagh. These changes in depth changed the wave behaviour and direction within the bay which increased the sediment transport along the Towra Point coastline (SPCC, 1978). The areas dredged between 1948 and 1978 are shown on Figure 3.5. Some further dredging occurred in 1984-85 for the maintenance of the facilities at AOR and in 1992-94 at Botany Bay entrance, between the Third Runway and the Port. The dredged material was used as fill material in the construction of the Third Runway. Some further dredging and reclamation are currently underway for the Port Botany Expansion Project.

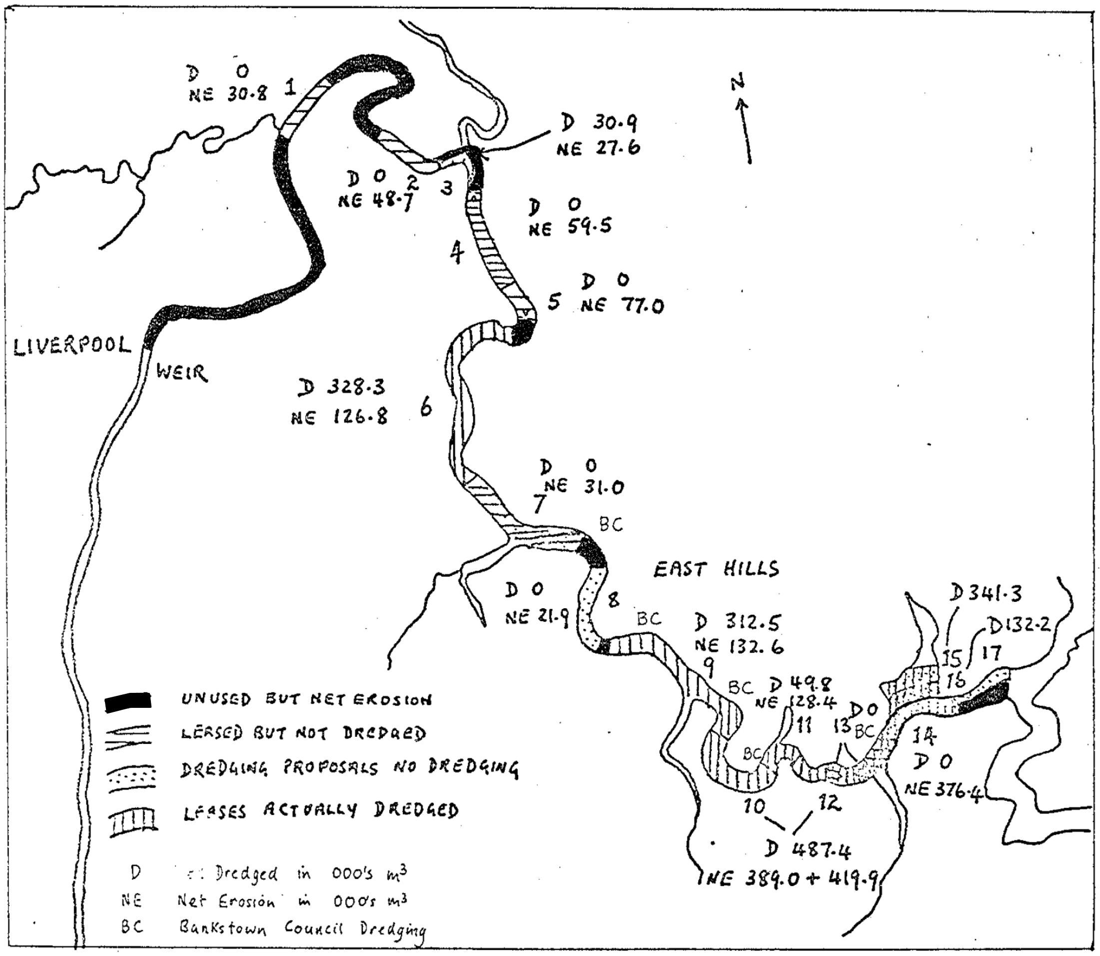


Figure 3.4 – Areas dredged between 1959 and 1974 in the Georges River (Warner & Pickup, 1976)

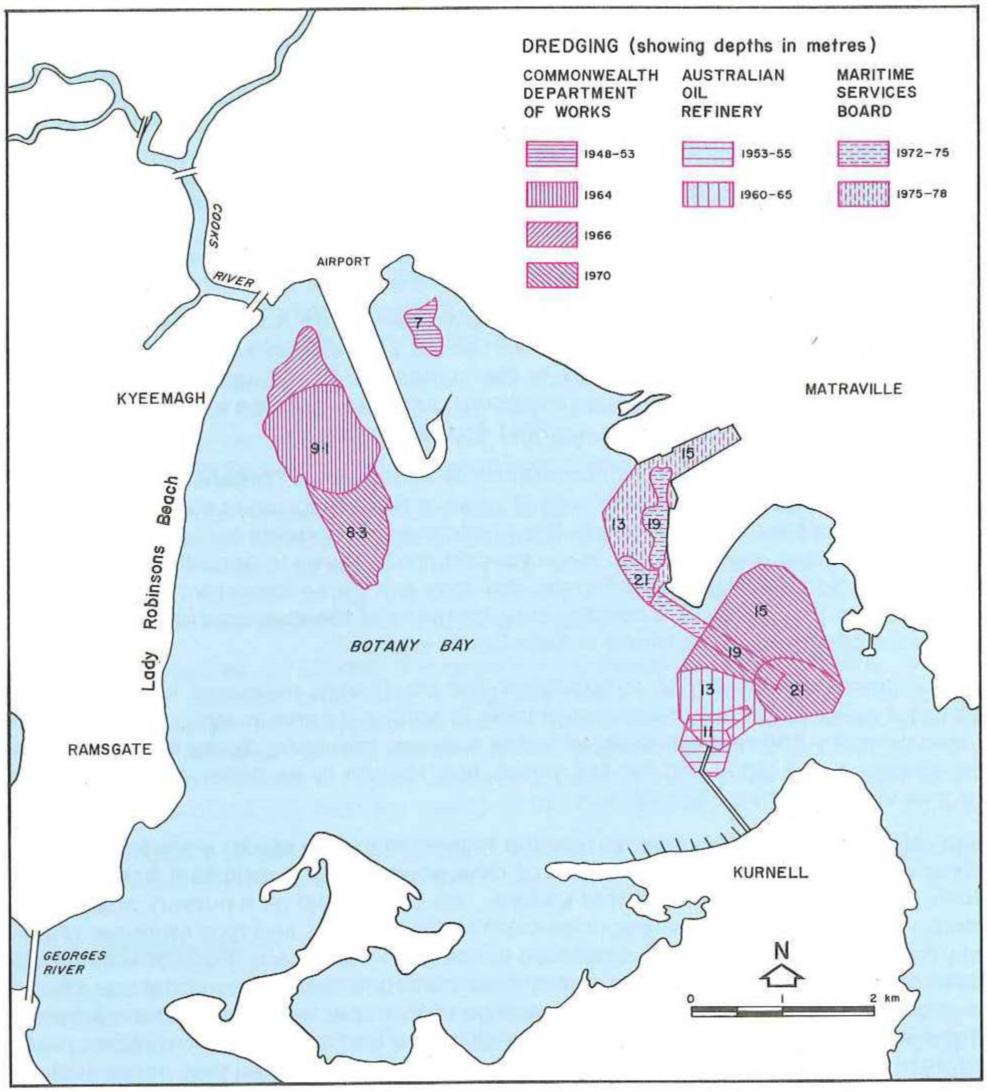


Figure 3.5 – Areas dredged within Botany Bay between 1948 and 1978 (SPCC, 1980)

Several areas have been reclaimed along the Georges River and Botany Bay. Large areas of reclamation have an immediate effect in reducing the tidal prism, which can affect the tidal currents and stage, channel capacities, and the amount of water available for flushing industrial waters within the bay. This change in tide characteristics could lead to siltation.

Some reclamation occurred in the 1970s at Port Botany and at Sydney Airport. The new port layout refracted and reflected waves in the direction of Towra Point which, in addition to the Botany Bay entrance dredging, increased wave heights and erosion in this area and a westerly sediment transport was generated along Towra Point. Since then, Towra Beach has been eroding and the western part of Towra Point is accumulating sand. Several groynes were constructed in 1980 at Silver Beach and eight groynes along Lady Robinsons Beach in 1997.

Heron Park Beach has been reclaimed as well as the beach opposite Heron Park. The beach opposite Heron Park was constructed using sand from the Kurnell area. However, this sand is much finer than the sand which is native to the beach and would therefore be regularly eroded. Hence, regular sand replenishment will be needed for this beach.

3.5 Erosion

The main areas where erosion occurs are in the upper reaches of the Georges River located in Wianamatta shale geology, as lateral channel movement occurs more easily here than in sandstone. The impervious Wianamatta shales are covered by tight clay and clayey loams and some gully and sheet erosion makes the water turbid even at low discharge. Most silt in the lower reaches of the river comes from this area.

In shale areas, widths of the channel usually increase over time while in sandstone areas, widths mainly decrease over time. In both shale and sandstone, mean and maximum depths increase over time. Channel capacity increased by 60% in the uppermost reaches of the river between 1959 and 1976 while in the lower reaches the rate of increase was only 3%. Reclamation of bank and mangrove/saltmarsh is largely responsible for width losses (Bankstown Municipal Council, 1978).

Two major kinds of erosion are identified along the Georges River which are:

- Scouring – predominant process in study area in the form of bed scouring and toe scouring; and
- Mass failure – common in high and steep riverbanks which results commonly from toe scour.

One main cause of erosion is dredging. This activity can have more or less impact on erosion depending on the depth of dredging and its distance from the banks. Some other causes of bank erosion include water in the soil profile causing a loss of bank coherence, passage of floods undermining the banks, wash from boats at high tide, wind waves, increasing tidal velocities due to increased storage at Chipping Norton ponds, uncontrolled access up and down the foreshore and lack of vegetation along banks. Some erosion prone riverbank materials, presence of dispersive clay and change in flow regime at the Weir, Lake Moore inlet, river bend downstream of William Long Bridge and inlet to Chipping Norton Lake are also amongst the major contributing factors to erosion.

Inappropriate bank protection and channel modification may cause localized erosion (e.g. edge effects). Hence, controls, maintenance and management have to be undertaken.

Some bank stabilisation has occurred for riverbanks and tailings, as well as removal of ponds exposed to erosion during floods, reduction of flood impacts, and creation of habitat and recreation waterway and parkland assets all along the estuary as part of the Georges River Foreshore Improvement Program (NSW Department of Commerce, 2003).

Bank erosion was fairly common between Cabramatta Creek and Prospect Creek (Warner and Pickup, 1973) and some erosion is still visible nowadays.

The different types of erosion which occurred between 1959 and 1974 along the Georges River are mapped on Figures 3.6 to 3.8. On these maps, “W” represent the width, “D” the depth, “+” an increase in the depth or width and “-“ a decrease.

SMEC examined available hydrosurvey information for the Georges River at DECCW Parramatta library. This data covered the area between Liverpool weir and Monash Reserve at East Hills between 1976 and 1989. A general channel widening has been observed along the Georges River between Liverpool Weir and Monash Reserve at East Hills. This has been observed in the surveys undertaken between 1976 and 1989. During this period, six surveys illustrated some cross-sections every 100m, looking downstream. Between Vale Of Ah Reserve (around index 30-31 in Figure 3.5) and East Hills, the southern embankment mostly eroded between 2 and 4 metres and up to 10 metres in some areas. Some bed scour occurred between Vale Of Ah and Williams Creek entrance.

Significant bed scouring was observed between Milperra Bridge and Dhurawal Bay (index 46), possibly due to some dredging or as a response to Dhurawal Bay construction between 1977 and 1984. Floyd Bay (index 48-49), Chipping Norton Lake and Moore Lake (index 62) constructions also started during this period. In response to the lakes construction, the river channel located between Moore and Chipping Norton Lakes and between Moore Lake and Liverpool Weir was deepening and the banks were mostly eroding during the same period.

At the southern end of Vale of Ah, the left bank (looking downstream) eroded by 5 to 10m between 1930 and 1984 while the opposite side was relatively stable due to a heavy mangrove protection. At the apex of Vale Of Ah Reserve bend, the bank on the inside of the bend is stable and protected by heavy covering of mangrove while the opposite side eroded quickly since 1970. A scarp movement of 10 to 15m inland has been measured since 1930. However some protection works slowed erosion. In the bend north of Vale Of Ah, both sides of the river were eroding over time. The bank on the outside of the bend eroded consistently at a rate of 0.2-0.25m/year due to the presence of silty soils which are easily undercut, while the bank on the inside of the bend eroded up to 17m due to alteration by dredging between the 1950s and the 1970s. From the recycling plant up to 1km upstream, the inside of the bend was relatively stable with the river bank both eroding and accreting. The outside of the bend eroded rapidly of between 7 and 18m since 1930. However, some protection works and significant dumping of concrete block, bricks and other building refuses slowed down erosion.

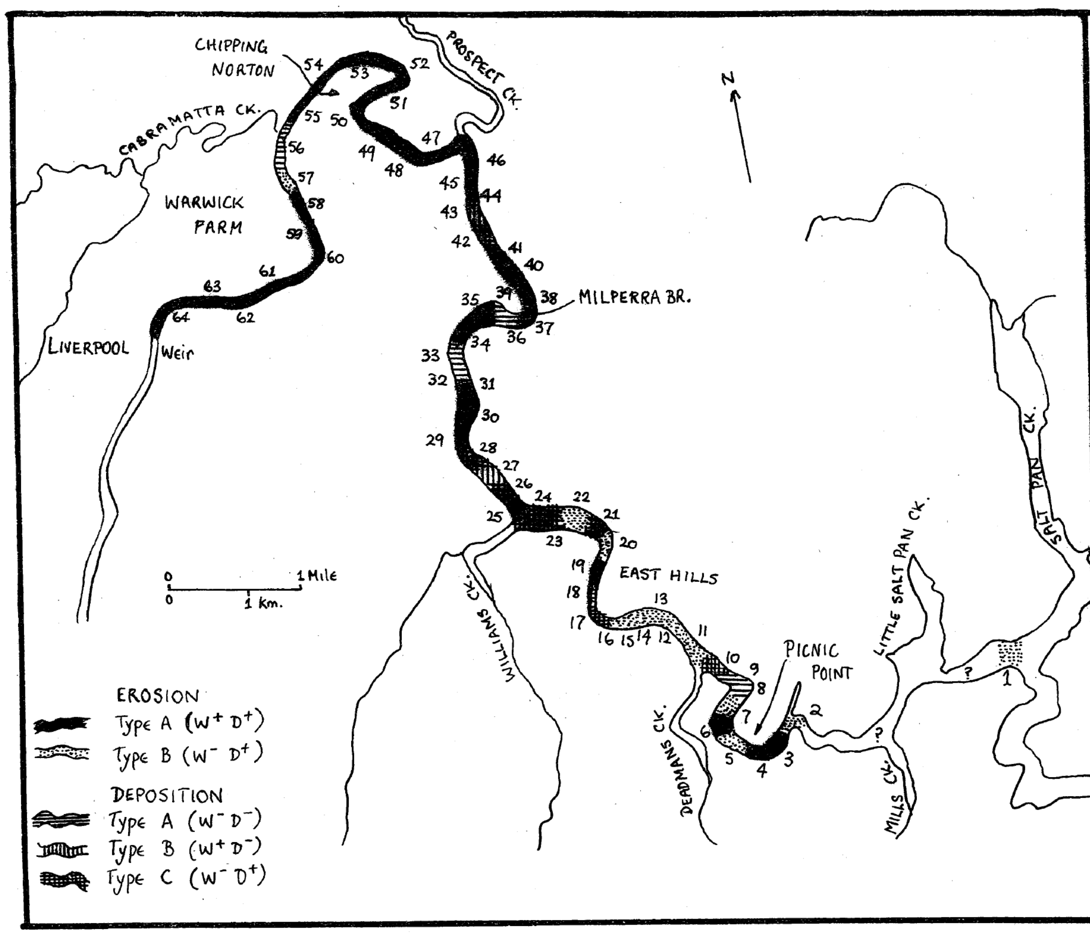


Figure 3.6 – Types of erosion and accretion between Liverpool Weir and Picnic Point (Warner & Pickup, 1973)

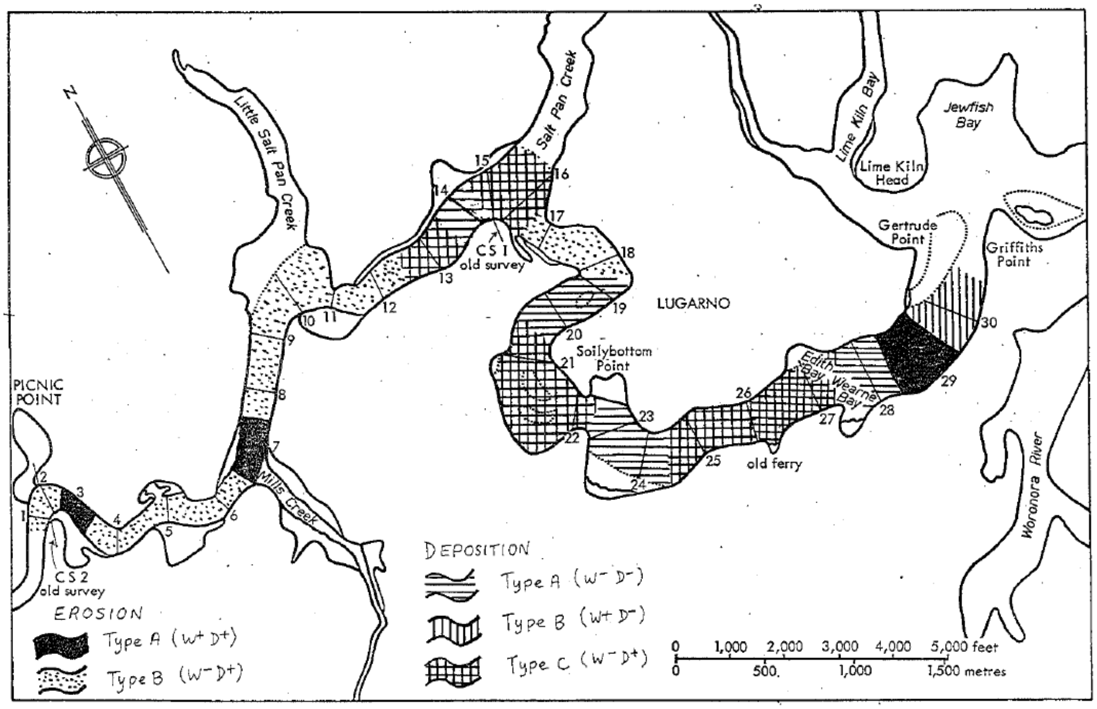


Figure 3.7 – Types of erosion and accretion between Picnic Point and Lime Kiln Bay (Warner & Pickup, 1976)

Current erosion was observed by SMEC team along the whole estuary and observations are detailed in the site summaries in Section 7 and in Appendix 2 of this report. While no recent depth data were available, the change in river width observed, were compared with the results of Warner & Pickup (1973 and 1976). Some light erosion is still noticeable between East Hills and Dhurawal Bay. Chipping Norton Lake and Floyd Bay have mostly been stabilized by seawalls and the channel upstream Chipping Norton is still eroding significantly. The lower reaches of the river are more stable and much less erosion is noticeable in this area. However some erosion is visible at localized areas like Connells Point Reserve or opposite Lugarno.

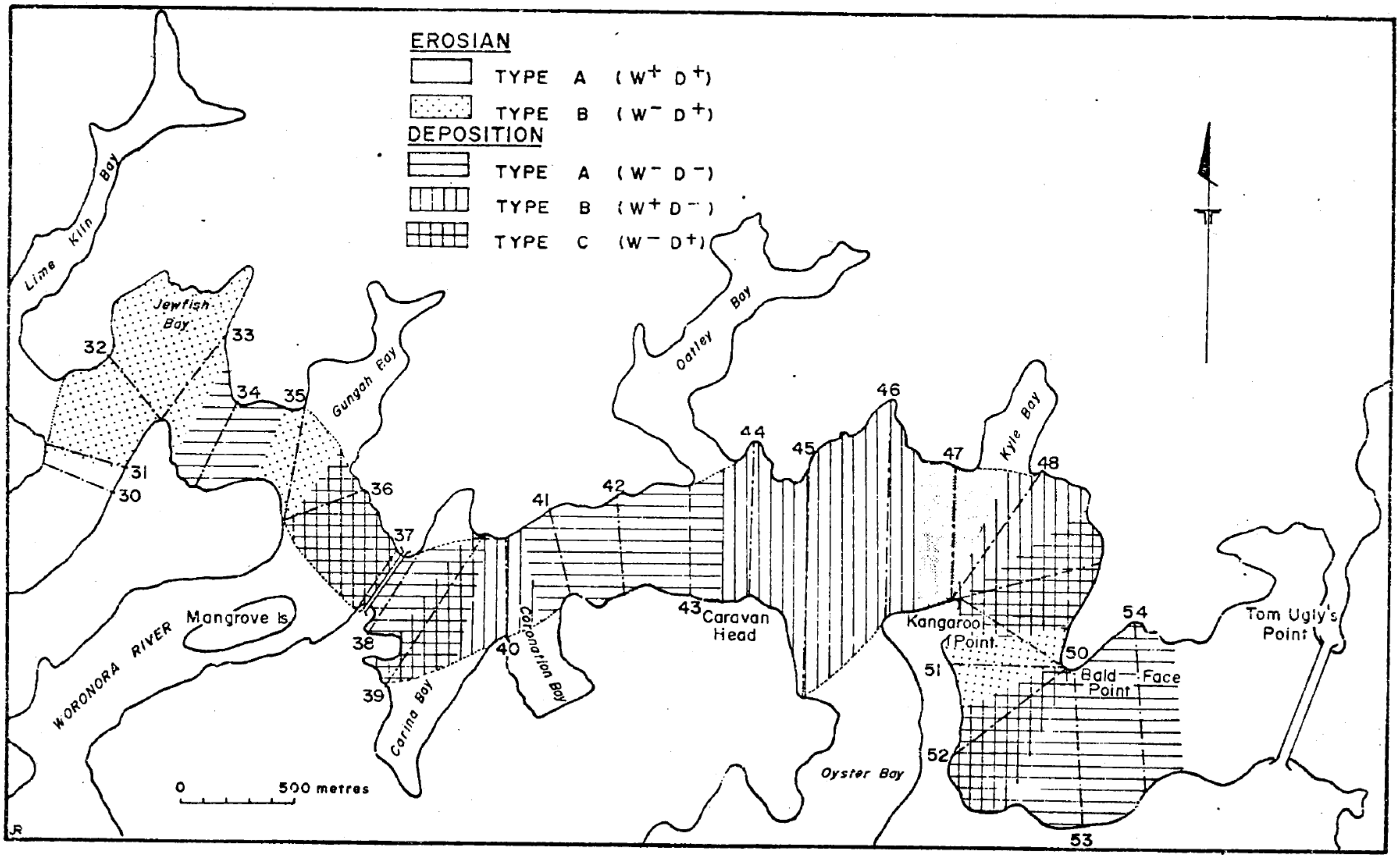


Figure 3.8 – Types of erosion and accretion between Lime Kiln Bay and Bald Face Point (Warner & Pickup, 1976)

3.6 Siltation/ Infilling

The sources of sand supply within the Georges River and its tributaries are predominantly located in the sandstone soil area. Very little sand is derived from tributaries flowing off from Wianamatta Shales like Prospect and Cabramatta Creek. Siltation and infilling often occur in non-uniformly dredged areas. Deep areas, such as Chipping Norton Lake, act as a sediment sink.

Reclamations along the Georges River have increased erosion in the upper reaches and the eroded sediments are depositing in the lower reaches. Some reclaimed areas also reduced the tidal prism and generated siltation as a consequence of the lower tidal flush.

The type of accretion which occurred between 1959 and 1974 is shown on Figures 3.6 to 3.8 (Warner & Pickup, 1973-76).

As previously specified in Section 3.5, examination of DECCW hydrosurveys carried out between 1976 and 1989 from Liverpool Weir to Monash Reserve at East Hills, has been undertaken by SMEC. These surveys have shown some deposition occurring at several places along this section of the river. Some significant deposition occurred between 1976 and 1984 in front of Kelso Park as well as at the mouth of Williams Creek. Significant deposition was noted on both sides of the river directly upstream of the recycling plant.

3.7 Acid Sulphate Soils

Acid sulphate soils (ASS) are sediments from the Holocene epoch (i.e. greater than 10,000 years ago). They are divided into two types of soil: actual acid sulphate soils (AASS) and potential acid sulphate soils (PASS). Both soils are mostly found in the same soil profile, with potential acid sulphate soils generally overlain by actual acid sulphate soils.

AASS contain highly acidic soil horizons or layers resulting from the aeration of soil materials that are rich in sulphide, primarily iron sulphide. This oxidation produces hydrogen ions in excess of the sediment's capacity to neutralize the acidity resulting in soils of pH of 4 or less when measured in dry season conditions. These soils can usually be identified by the presence of pale yellow mottles and coating of jarosite.

PASS contain iron sulphides or sulfidic material which have not been exposed to air and oxidized. The field pH of these soils in their undisturbed state is pH 4 of more and may be neutral or slightly alkaline. However, they pose a considerable environmental risk when disturbed, as they will become severely acid when exposed to air and oxidized.

The formation of Acid Sulphate Soils typically occurs in low-lying coastal areas where iron rich sediments can interact with sulphate from seawater, organic matter and sulphate-reducing bacteria. These conditions are usually limited to mangroves, salt marshes vegetation or tidal areas, and the bottom of coastal rivers like the Georges River and lakes like the Chipping Norton and Moore Lakes. However, flooding and stormwater erosion can redistribute ASS throughout the floodplain. ASS can mobilise metal ions such as iron and aluminium, particularly from clay soils into the groundwater system. Therefore, acid sulphate soils can be found anywhere within the Georges River catchment and especially in the areas which have been dredged. In water bodies, low pH, high aluminium levels and low oxygen levels due to oxygenation of iron precipitates can result in a high toxicity environment, detrimental to aquatic life.

These soils can be found using pH testing of the soils with some solution allowing a fast oxygenation of the soils.

Several possible mitigation measures exist for the acid sulphate soils. These measures are listed in the Table 3.1.

Table 3.1 – Mitigation measures for the management of Acid Sulphate Soils (Connell Wagner, 2009)

Mitigation Measures	Objectives	Associated Action
Avoidance	Minimise the potential exposure of acid sulfate soils	Avoid construction work in disturbed areas
Oxidation prevention	Minimise the time of exposure	Stockpile and cover excavated material
Leachate collection and treatment	Determine the level of acidity in soils	Contain leachate in appropriately designed containment ponds, extract regularly for treatment off-site in accordance with the ASSM[2]
Acid neutralisation	Mix soils with lime to reduce acidity	Mix excavated soil material and surfaces with lime at a rate, as specified by laboratory POCAS testing
Construction materials	Minimise corrosion	Select corrosion resistant construction materials
Monitoring	Determine the fluctuation of acidity	Monitor pH levels in surface trench water throughout construction and annually at relevant locations along the route
Approval	Implement effective mitigation measures	Obtain approval of a detailed acid sulfate soil management plan

The Soil Class categorises the ASS Planning data into 5 classes of land based on the probability of acid sulphate soils occurrence and the type of works that might disturb them. Class 1 indicates the highest risk and Class 5 the least risk from ASS.

Where development will take place on land identified as ASS the following consent is required:

- Class 1 Any works
- Class 2 Works below natural ground surface. Works by which the watertable is likely to be lowered.
- Class 3 Works beyond 1 metre below natural ground surface. Works by which the watertable is likely to be lowered beyond 1 metre below natural ground surface.
- Class 4 Works beyond 2 metres below natural ground surface. Works by which the watertable is likely to be lowered beyond 2 metres below natural ground surface.
- Class 5 Works within 500 metres of adjacent Class 1, 2, 3 or 4. Land which are likely to lower the watertable below 1 metre AHD on adjacent Class 1, 2, 3 or 4 land.

Most Councils have created planning maps of the acid sulphate soils. These maps can be found on the Council websites (see Table 3.2 with the links below). Maps of the ASS in Botany Bay are given in Figure 3.9. A global map illustrating the location of the different probability of occurrence (Low or High) of ASS is provided in Figure 3.10.

Table 3.2 – Links to the Acid Sulphate Soils for each Council (if available)

Council	Link to ASS planning maps
Bankstown	http://www.bankstown.nsw.gov.au/pdfmap/WebIndexMap.htm
Fairfield	N/A
Hurtsville	http://www.hurstville.nsw.gov.au/IgnitionSuite/uploads/docs/Acid%20Sulphate%20Map.pdf
Kogarah	http://www.kogarah.nsw.gov.au/resources/documents/LEP17_Acid_Sulfate_Map.pdf
Liverpool	http://www.liverpool.nsw.gov.au/LCC/INTERNET/me.get?site.home&PAGE1821
Rockdale	N/A
Sutherland Shire	http://www.sutherland.nsw.gov.au/SSLEP2006/SSLEP06_AcidSulfateSoils/A3TitlePage_%20SSLEP06_AcidSulfateSoils.pdf

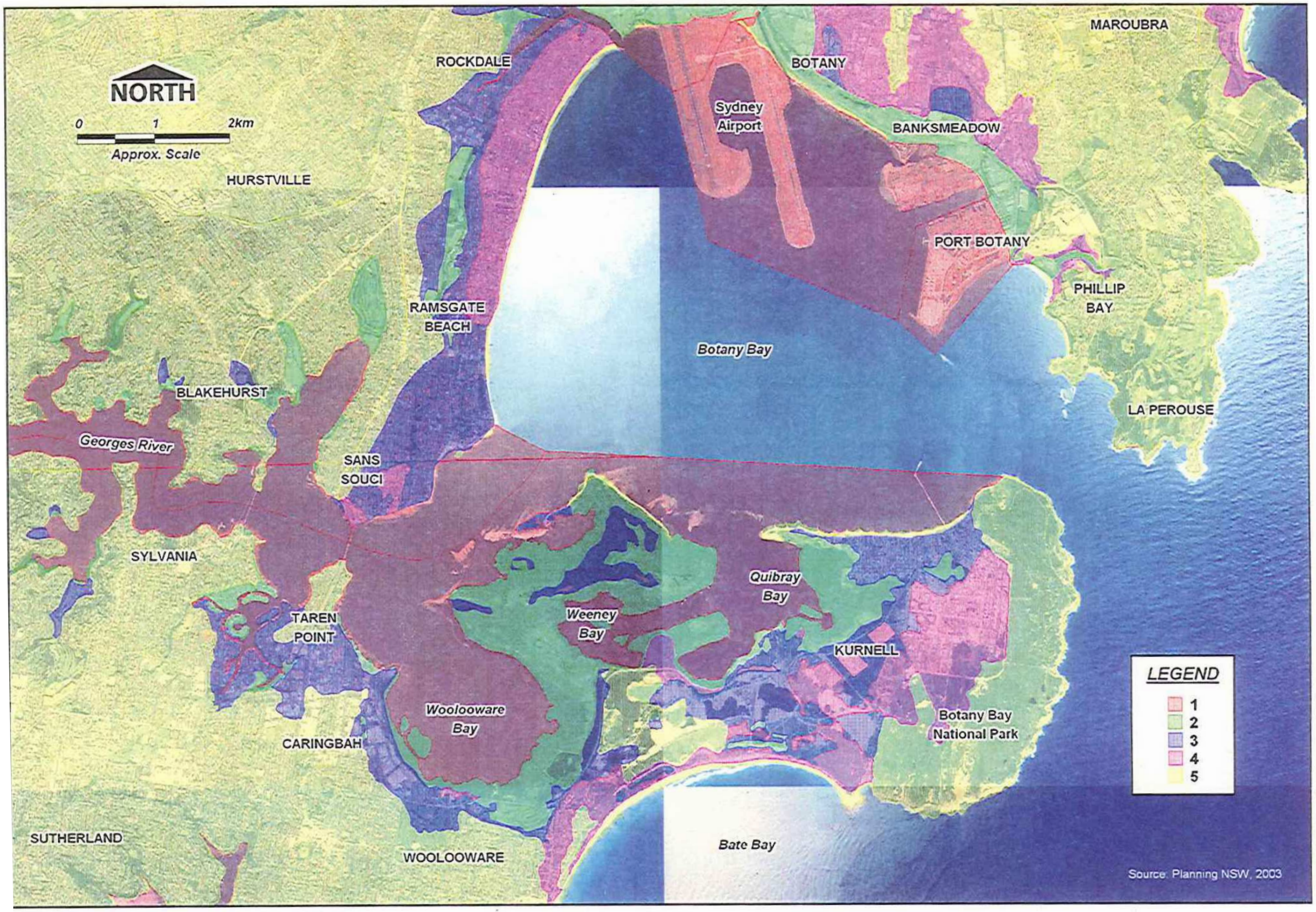
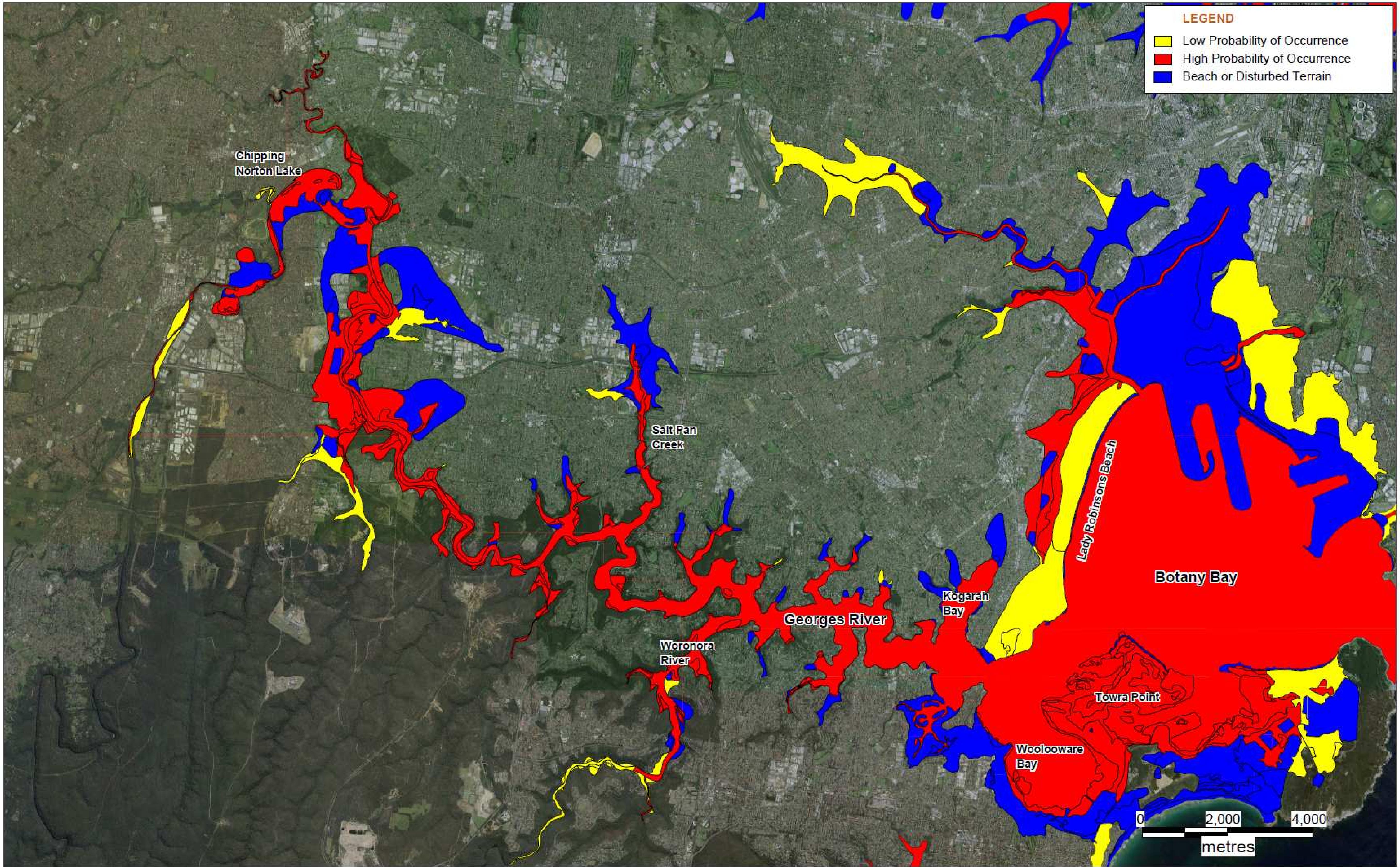


Figure 3.9 – Acid Sulphate Soil Planning Map for Botany Bay (WBM, 2003) – The numbers in the legend refer to the different Class of Acid Sulfate Soils



DATE 08/12/2009	COORDINATE SYSTEM GDA 94 Zone 56	FIG NO. 3.10	FIGURE TITLE Probability of Occurrence of Acid Sulphate Soils in the Georges River Catchment
PROJECT NO. 3001765	PROJECT TITLE Georges River Data Compilation and Estuary Processes Study	CREATED BY M.GLATZ	LOCATION I:\projects\3001765 - Georges River Estuary Process Study\009DATA\GIS\Mapinfo Workspaces

SMEC

4 HYDRODYNAMICS

The Georges River is split into two different sections by the Liverpool Weir. The section upstream of the Weir is freshwater while downstream of the Weir is estuarine and therefore impacted by the effects of tide.

The tides and hydrodynamic processes have been studied in this section, as well as the wave and wind actions. The impact of sea level rise due to climate change on hydrodynamic processes is also discussed.

The Georges River and its tributaries form a vertically well mixed estuary with waters in the lower reaches having essentially marine salinities.

4.1 Tides

The tides in the Georges River area are semidiurnal with a diurnal inequality. This means that there are two high tides and two low tides each day and the two high or two low tides do not have the same amplitude. The mean tidal range is around one metre and the tidal period is around 12.5 hours. Tides vary according to the phases of the moon. The higher spring tides occur near and around the time of new or full moon and rise highest and fall lowest from the mean sea level. The average spring tidal range is 1.3 metres and the maximum range reaches two metres. Neap tides occur near the time of the first and third quarters of the moon and have an average range of around 0.8 metres. The diurnal inequality ranges from 0 to 0.6m with an average value of around 0.4m.

Tidal range is relatively constant along the River with differences in levels of less than 0.1m between the Liverpool Weir (mean spring range of 1.31m) and Botany Bay (mean spring range of 1.25m). A tidal lag is noticeable between the Georges River mouth and the Weir. This tidal delay is about 2.5 hours (SPCC, 1978).

4.2 Tidal Flushing

The tidal flushing predominantly depends on the tidal prism. The tidal prism is the volume of water in an estuary or inlet between mean high tide and mean low tide or the volume of water leaving an estuary at ebb tide. Calculations of tidal prism are useful in determining the residence time of water (and pollutants) in an estuary. If it is known how much water is exported compared to how much of the estuarine water remains, it can be determined how long pollutants reside in that estuary. If the tidal prism forms a large proportion of the water in an estuary at high tide, then when the tide ebbs, it will take with it the majority of the water (this occurs in shallow estuaries) and any pollutants or sediments suspended in that water. This means that the estuary has a good flushing time, or that the residence time of water in that estuary is low. On the contrary, in deeper estuaries, the amount of water that is influenced by the tides forms a smaller proportion of the total water volume.

Between 1960 and 1980, the tidal prism of the Georges River upstream of Milperra increased from 700,000 m^3 to 1.6 million m^3 due to the lakes construction. This construction of the Chipping Norton Lake has reduced tidal range by approximately 0.2m in the upper reaches since 1960. This reduction in tidal range could lead to longer flushing times and, hence poorer water quality.

Tidal flow in Botany Bay is 4000 m^3/s while the freshwater flow rate in Georges River is usually less than 5 m^3/s in dry weather (a 1-in-10-year flood event reaches a peak flow of 850 m^3/s). The flushing in Botany Bay is therefore dominated by the tide. Only 10% of water-borne pollutants which leave the bay on an ebb tide return on the flood tide. This is observed for the Bay but is different along the Georges River.

The lower reaches of the Georges River are relatively well flushed as they are well influenced by the tide. Some creeks like Mill and Deadman's Creeks are almost totally cleared out at low tide. However, some areas within the estuary are subject to a lack of tidal ventilation and are called 'dead water areas'. A map of these areas in the lower reaches of the Georges River is provided in Figure 4.1. Most embayments of the lower reaches have a dead water area upstream in dry weather conditions. .

Along the upper reaches of the Georges River, most of the main stream is much less flushed out and water takes more time to be exchanged, meaning that pollutants stay in the system longer and are either taken up or consolidated.

Moreover, some reclamation along the Georges River has had an effect in reducing the tidal prism, which affects tidal currents, channel capacities and the amount of water available for flushing industrial, urban and rural pollutants.

Circulation in Woolooware Bay is greater under flood tide than under ebb tide (SPCC, 1979). The flood tide sweeps the western side of the bay whereas the ebb tide misses it. This phenomenon reduces the flushing time of the bay. Hence, the water quality of the bay is reduced due to polluted water stagnating longer in the bay.

4.3 Water Levels

During storms, the ocean water level and hence that along the river is elevated above the normal tide level. While these higher levels are infrequent and last only for short periods, they may exacerbate any storm damage on the foreshore. Elevated water levels allow larger waves to cross the offshore sand bars and reefs and break at higher levels on the beach, especially in places like Towra Point. Further, they may cause flooding of low lying areas and increase tail water control levels for river flood discharges in the upper reaches of the river.

The components of these elevated water levels comprise the astronomical tide, barometric water level setup, wind setup, wave setup and runup (see Figure 4.2). All of the components do not act or occur necessarily independently of each other but their coincidence and degree of inter-dependence, generally, is not well understood.

Storm surge is the increase in water level above that of the normal tide that results from the low barometric pressures, which are associated with severe storms and cause sea level to rise, and strong onshore winds that pile water up against the coast (e.g. at Botany Bay). Measured values of storm surge at Sydney include 0.59 m for the extreme storm event of 25 – 26 May 1974 and 0.54 m for the extreme storm event of 31 May – 2 June 1978, which were computed to have recurrence intervals of 77 and 39 years respectively (Haradasa *et al*., 1991). Both of these extreme events were coincident with spring high tides with the water level in the 1974 event reaching the maximum recorded at Fort Denison of 1.48 m AHD.

Return periods for ocean water levels comprising tidal stage and storm surge for Sydney, which are representative of the study region, are presented in Figure 4.3.

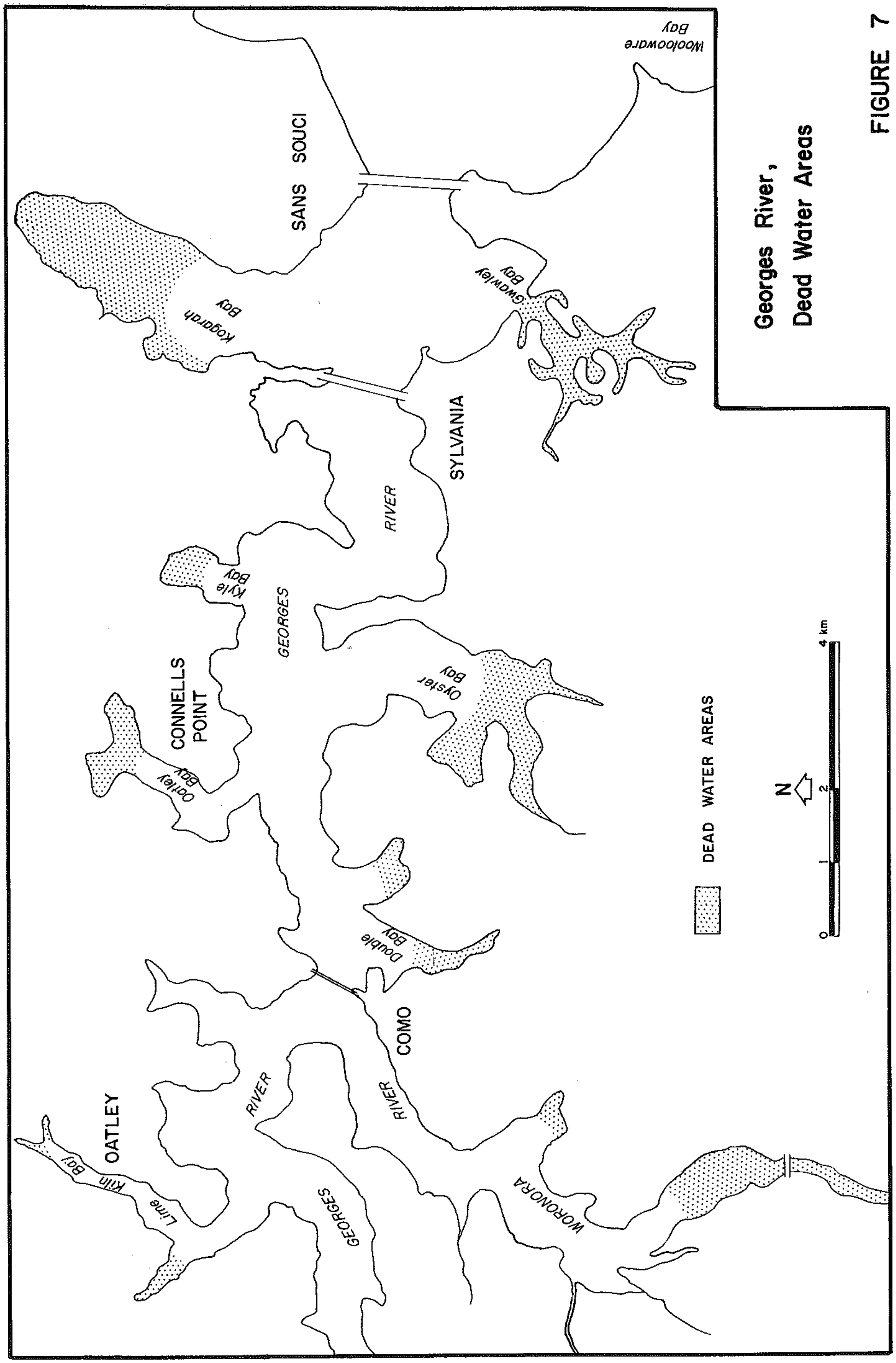


Figure 4.1 – Dead Water Areas in the Lower Georges River (SPCC, 1979)

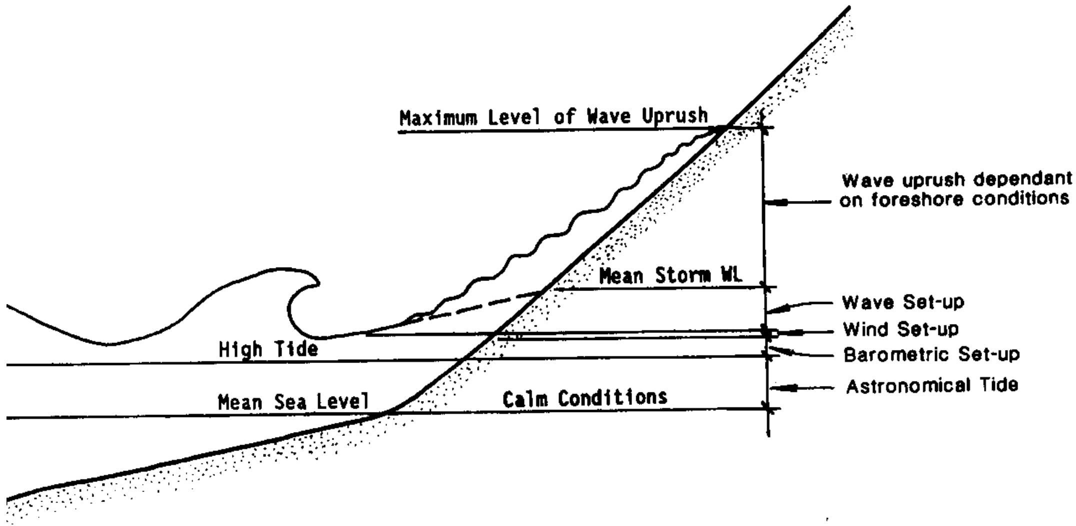


Figure 4.2 – Components of elevated water levels on the coast (NSW Government, 1990)

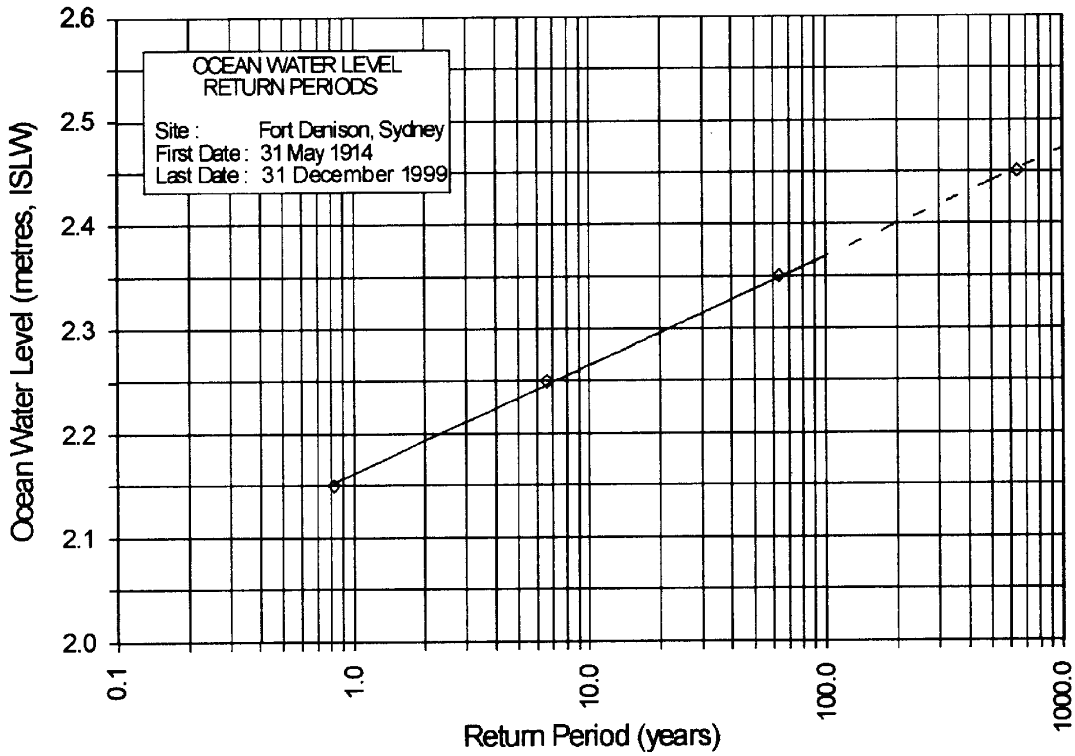


Figure 4.3 – Sydney ocean level recurrence (Lord & Kulmar, 2000)

4.4 Climate Change/ Sea Level Rise

A significant issue is the rise in sea level resulting from climate change. A rising sea level may result in an increased potential for bank erosion along the river where there is no protection against erosion like a seawall or estuarine vegetation as well as increased inundations of assets.

In the longer term, there may be global changes resulting from a postulated warming of the earth due to the accumulation in the atmosphere of certain gases, in particular carbon dioxide, resulting from the burning of fossil fuels. The current consensus of scientific opinion is that such changes could result in global warming of 1.5° to 4.5°C over the next 100 years. Such a warming could lead to a number of changes in climate, weather and sea levels. These, in turn, could cause significant changes to coastal alignments and erosion.

Global warming may produce also a worldwide sea level rise caused by the thermal expansion of the ocean waters and the melting of some ice caps. According to the Intergovernmental Panel on Climate Change (IPCC, 2007), the upper range estimate for sea level rise for the 21st century is 0.59 m (Figure 4.4). This is made up of various components, including thermal expansion of the oceans (the largest component), melting of the Greenland and Antarctic ice sheets and melting of land-based glaciers. There is considerable uncertainty also in the level of ice-sheet discharge, which could contribute, at a maximum, an additional 0.17 m to the worst-case scenario global average sea level rise. In addition to the effects of climate change, there is also an existing underlying rate of sea level rise which includes the effects of current local rates of isostatic and tectonic land movements. Mitchell et al. (2001) quantified underlying rates of existing sea level rise at various tide gauge locations around Australia. The sum total of these influences would give an upper bound sea level rise of 0.90 m for a 100 year planning period. The IPCC were unable to exclude larger values and there is emerging evidence in the current measurements and observations, suggesting the IPCC's 2007 report may have underestimated the future rate of sea level rise. Therefore, the NSW Government through the Sea Level Rise Policy Statement have set the NSW Sea Level Rise Planning benchmark at the upper bound levels of a 0.40 m increase above 1990 levels by 2050 and 0.90 m by 2100.

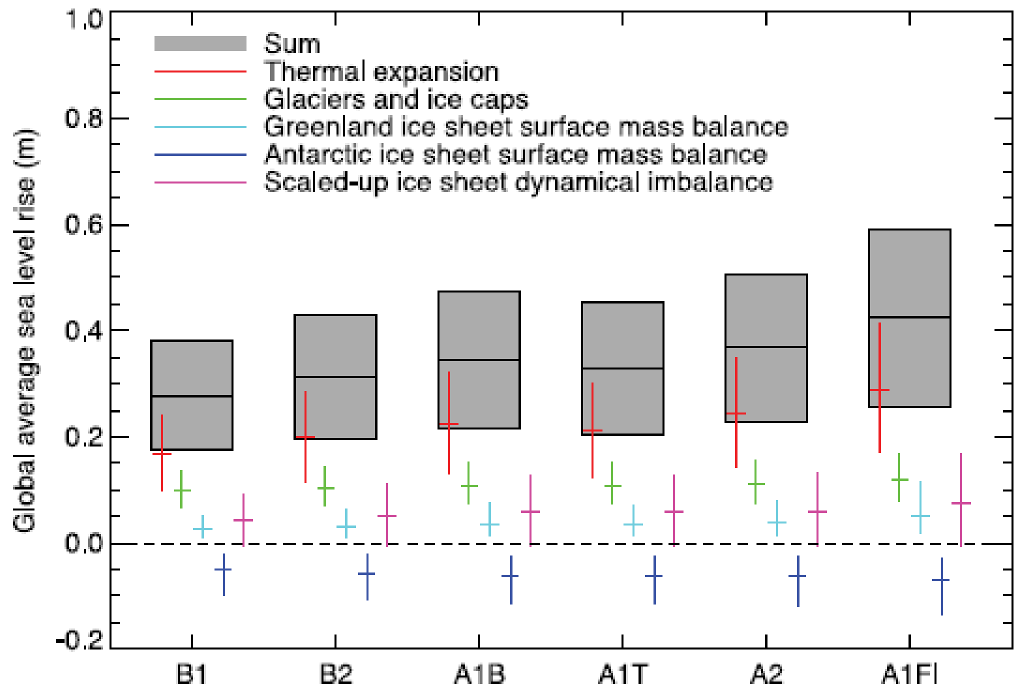


Figure 4.4 – Projected sea level rise between 2000 and 2100 (after IPCC, 2007)

4.5 Water Currents

The principal drivers of currents are tides, floods, winds, waves breaking and wave orbital motion at the seabed.

Current speeds in both Botany Bay and Georges River are generally less than 1m/s. Dredging in Botany Bay have reduced currents in deep holes and the airport development within the Bay has disturbed the current pattern as shown on Figure 4.5.

The construction of the Lakes Scheme has affected the current velocities upstream of the lake and allowed some minor sediment transport which was non-existent previously upstream of the lake. This recent sediment transport is responsible of the exacerbated erosion along these reaches of the river.

The current increases in constriction and is very low in the bays and bends of the river. Therefore, erosion is more significant in constricted area like in the shale-dominated soils located in the upper reaches of the river.

The tidal flow has been illustrated for ebb and flood tide at the Georges River Entrance including Kogarah Bay in Figure 4.6.

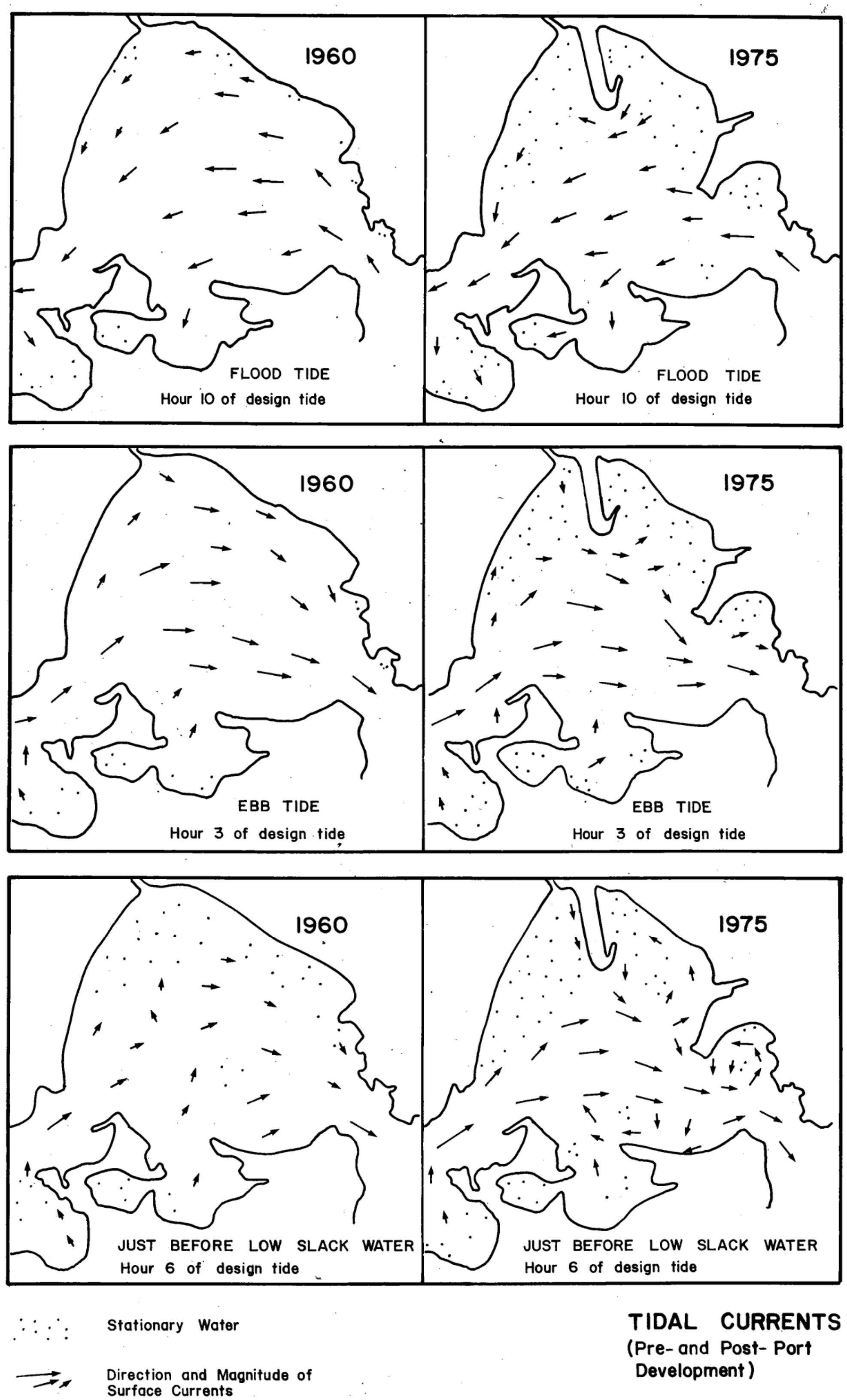
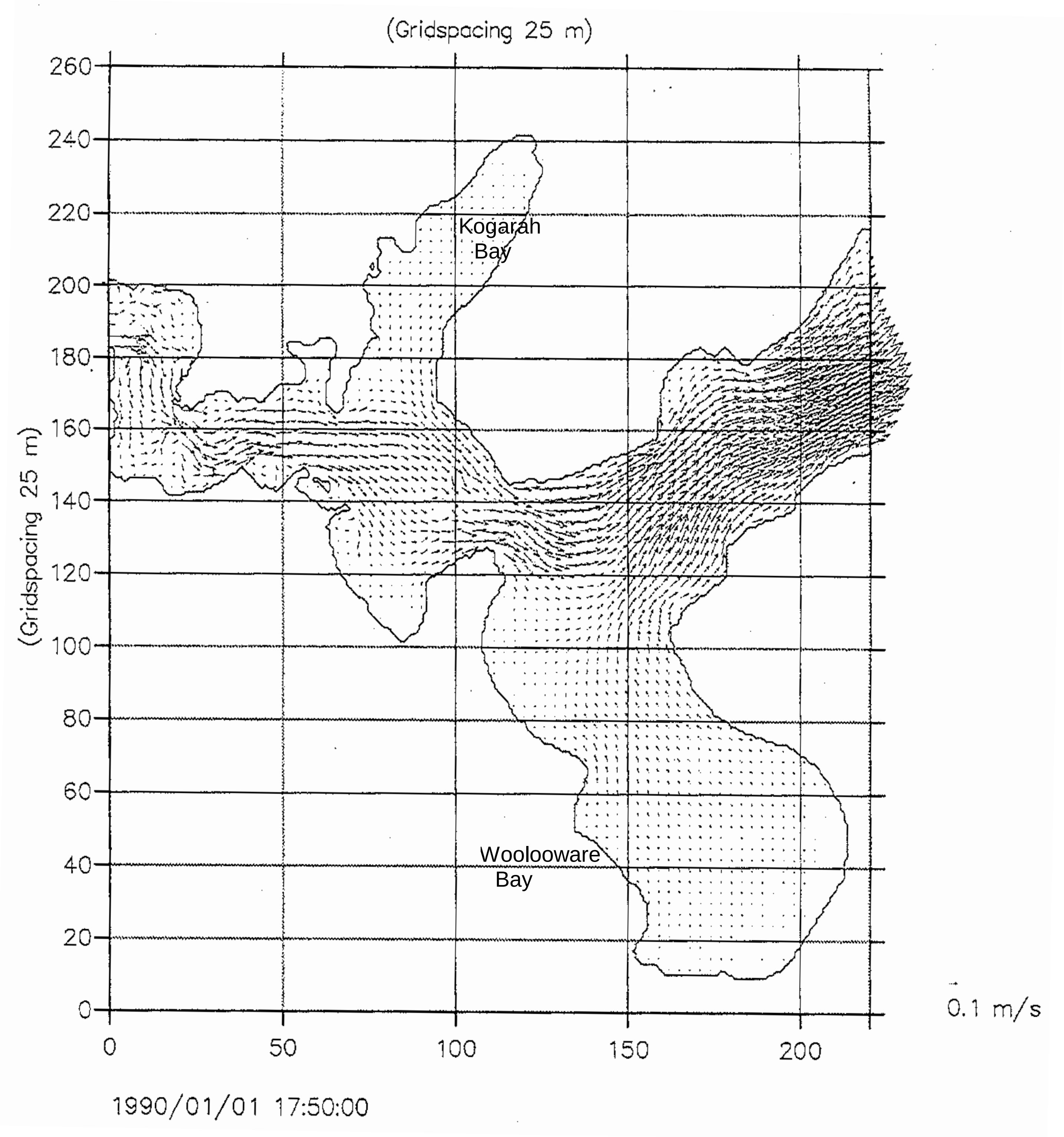
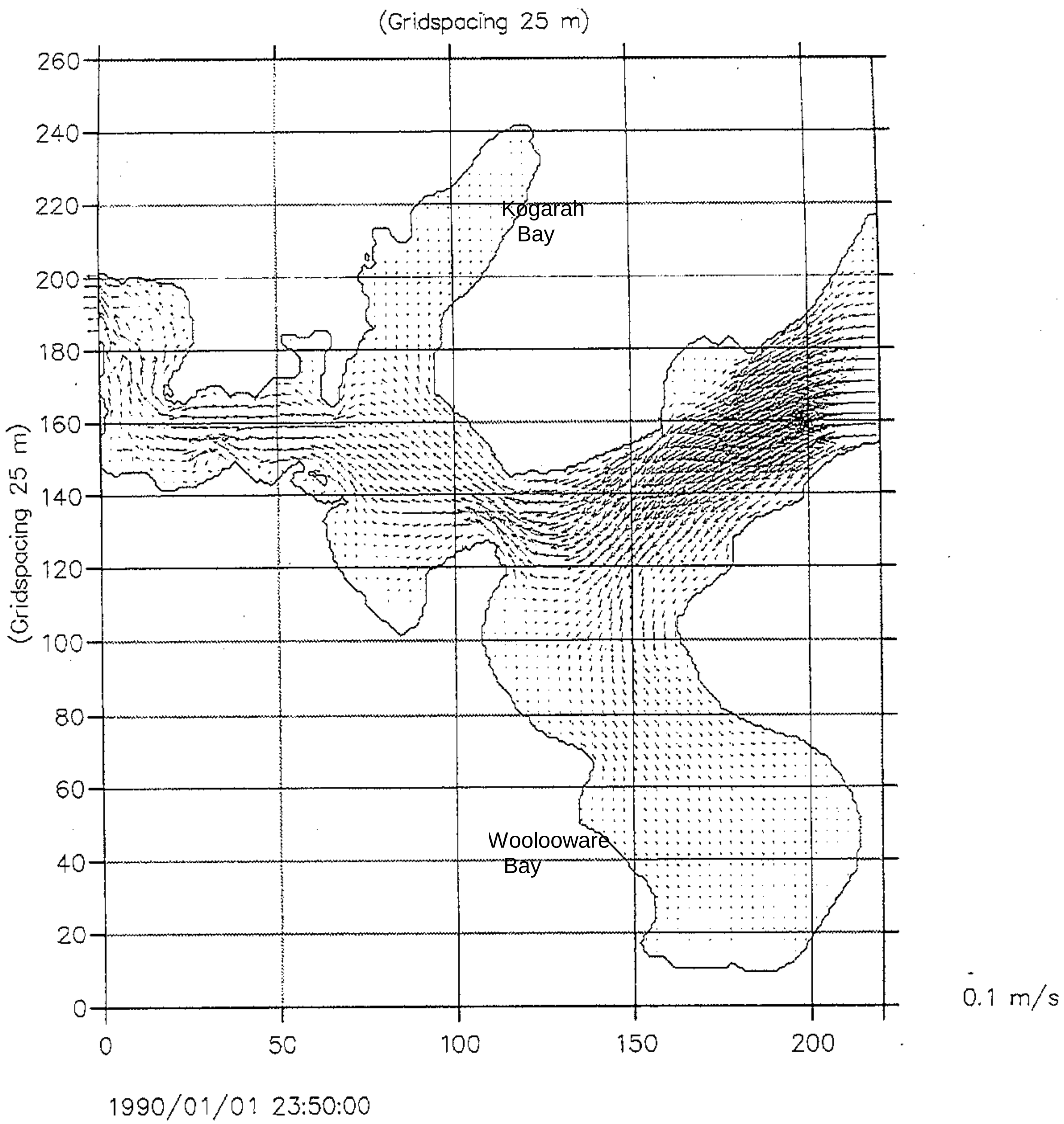


Figure 4.5 – Changes in Tidal Current due to the Dredging in Botany Bay (SPCC, 1978)



Peak ebb current



Peak flood current

Figure 4.6 – Tidal Current at Georges River mouth (Lawson & Treloar, 2001)

4.6 Wind Waves

Waves can be locally generated by wind. This phenomenon is more likely to occur within the upper reaches at the Chipping Norton lakes or Botany Bay where longer fetch (i.e. the length of water over which a given wind has blown) can be observed. These waves have a characteristic period ranging from 1 to 5 seconds and possess little energy. A table of the fetches and significant wave heights (i.e. the average of the highest 33% of the waves) in different specific locations is given in Table 4.1.

Table 4.1 – Wave characteristics (Significant Wave Height Hs and Wave Period Tp) for different wind speeds and fetch lengths (SMEC calculation)

Fetch Length (m)	Location	Mean Wind (5m/s)		Strong Wind (15m/s)		Storm Wind (32m/s)	
		Hs (m)	Tp (s)	Hs (m)	Tp (s)	Hs (m)	Tp (s)
300	Georges River Width or Dhurawal Bay	< 0.10	< 1.00	0.14	1.00	0.37	1.4
600	Moore Lake	< 0.10	< 1.00	0.21	1.33	0.57	1.85
700	Floyd Bay	< 0.10	< 1.00	0.23	1.39	0.61	1.94
1000	Lime Kiln Bay	< 0.10	< 1.00	0.27	1.56	0.71	2.17
1200	Mill Creek to Little Salt Pan Creek	< 0.10	1.05	0.30	1.65	0.77	2.29
1300	Captain Cook Bridge to Tom Ugly Bridge	< 0.10	1.07	0.31	1.69	0.80	2.35
1400	Quibray Bay	< 0.10	1.10	0.32	1.73	0.82	2.40
1500	Salt Pan Creek	< 0.10	1.12	0.33	1.77	0.84	2.45
1600	Chipping Norton Lake	< 0.10	1.14	0.34	1.80	0.87	2.50
1700	Little Salt Pan Creek to Salt Pan Creek	0.10	1.16	0.35	1.83	0.89	2.55
1800	Jewfish Bay	0.10	1.18	0.36	1.87	0.91	2.59
2200	Along Lugarno	0.11	1.25	0.39	1.98	0.98	2.75
2700	Kogarah Bay	0.12	1.32	0.43	2.10	1.06	2.92
3300	Woolooware Bay or from Como Bridge to Kyle Bay	0.13	1.40	0.47	2.23	1.13	3.09
4000	Towra Point to Kangaroo Point	0.14	1.47	0.51	2.35	1.20	3.26
8000	Botany Bay	0.19	1.76	0.66	2.83	1.42	3.91

It is to be noted that the results in this table assumes that the wind occurs in the exact direction of the longest fetch and last for 3 hours. However, the wave height rarely exceeds 1m as the storm conditions are rare. For usual conditions (i.e. 5m/s as observed in section 2.2) the wave heights do not exceed 0.2m.

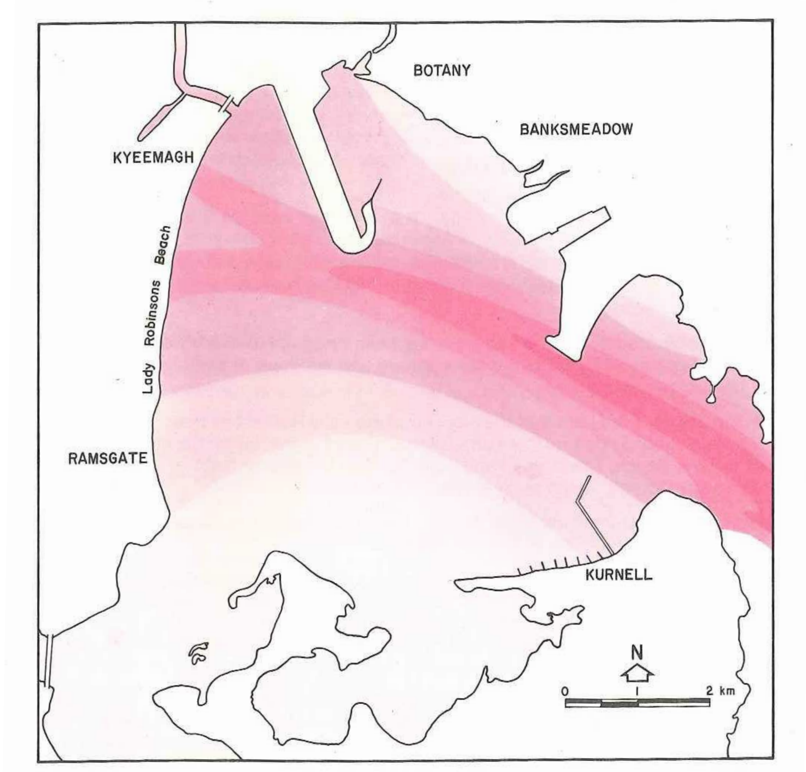
4.7 Ocean Swell

Botany Bay is subject to ocean swells propagating through the entrance. The entrance of the bay is facing south-east which allows the penetration of the ocean swell from south to east-south-east.

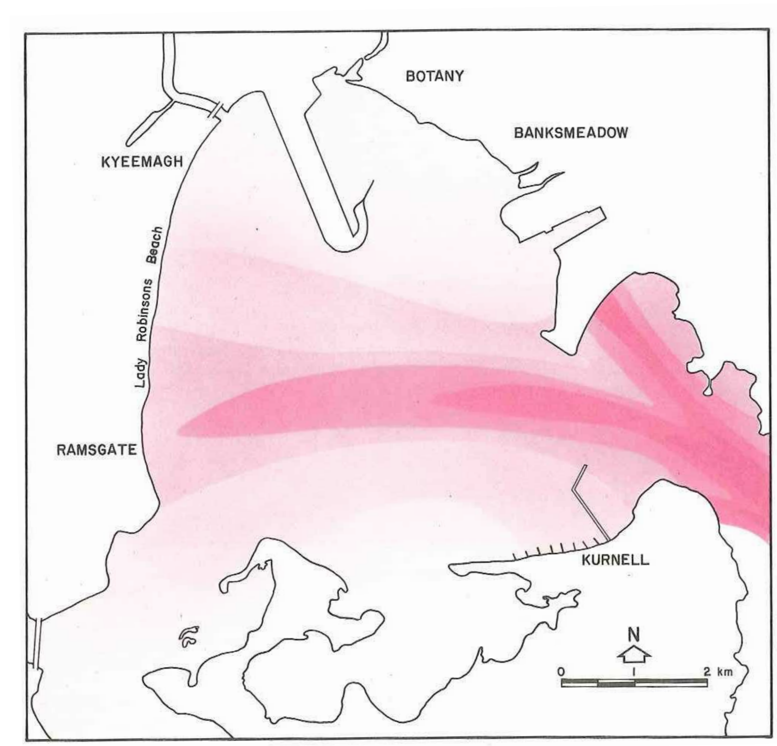
Ocean swell is generated by the transfer of energy from wind to water over long fetches. The usual wave period for ocean swell waves is between 8 and 15 seconds. A maximum wave height of 9m can be reached every five years and a 6m wave height every six months. The height of the wave within the Bay is limited. Wave heights are generally less than 0.5m with only 10% of the waves exceeding 1m and rare occurrences of up to 2m in some locations. Some wave diffraction can be observed around different obstacles such as the reclamations which were undertaken within the bay.

Ocean swells are energetic and influenced by the changes in bathymetry. Therefore, the swell influence has been modified by the dredging and reclamation which took place within the Bay, mostly between 1948 and 1978. The change in wave distribution is illustrated in Figures 4.7 and 4.8.

Before the development at the Bay entrance, Lady Robinsons Beach was frequently damaged during storms at Brighton le Sands. Dredging of the entrance channel reduced the wave climate along Lady Robinsons Beach. However, the works increased the wave heights along the southern shore. At Towra Point, the shallow waters protect the beach from high waves as the waves shoal and break over the sandy shoals, but small local wind-generated waves occur more frequently. The change of wave climate created a westward longshore current along Towra Point generating a longshore sediment drift eroding the beach. Changes in direction of the wave induced a beach rotation of Towra Beach to realign with the new wave direction.



Diffusion of the Wave Energy Before Dredging (SE and 10s wave)



Diffusion of the Wave Energy After Dredging (SE and 10s wave)

Figure 4.7 – Changes in wave energy due to dredging between 1948 and 1978 (SPCC, 1980)

(N.B.: the darker the color, the more energy it represents)

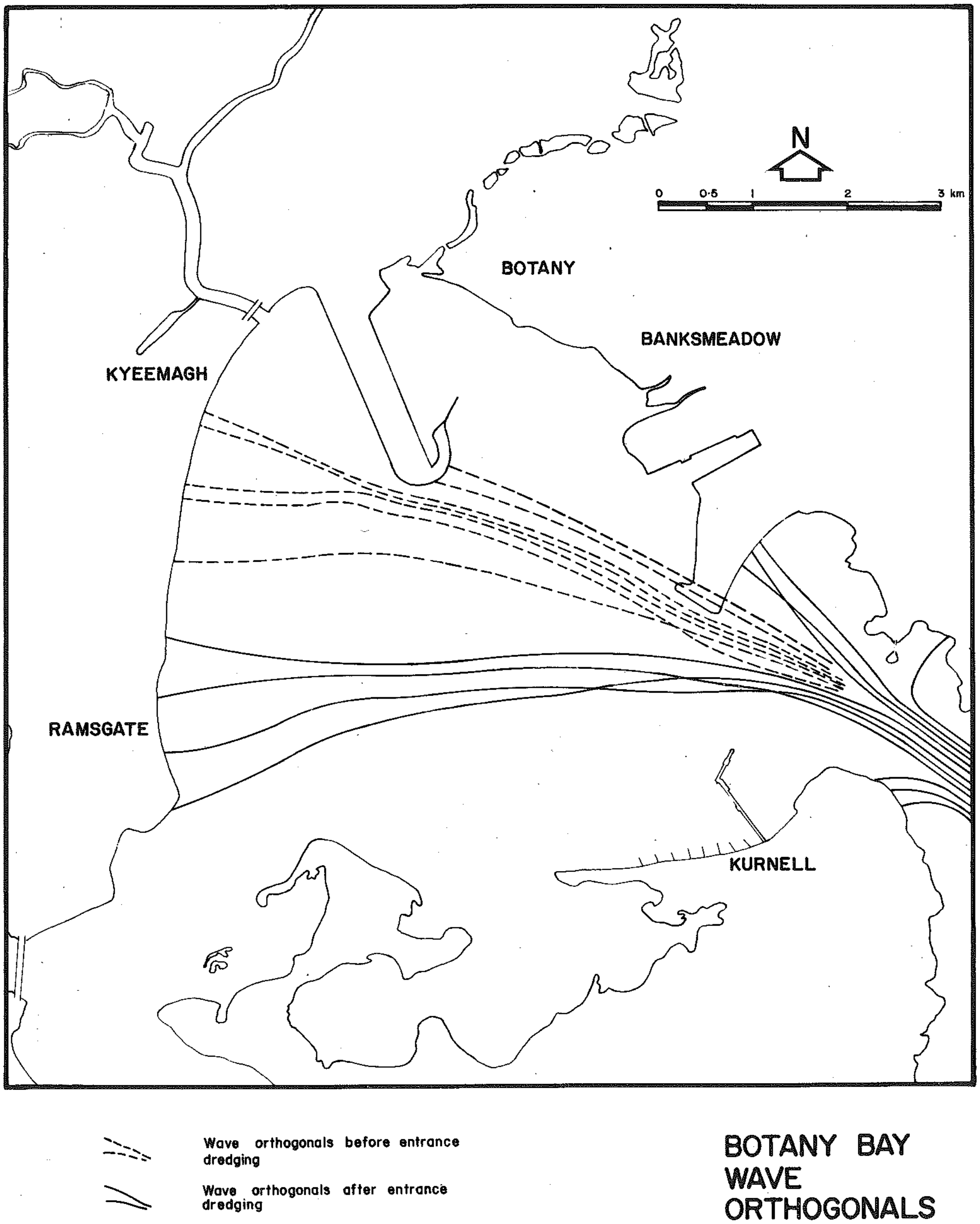


Figure 4.8 – Change in Wave Direction due to dredging (SPCC, 1978)

5 FLOOD ANALYSIS

Parts of the Georges River Estuary are subject to flooding, with the major floodplain of the Georges River located between Liverpool and East Hills, and along Cabramatta and Prospect Creeks. Increasing urbanisation in the catchments is increasing the proportion of impervious area, increasing flood flows and reducing response times, leading to an increase in flood hazard.

This section of the report describes the flood history within the study area, reviews existing flood studies and model results and describes major developments which have affected flood behaviour in the study area. Various floodplain management options that have been undertaken in the study area are discussed.

5.1 Description of the Floodplain

The major floodplain area of the Georges River catchment is the urban area located between Liverpool and East Hills, along Cabramatta and Prospect Creeks. These areas are subject to the most significant damage as they are located in low-elevated and shale-dominated landscape being much less pervious than sandstone areas. The Cabramatta and Prospect Creeks areas are of special concern because they are expected to be fully urbanised in the future which would ultimately increase the flows by 60% for Prospect Creek and 190% for Cabramatta Creek. This would cause increases in flood flows and significantly reduce response times. Around 30% of flood prone areas are residential and industrial/commercial developments and 70% are open spaces. Runoff in these areas is approximately twice the runoff in Salt Pan Creek (Sinclair Knight & Partners, 1981).

Flood damage is not significant for sandstone areas that have narrow flood plains downstream of East Hills. Only minor impacts are expected in some small pockets of development and there should be no major bank instabilities.

5.2 Flood History

Several flood events occurred in the last 150 years. Most flood observations have been recorded at the Liverpool Weir, constructed in 1836. A histogram of flood records at the Liverpool Weir is given on Figure 5.1.

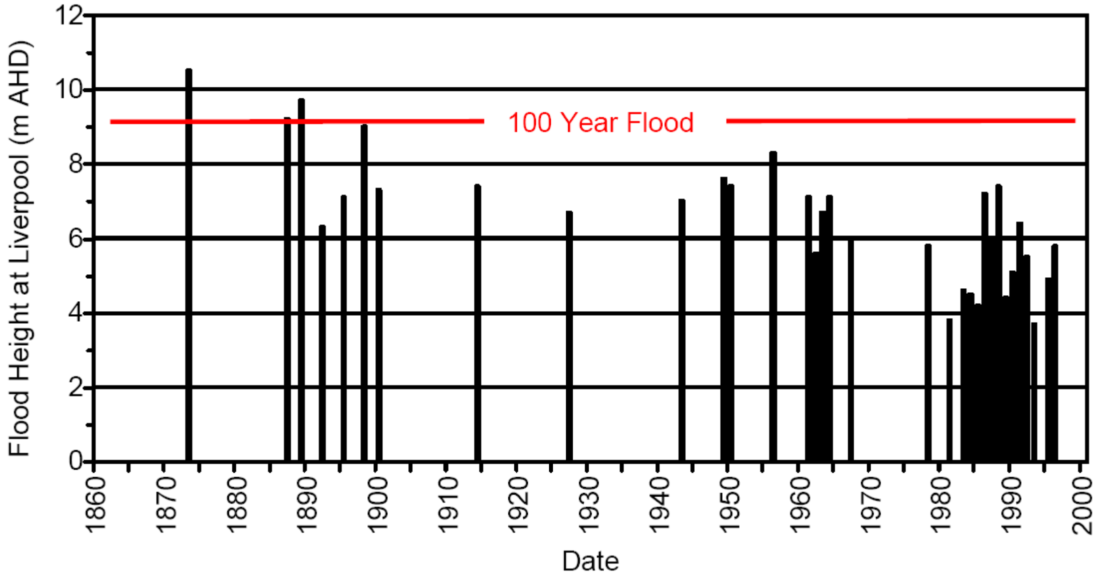


Figure 5.1 – Flood record at Liverpool Weir (DLWC, 1997)

The largest flood events which have occurred within the 30 past years are the 1986 and 1988 floods. These events are assessed to be around a 1 in 20 year Annual Recurrence Interval (ARI) flood. More than 1000 residential properties were flooded by the 1988 flood along the Georges River, Cabramatta and Prospect Creeks.

The major flood which occurred within the last 100 years was the 1956 flood event but this flood is still relatively small in comparison to some other floods from the previous century. The most significant flood ever recorded occurred in 1873 and was 1m higher than the estimated 100 year ARI flood, while three other large floods equalling the 100 year ARI event were recorded at the end of the 19th century (DLWC, 1997).

5.3 Freshwater Inflow

Freshwater inflows are directly linked to rainfall. In highly urbanised areas, there is more impervious area which results in higher runoff flowing into the river after a storm rainfall event. Natural freshwater inflow from the uppermost reaches of the river is controlled by the Liverpool Weir.

Freshwater inflows in the Georges River are generally low (dry weather conditions). In the higher reaches the water becomes brackish and reaches fresh conditions. Under wet weather conditions, the Georges River may be stratified for up to two weeks.

Figure 5.2 represents 20 years of measure of the annual flow for the Georges River/Botany Bay Catchment between 1986 and 2005. Between 1993 and 2005, relatively dry conditions prevailed.

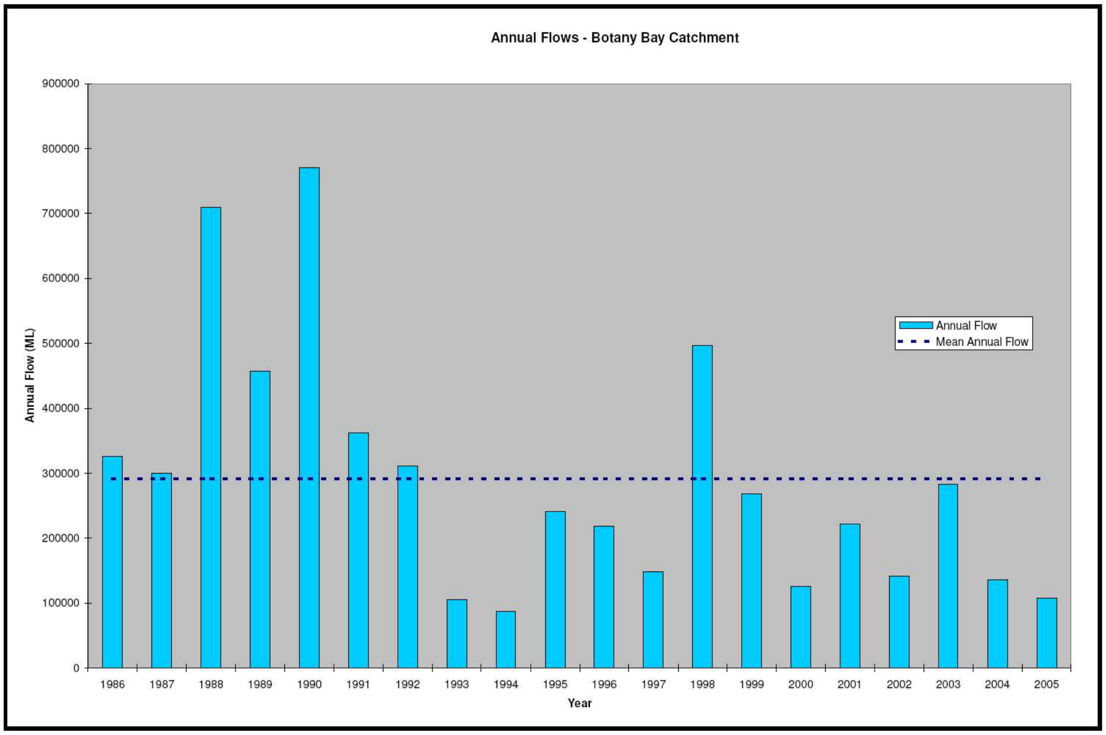


Figure 5.2 – Mean annual Flow between 1986 and 2005 for the Botany Bay Catchment (BBCCI, 2007)

Figure 5.3 represents the mean annual flows of each sub-catchment. Runoff is more important in the lower reaches of the Georges River Catchment, along Prospect Creek and at the southern end of the Georges River. Flows coming from the uppermost reaches of the river are mostly retained by the Liverpool Weir and the Woronora Dam.

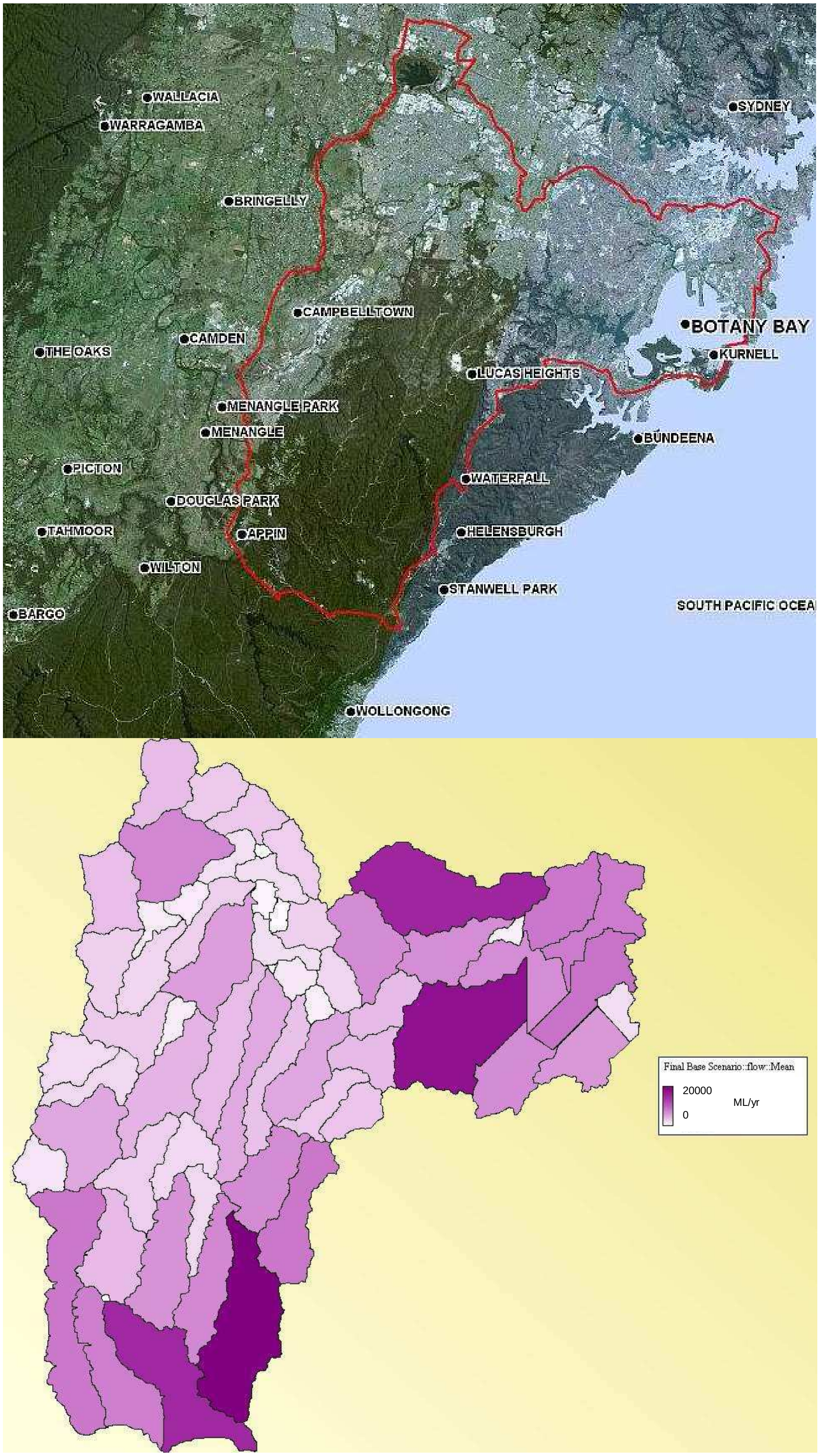


Figure 5.3 – Mean annual areal flow along Botany Bay Catchment (BBCCI, 2007)

5.4 Previous Flood Models and Studies

Several studies of the flood behaviour have been undertaken using different methods of analysis. PWD (1966) assumed that the floodplain between Liverpool and East Hills was comprised of four interconnected ponds. The water level in each pond was linked with the flood height at Liverpool gauge. This flood model was predominantly used for warning purposes.

Sinclair Knight and Partners (1978) prepared preliminary floodplain maps to define the extent of the floodplain, in response to the government's 1977 floodprone land policy. However, this investigation assumed that all floods would behave like the 1956 event which is not likely now, given the significant changes due to the works in the Chipping Norton Area. In 1981, SKP proposed flood mitigation measures for the identified flood problem areas which were Carinya Road, East Hills, Kelso Creek, the Milperra-Moorebank floodway, Rabaul Road, Prospect Creek and Cabramatta Creek.

Some physical models have been set up by the Public Department Works (1983) to investigate the flood mitigation options. The first model was an investigation of the flood mitigation works for the Milperra-Moorebank floodway whose conclusion was the adoption of extensive voluntary purchase schemes for Liverpool and Bankstown Councils. Three kilometres of the river centred on the Milperra Bridge were modelled and the model was extended downstream to East Hills for investigations of the proposed M5 bridge two years later. The model was extended further downstream to Picnic Point for the study of the flood mitigation works at East Hills and Carinya Road.

A separate model was constructed at Manly Hydraulics Laboratory in 1979/1980 to study the tidal hydraulics of the proposed Chipping Norton Lakes Scheme. Overbank flows consideration was added to the model in 1982 and the model was extended to incorporate Prospect Creek and Rabaul Road.

In 1991, the University of NSW Water Research Laboratory undertook the investigation of flood mitigation measures between Liverpool and Picnic Point using a physical model (see Figure 5.4). Inflows from the various creeks and from the Liverpool Weir were computer controlled and flood levels throughout the model were recorded.

An extensive MIKE-11 hydraulic model was developed by Bewsher Consulting in 2004. This numerical model covered the Georges River from Botany Bay to Cambridge Avenue at the Liverpool/Campbelltown LGA boundary. These MIKE-11 models used the physical models as a calibration and allow the determination of the design flood level downstream of Picnic Point. Flooding in the Lower Georges River can result from rising water levels in Botany Bay or high river flows. The calculation of the 20 and 100 year flood levels have assumed a coincidence with a mean high water level in Botany Bay while the Probable Maximum Flood (PMF) coincides with an extreme storm tide level. A flood rise rate of 0.5m/hr was adopted for the majority of the river. The mean high water levels are around 0.6m AHD while the highest tides reach around 1.1m AHD. Taking into account the storm surge due to low pressure systems, the wind setup and the wave setup, the Department of Land and Water Conservation recommended the Storm Tide Levels in Botany Bay given in Table 5.1.

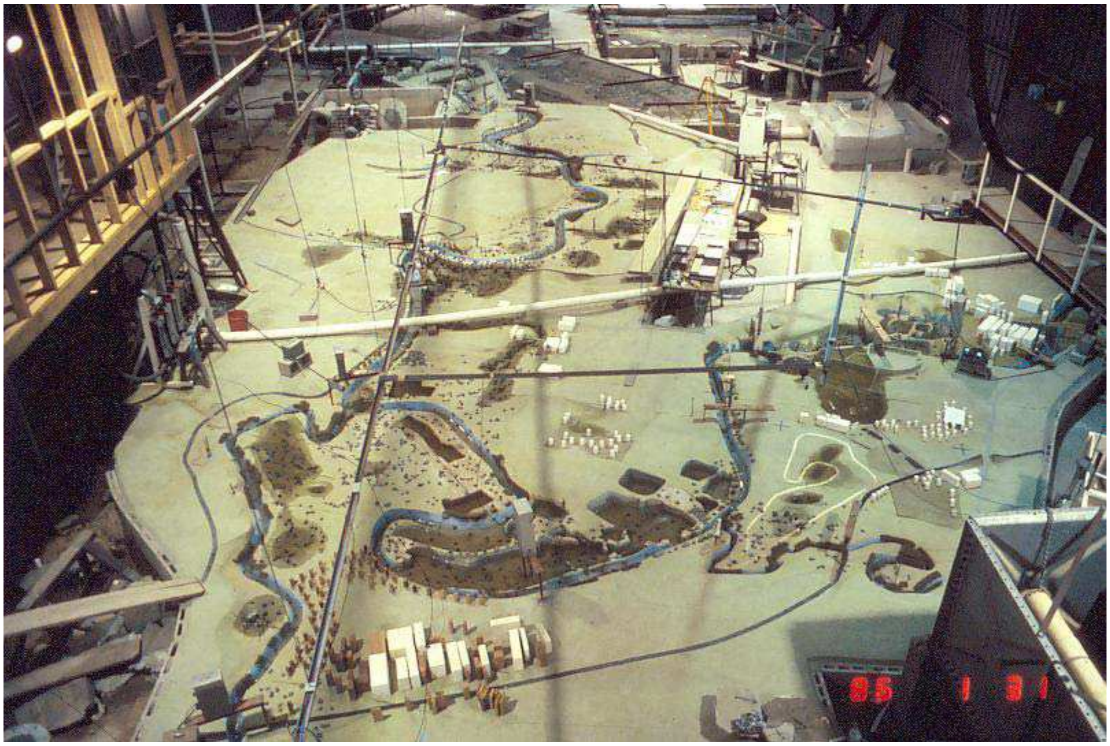


Figure 5.4 – Physical model of the upper reaches of the Georges River (WRL, 1991)

Table 5.1 – Storm tide levels in Botany Bay from the Department of Land and Water Conservation (2002) (Bewsher Consulting, 2004)

Type of Tide	Peak Water Level (m AHD)
Normal High Tide	0.6
High Spring Tide	1.1
20 year Storm Tide	1.5
100 year Storm Tide	1.7
Extreme Storm Tide	2.0

The flood level contour for the 20, 50 and 100 year ARI events between Picnic Point and Liverpool Weir are given in Figures 5.5 to 5.10, while the 20 year ARI, 100 year ARI and PMF flood events for the lower reaches are given in Figures 5.11 to 5.13. Moreover, a summary of the homes and buildings impacted by flooding from the Georges River (identified in Bewsher 2004) and the number of properties located in the different flood risk areas (high, medium and low) is provided in Tables 5.2 and 5.3. The different zones are defined as:

- ***High Flood Risk:*** Land below the 100 year ARI flood that is either subject to a high hydraulic hazard (i.e. provisional high hazard in accordance with the criteria outlined in the *Floodplain Management Manual*) or where there are significant evacuation difficulties.
- ***Medium Flood Risk:*** Land below the 100 year ARI flood level that is not subject to high hydraulic hazard and where there are no significant evacuation difficulties.
- ***Low Flood Risk:*** All land within the floodplain (i.e. within the PMF extent) but not identified as either in a high flood risk or medium flood risk area.

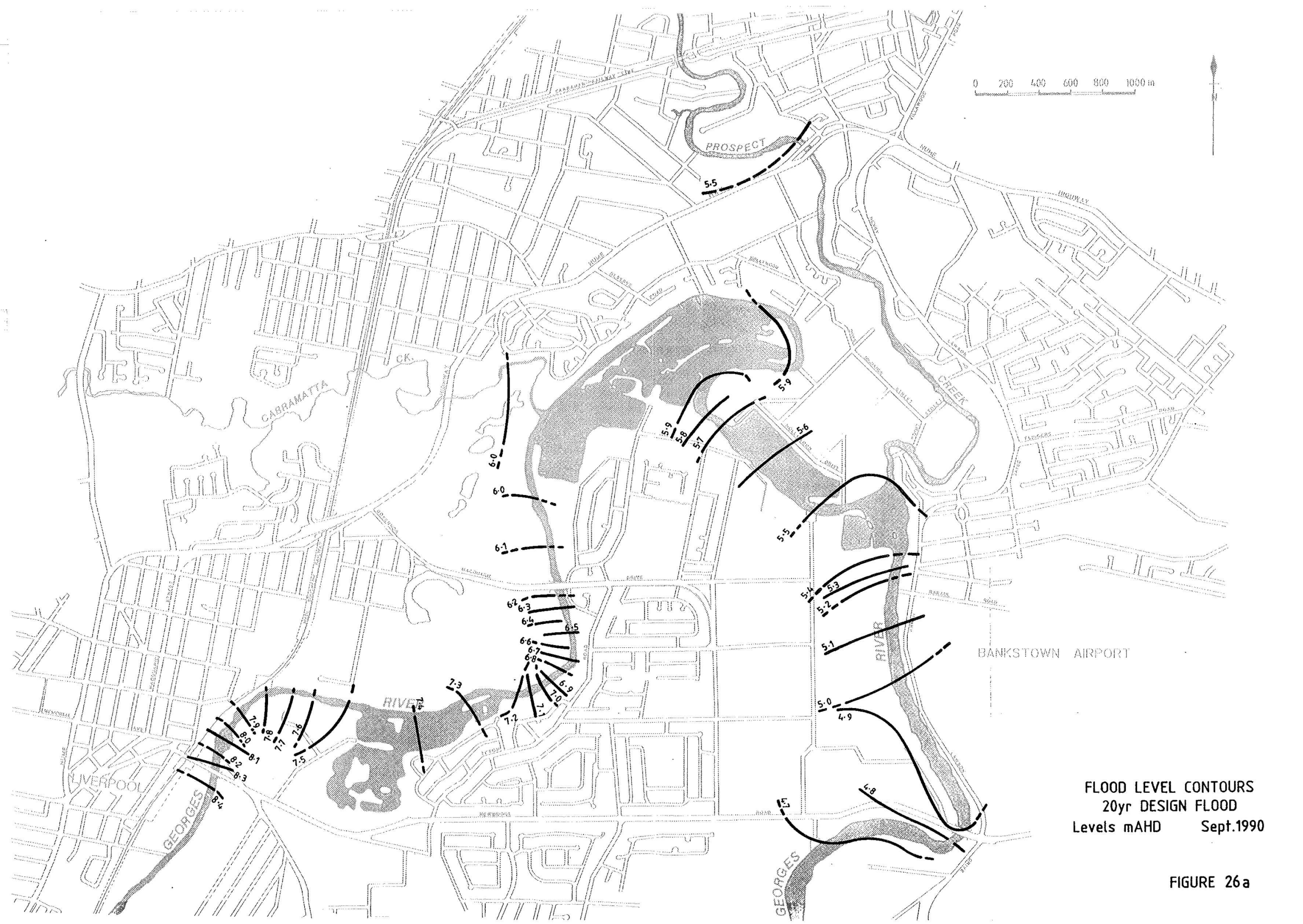


Figure 5.5 – Flood Level Contours between Liverpool Weir and Newbridge Road Bridge for a 20 year ARI event (PWD/WRL, 1991)

Figure 5.6 – Flood Level Contours between Vale of Ah and Picnic Point for a 20 year ARI event (PWD/WRL, 1991)

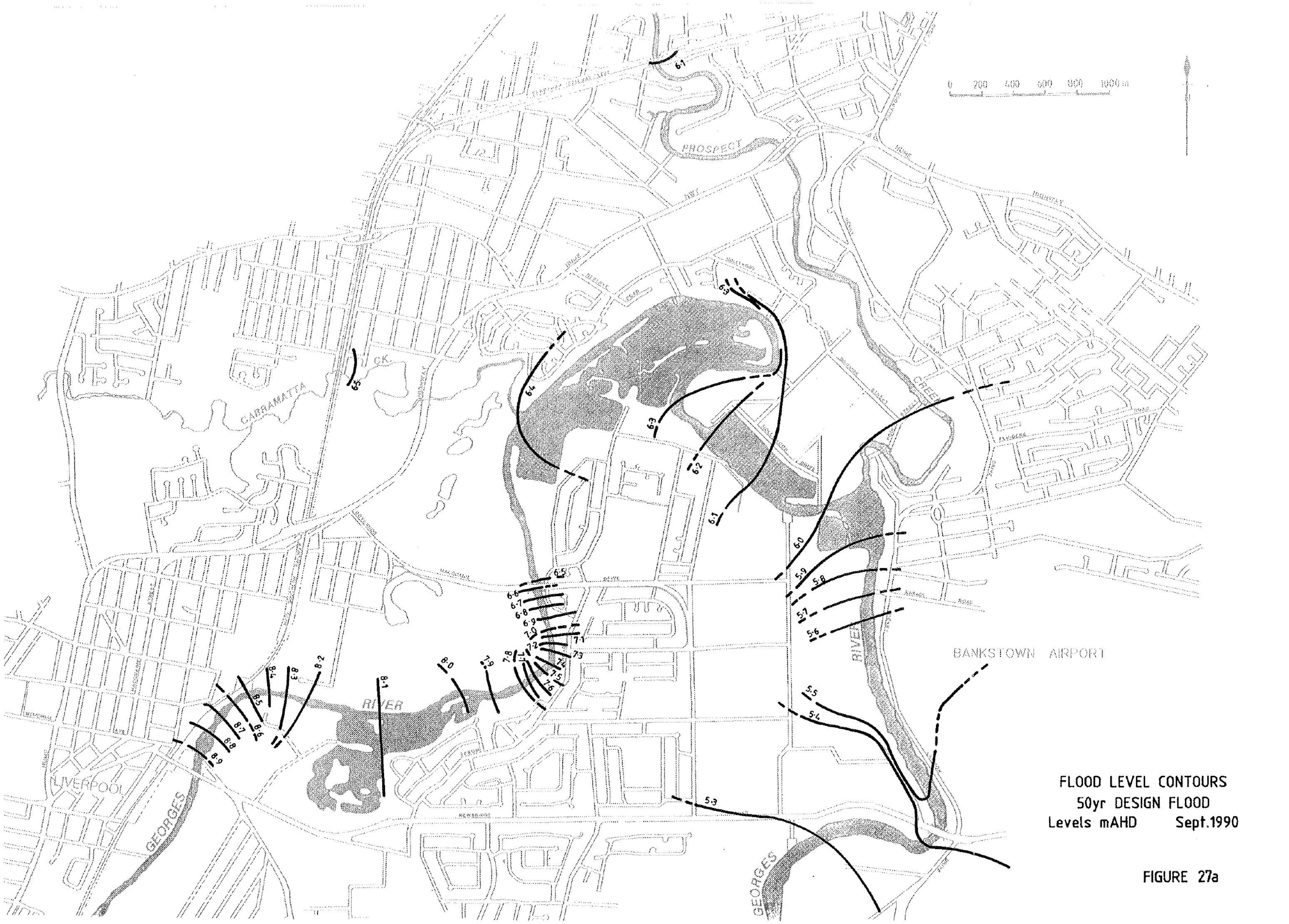


Figure 5.7 – Flood Level Contours between Liverpool Weir and Newbridge Road Bridge for a 50 year ARI event (PWD/WRL, 1991)

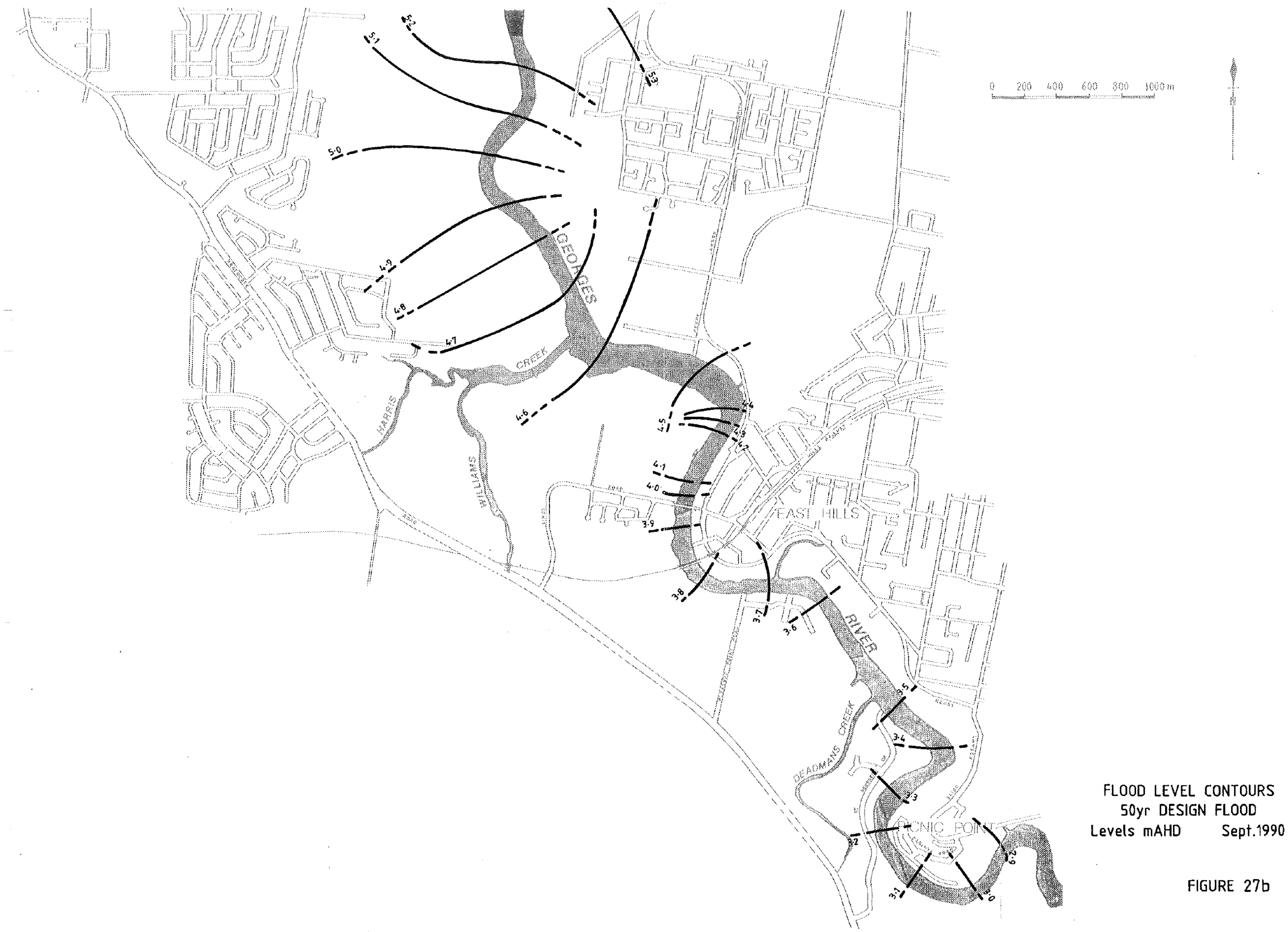


Figure 5.8 – Flood Level Contours between Vale of Ah and Picnic Point for a 50 year ARI event (PWD/WRL, 1991)

SMEC

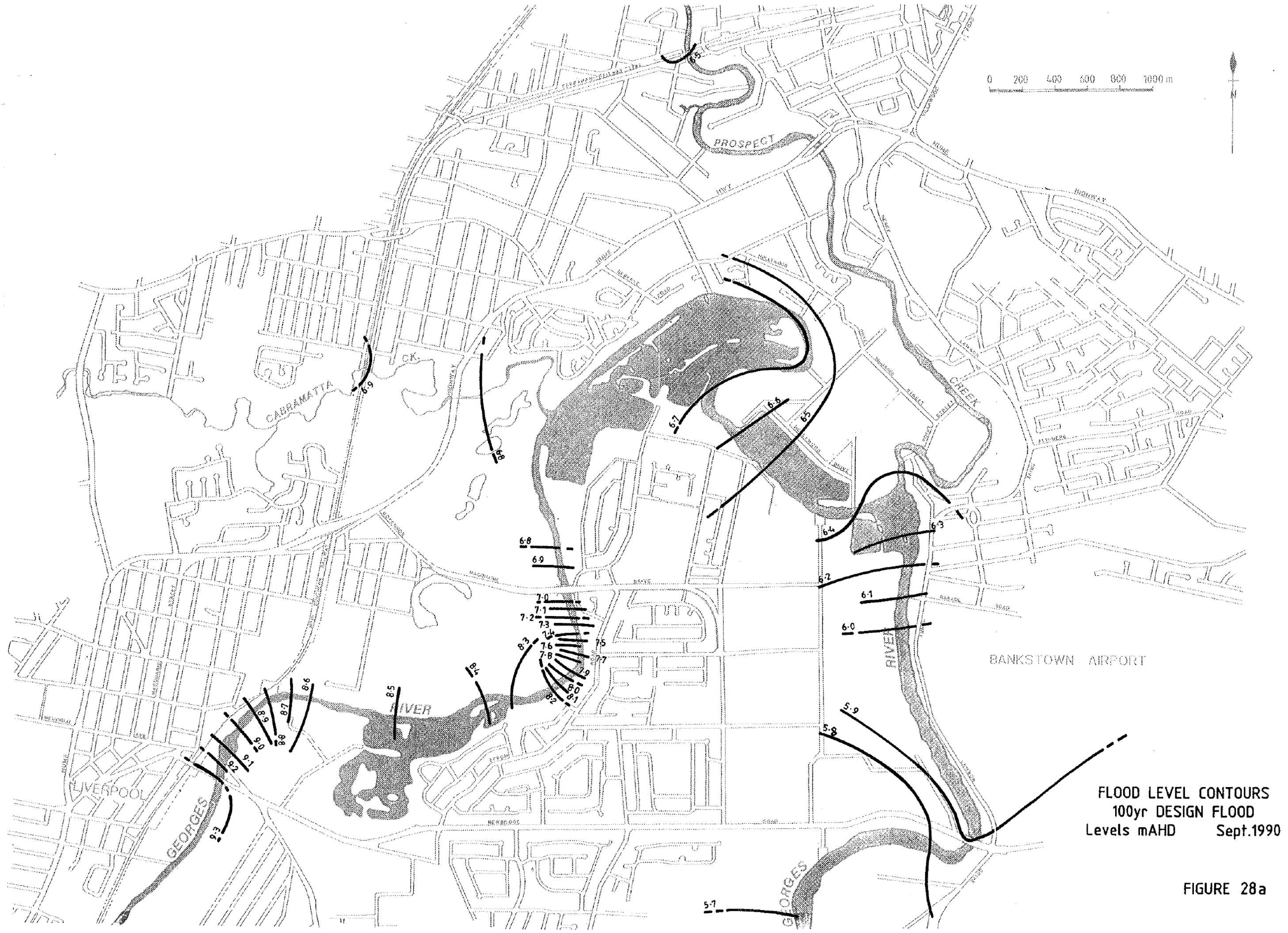


Figure 5.9 – Flood Level Contours between Liverpool Weir and Newbridge Road Bridge for a 100 year ARI event (PWD/WRL, 1991)

Figure 5.10 – Flood Level Contours between Vale Of Ah and Picnic Point for a 100 year event (PWD/WRL, 1991)

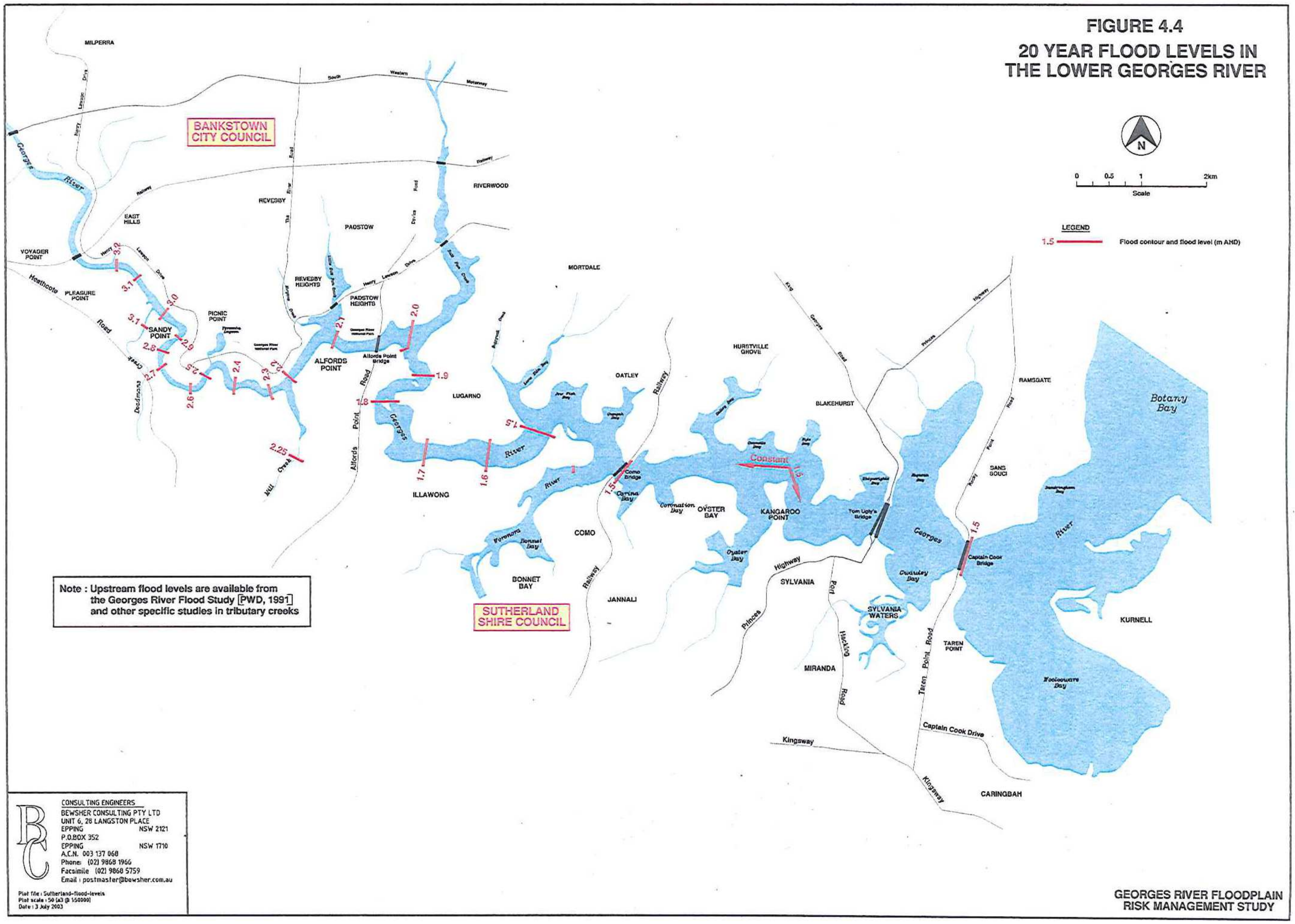


Figure 5.11 – Flood Level Contours between East Hills and Botany Bay for a 20 yearARI flood event (Bewsher Consulting, 2004)

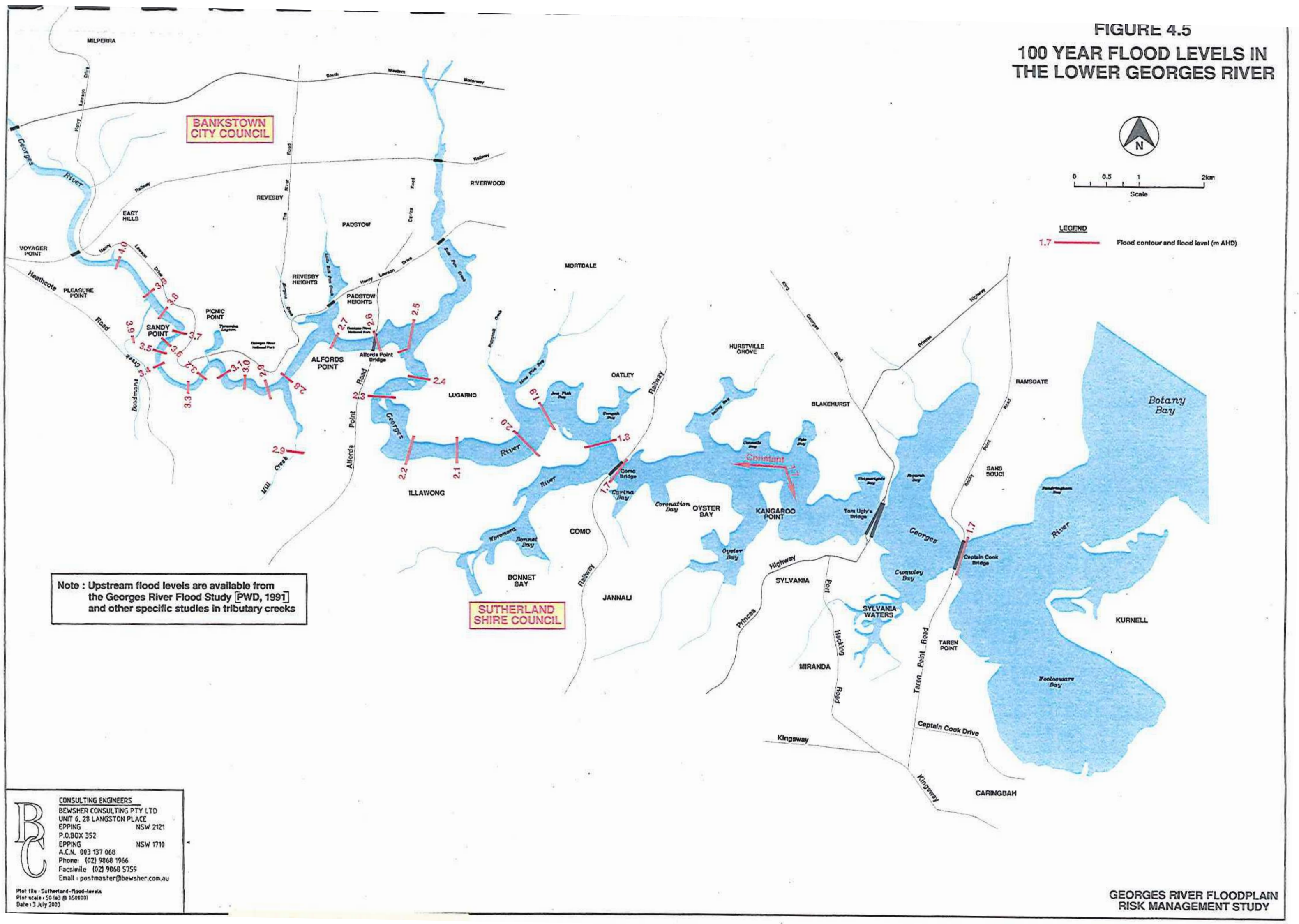


Figure 5.12 – Flood Level Contours between East Hills and Botany Bay for a 100 year ARI flood event (Bewsher Consulting, 2004)

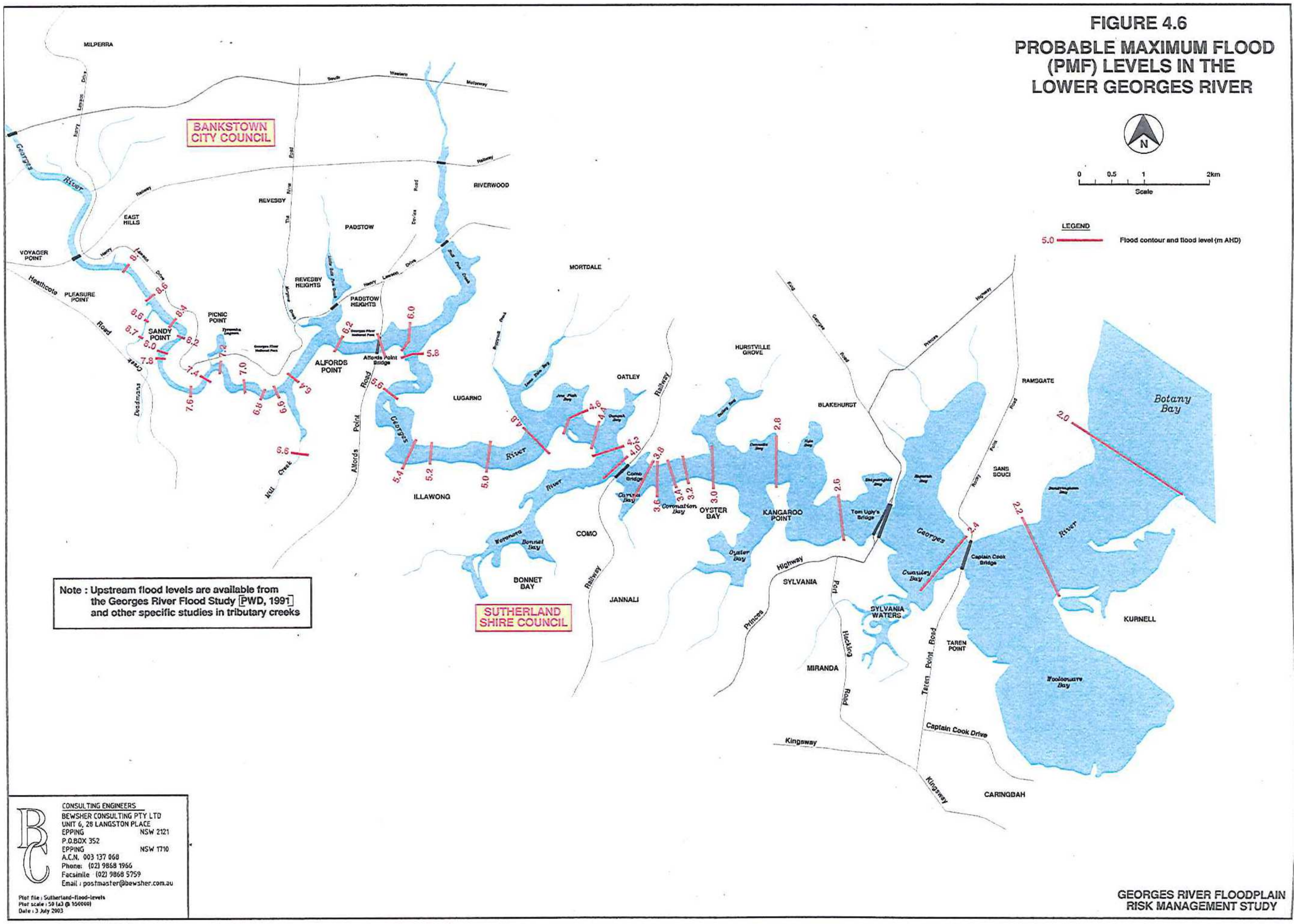


Figure 5.13 – Flood Level Contours between East Hills and Botany Bay for a PMF flood event (Bewsher Consulting, 2003)

Table 5.2 - Table of the buildings and properties affected by flooding from the Georges River (Bewsher Consulting, 2004)

Residential Properties containing a house affected by Flooding						
Location	20 Year Flood		100 Year Flood		PMF	
	Property	Homes	Property	Homes	Property	Homes
Liverpool City Council	231	118	732	308	2,637	2,463
Fairfield City Council	227	136	326	239	656	645
Bankstown City Council	126	45	261	156	2321	2024
Sutherland Shire Council	32	11	44	18	83	72
TOTAL	616	310	1,363	721	5,697	5,204
Commercial and Industrial Properties containing a building affected by Flooding						
Location	20 Year Flood		100 Year Flood		PMF	
	Property	Building	Property	Building	Property	Building
Liverpool City Council	49	21	162	122	266	265
Fairfield City Council	23	15	34	30	85	84
Bankstown City Council	42	36	65	64	266	242
Sutherland Shire Council	0	0	0	0	0	0
TOTAL	114	72	261	216	617	591

Table 5.3 - Number of properties in the different flood risk areas (Bewsher Consulting, 2004)

Location	Flood Risk Area			
	High Risk	Medium Risk	Low Risk	Total
Liverpool City Council	608	422	2513	3543
Fairfield City Council	389	148	288	825
Bankstown City Council	1629	720	1621	3970
Sutherland Shire Council	22	52	18	92
TOTAL	2648	1342	4440	8430

5.5 Major developments impacting the flood behaviour

The different studies and models give the flood behaviour in 1988. However, several significant developments were undertaken over the last 20 years within the Georges River catchment, which can have an impact on the flood behaviour. These developments are listed below.

- Upstream catchment development: New development area in the upper Prospect Creek and Cabramatta Creek catchments over the last 15 years have increased impervious catchment area and hence, urban runoff. However the impact has been mitigated by several drainage strategies and flood mitigation measures implemented by Councils in the upper reaches (Bewsher Consulting, 2004).
- Chipping Norton Lake Scheme: The scheme commenced in 1977 and was completed in the mid-1990s. Only some minor changes occurred after 1988 as the flood behaviour in the Lakes scheme is influenced by channel constrictions along Long Point, Coot Island and the Georges River downstream of Dhurawal Bay, which did not change since 1986.
- Filling at Bankstown Airport: The areas near Milperra Road and Henry Lawson Drive are low and were affected by the 1986 and 1988 floods. Therefore, these areas have been filled to the 100 year ARI flood level. The resulting loss in floodplain storage will increase the flood levels as shown in Table 5.4.

Table 5.4 – Mike 11 model results for the impact of the Bankstown Airport Filling (Bewsher Consulting, 2004)

Location	River Chainage (Km)	Section No. (Refer Fig. 4.1)	Change in 100 year Flood Level (mm)
Liverpool Weir	0	UPPERGEORGES 106530	0
William Long Bridge	3060	CNWEIR 3060	+13
Cabramatta Creek	4360	CNWEIR 4360	+18
Prospect Creek	8720	MILCN 8720	+23
Rabaul Road	9880	MILCN 9880	+34
Moorebank VP area	N/A	ARTHUR 180	+47
Airport Site	N/A	MIL DRAIN 7670	+65
Milperra Road	10930	MILCN 10930	+37
Milperra Drain	12620	SPMIL 12620	+37
M5 Motorway	14150	SPMIL 14150	+37
Williams Creek	14760	SPMIL 14760	+32
Kelso Creek	15880	SPMIL 15880	+31
East Hills Railway	16970	SPMIL 16970	+30
Deadmans Creek	18610	SPMIL 18610	+28
Salt Pan Creek	25220	SPMIL 25220	+19
Como Bridge	31635	GEORGES 31635	+1

- Moorebank-Milperra floodway: Around 194 houses of Liverpool and Bankstown Council had to be removed from the floodway. Over half of the houses were demolished and this resulted in changes in the flood level provided in the Table 5.5 below.

Table 5.5 – Mike 11 model results for the impact of the houses removal along the Moorebank-Milperra floodway (Bewsher Consulting, 2004)

Location	River Chainage (Km)	Section No. (Refer Fig. 4.1)	Change in 100 year Flood Level (mm)
Liverpool Weir	0	UPPERGEORGES 106530	0
William Long Bridge	3060	CNWEIR 3060	-7
Cabramatta Creek	4360	CNWEIR 4360	-8
Prospect Creek	8720	MILCN 8720	-10
Rabaul Road	9880	MILCN 9880	-14
Milperra Road	10930	MILCN 10930	-9
Milperra Drain	12620	SPMIL 12620	+5
M5 Motorway	14150	SPMIL 14150	+6
Williams Creek	14760	SPMIL 14760	+6
Kelso Creek	15880	SPMIL 15880	+5
East Hills Railway	16970	SPMIL 16970	+5
Deadmans Creek	18610	SPMIL 18610	+4
Salt Pan Creek	25220	SPMIL 25220	+4
Como Bridge	31635	GEORGES 31635	0

- Activities at Moorebank: Many sand extraction and stockpiling works occurred on land at Moorebank since the 1970s. These activities have increased the 100 year ARI flood level by 120mm at Newbridge Road. Most changes were realised before 1988 and are included in the previous model. However, the site should be rehabilitated to its natural shape at the end of the works, which would improve the flood condition.
- M5 Bridge construction: The RTA started the construction of the bridge in 1991. A temporary access track 1-2m above natural floodplain levels was formed downstream of the bridge to assist with the bridge construction. However this track was not removed after the construction as expected and the combined effect of it and the bridge impact on the flood level is shown on the Table 5.6 below.

Table 5.6 – Mike 11 model results for the impact of M5 bridge and its access track (Bewsher Consulting, 2004)

Location	River Chainage (Km)	Section No. (Refer Fig. 4.1)	Change in 100 year Flood Level (mm)
Liverpool Weir	0	UPPERGEORGES 106530	0
William Long Bridge	3060	CNWEIR 3060	+3
Cabramatta Creek	4360	CNWEIR 4360	+4
Prospect Creek	8720	MILCN 8720	+9
Rabaul Road	9880	MILCN 9880	+25
Milperra Road	10930	MILCN 10930	+42
Milperra Drain	12620	SPMIL 12620	+52
M5 Motorway	14150	SPMIL 14150	+74
Williams Creek	14760	SPMIL 14760	-51
Kelso Creek	15880	SPMIL 15880	-50
East Hills Railway	16970	SPMIL 16970	-47
Deadmans Creek	18610	SPMIL 18610	-41
Salt Pan Creek	25220	SPMIL 25220	-3
Como Bridge	31635	GEORGES 31635	-1

- Flood Mitigation Works at East Hills: Bankstown Council started the construction of an upstream deflector levee and five finger levees at East Hills in 1995. The flow of water across the floodplain has been reduced and the changes in flood behaviour are shown in the Table 5.7 below.

Table 5.7 – Mike 11 model results for the impact of the East Hills Levees (Bewsher Consulting, 2004)

Location	River Chainage (Km)	Section No. (Refer Fig. 4.1)	Change in 100 year Flood Level (mm)
Liverpool Weir	0	UPPERGEORGES 106530	0
William Long Bridge	3060	CNWEIR 3060	+1
Cabramatta Creek	4360	CNWEIR 4360	+2
Prospect Creek	8720	MILCN 8720	+2
Rabaul Road	9880	MILCN 9880	+3
Milperra Road	10930	MILCN 10930	+3
Milperra Drain	12620	SPMIL 12620	+3
M5 Motorway	14150	SPMIL 14150	+5
Williams Creek	14760	SPMIL 14760	+6
Kelso Creek	15880	SPMIL 15880	+7
East Hills Railway	16970	SPMIL 16970	0
Deadmans Creek	18610	SPMIL 18610	-1
Salt Pan Creek	25220	SPMIL 25220	0
Como Bridge	31635	GEORGES 31635	0

- Flood Mitigation Works at Carinya Road: a finger levee scheme was also undertaken at Carinya Road. Its impact on the flood level is provided in Table 5.8.

Table 5.8 – Mike 11 model results for the impact of the Carinya Road Levees (Bewsher Consulting, 2004)

Location	River Chainage (Km)	Section No. (Refer Fig. 4.1)	Change in 100 year Flood Level (mm)
Liverpool Weir	0	UPPERGEORGES 106530	0
William Long Bridge	3060	CNWEIR 3060	0
Cabramatta Creek	4360	CNWEIR 4360	+1
Prospect Creek	8720	MILCN 8720	+2
Rabaul Road	9880	MILCN 9880	+4
Milperra Road	10930	MILCN 10930	+6
Milperra Drain	12620	SPMIL 12620	+6
M5 Motorway	14150	SPMIL 14150	+9
Williams Creek	14760	SPMIL 14760	+9
Kelso Creek	15880	SPMIL 15880	+12
East Hills Railway	16970	SPMIL 16970	+17
Deadmans Creek	18610	SPMIL 18610	+21
Salt Pan Creek	25220	SPMIL 25220	-1
Como Bridge	31635	GEORGES 31635	-1

- Carpark Filling of the Deepwater Motor Boat Club: The carpark was filled in 1998 by the club owner and an investigation by Bankstown Council noted that it could impact the upstream flood level by up to 10mm in the 100 year ARI flood.

The cumulative effect of the different development is given in Table 5.9.

Table 5.9 – Mike 11 model results for the cumulative impact of the different development (Bewsher Consulting, 2004)

Location	River Chainage (Km)	Section No. (Refer Fig. 4.1)	Change in 100 year Flood Level (mm)
Liverpool Weir	0	UPPERGEORGES 106530	0
William Long Bridge	3060	CNWEIR 3060	+15
Cabramatta Creek	4360	CNWEIR 4360	+23
Prospect Creek	8720	MILCN 8720	+33
Rabaul Road	9880	MILCN 9880	+63
Milperra Road	10930	MILCN 10930	+100
Milperra Drain	12620	SPMIL 12620	+117
M5 Motorway	14150	SPMIL 14150	+146
Williams Creek	14760	SPMIL 14760	+14
Kelso Creek	15880	SPMIL 15880	+18
East Hills Railway	16970	SPMIL 16970	+18
Deadmans Creek	18610	SPMIL 18610	+23
Salt Pan Creek	25220	SPMIL 25220	+27
Como Bridge	31635	GEORGES 31635	+2

Given the low difference in flood level, the design flood levels from 1991 were adopted. The 100 year ARI flood level (plus freeboard) has been retained as the principal floor level control for residential land uses in the study area.

5.6 Floodplain Management Options

Several different management measures have been undertaken along the Georges River. These mitigation measures are:

- Voluntary purchase: Around 200 houses located on the floodway have been identified by Liverpool and Bankstown City Councils to be acquired and demolished. This measure started in the early 1980's with financial assistance from the State and Commonwealth Government but the Commonwealth assistance stoped in the 1990s slowing down the process, while over half of the houses were acquired.
- House raising: this option was used by Fairfield City Council along the Lower Prospect Creek. More than 120 houses were raised and some others were demolished and replaced by new elevated houses.
- Levee banks: A levee was built in Kelso Park in 1986 and deflector levees were constructed at Carinya Road and East Hills. The deflector levees don't stop inundation but slow flood velocities to avoid major damages.
- Upstream Retarding Basins: Drainage strategies like schemes with numerous retarding basins were developed in Fairfield, Liverpool and Campbelltown to mitigate the increase in runoff volume.
- Flood warning: the warning system aims to provide at least 6 hours warning of expected peak flood heights based on actual rainfall and 12 hours warning based on predicted rainfall. Level recorder results are published on the Internet (http://www.bom.gov.au/hydro/flood/nsw).

6 WATER QUALITY

Water quality describes the suitability of a particular body of water for a specific use, but it can also generally indicate the relative health of a waterway.

This section of the report desrcibes the water quality of the Georges River Estuary in terms of:

- The physical, chemical and biological processes, interactions and management practices which influence water quality within the Georges River Estuary
- Water quality and river flow objectives for the Georges River
- Sources of pollution – diffuse and point sources
- Historical and contemporary water quality data and long term trends in water quality in relation to the ANZECC 2000 Water Quality Guidelines
- A review of historical and existing studies on water quality in the Georges River Estuary

6.1 Introduction

Water quality describes and measures the suitability of a particular body of water for a specific use, but it can also generally indicate the relative health of a waterway too. Like many other river estuary systems, the Georges River and Botany Bay system functions through a number of interacting and interdependent processes which largely characterises the river's behaviour and visual aspect - from which water quality is derived. These processes are dynamic and constantly changing in both their magnitude and influence on the environment. Some of the more fundamental processes directly affecting water quality involves material transport into and out of the system via natural water flows (freshwater and marine), anthropogenic sources and sinks, and through the atmosphere. On a smaller scale, this transportation can be explained by physical processes of mixing, and advective or dispersive transport. These transport processes interact with other processes involving chemical transformations, biological processes and energy inputs and outputs of light and heat. Thus, the water quality that is observed presently is the product of numerous past physical, chemical and biological interactions, many of which are still poorly understood today due to their highly complex nature.

In the past, the Georges River has been plagued by a number of poor management practices, where actions were taken based on little knowledge or foresight into the potential long term environmental impacts on the river's water quality and the possible implications for its use today. Up until the 1970's and 1980's, extensive dredging activities along the river and the eventual construction of the Chipping Norton Lakes has largely altered the hydrodynamics of the river and has subsequently increased turbidity through increased bank instability. On the other extreme, land reclamation activities up until the 1970's caused the destruction of many wetlands while also using landfill waste as fill. This has partially been responsible for the collapse of an oyster, prawn and fish industry in the Georges River due to a loss in spawning habitats and degradation of water quality caused by leachate seepage into the river. Raw sewage, which is high in nutrients, pathogens, wet weather sewage overflows and other pollutants were being discharged directly into the river from the Glenfield sewage treatment plant in the 1960's, causing wide spread issues of eutrophication and poor water quality in the upper sections of the Georges River. This legacy of uncontrolled waste dumping also expanded to industrial wastes and chemicals being discarded into the river. While some areas of the river have recovered from the past pollution, many of the toxic chemicals, heavy metals and pollutants still remain in the Georges River bound to bed sediment.

Presently, a much more ecologically sustainable and focused approach is being adopted to manage the Georges River, having realised the social, environmental and economical value that the river brings to the area. NSW Government put in place a $3 billion Waterways Program to clean up sewage and stormwater in urban areas in May 1997 as well as a $60 million Urban Stormwater Management Program in September 1997 (http://www.environment.nsw.gov.au/ieo/GeorgesRiver/index.htm). $2 million were allocated to local council in the Georges River catchment for specific works to stop stormwater pollution. Georges River Regional Environmental Plan was created in February 1999 to protect water quality and environmental quality of the whole catchment. Water Quality Objectives (WQOs) and River Flow Objectives (RFOs) have been defined for the Georges River Catchment and are summarised in Figure 6.1. WQOs include trigger values for various water quality criteria (e.g. nutrients, turbidity, pH, faecal coliforms, visual clarity, surface films...) for the different activities and goals described in Figure 6.1. RFOs detail the different measures to reach the objectives listed in Figure 6.1.

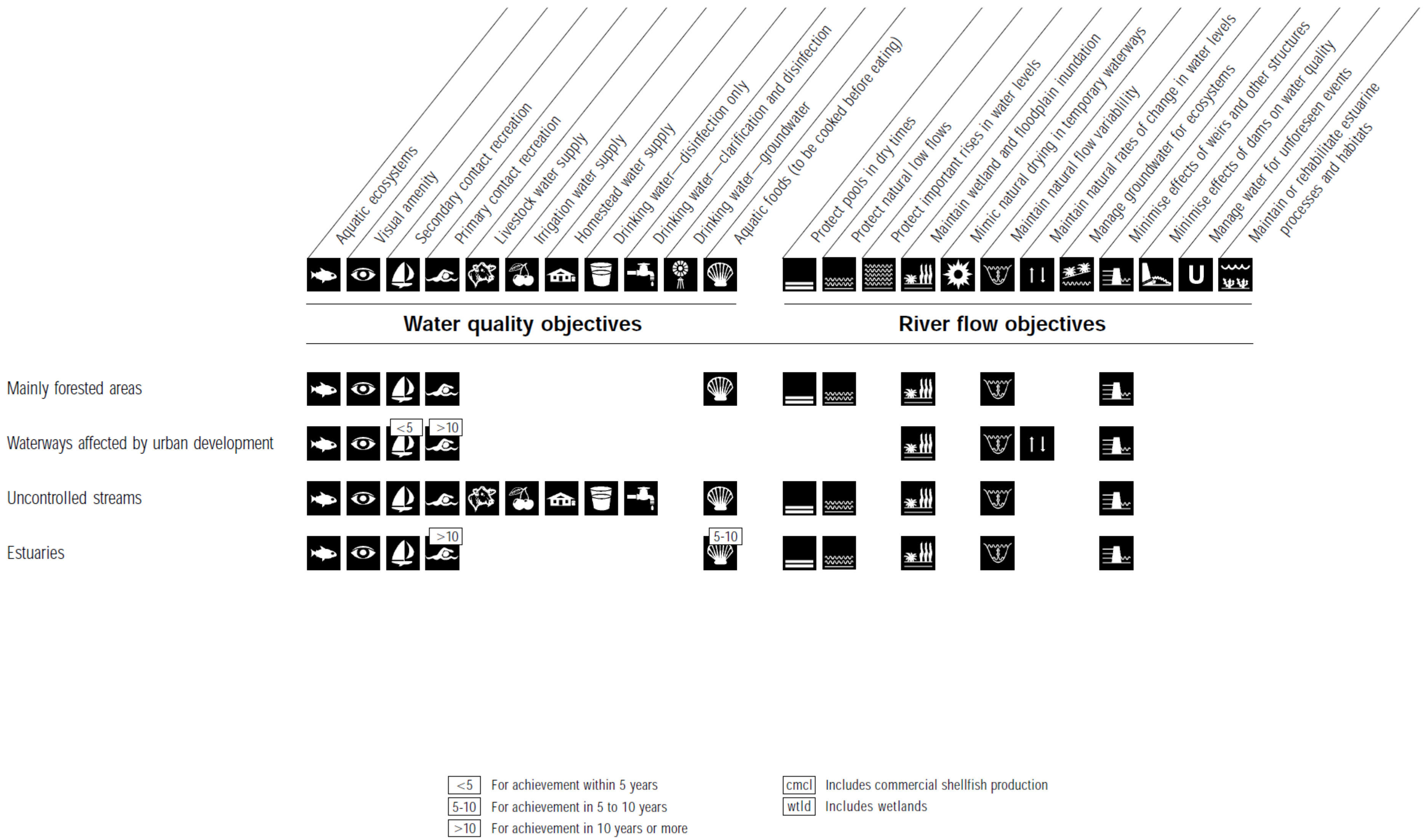


Figure 6.1 – Water quality and river flow objectives (http://www.environment.nsw.gov.au/ieo/GeorgesRiver/caag.htm)

The study area is located in the "Estuaries" area

While it is a move in the right direction, there still remain several significant challenges to upholding a level of water quality that is beneficial for ecosystems and recreational use. A number of point and diffuse sources continue to significantly contribute towards the degradation of water quality in the Georges River. The highly urbanised catchment areas surrounding the main river channel continue to grow in population density, exerting more pressure on the aging stormwater and sewerage infrastructure, along with increasing the amount of pollution and sediments that are being washed off an expanding catchment area of paved surfaces. Sewage overflows discharging into the river are becoming more frequent with less intense rainfall due to its aging capacity and the growing demand, while stormwater from urban catchments are contributing substantially to an increasing influx of gross pollutants, heavy metals and nutrients into the river (Sydney Water Corporation, 1998). Recreational activities like dirt biking and four wheel driving along some sections of the river's foreshores continue to contribute to water turbidity by destabilising soil structure and destroying foreshore vegetation resulting in increased risks of soil loss through erosion. A tension exists between the growing demands of human population needs, the recreational value of the river and its foreshores, and sustaining the environment such that it remains capable of serving the rich habitat of flora and fauna. By correctly balancing each of these pressures and ensuring a minimum standard of water quality for the Georges River, it will provide a way forward to securing the value that the river provides to the wider community.

6.2 Sources of Pollution

Poor water quality is usually a direct result of water pollution, and its impacts are frequently to the detriment of the flora and fauna in the affected environment. This is caused by direct or indirect pollutant discharge into the waterways without sufficient screening or treatment to remove the harmful constituents before it enters the river. Such sources of pollution can be broadly organised under two categories – diffuse source and point source.

6.2.1 Diffuse Source

Diffuse source pollution refers to contaminants and pollutants that emanate and enter the waterways from a non discrete single source. Urban runoff is the main diffuse source, concentrating a wide variety of pollutants from roads and other impervious surfaces. Diffuse sources include river bank erosion, atmospheric dust, illegal industrial discharges or agricultural and domestic runoff. Water used outside the home (e.g. watering garden or washing cars) was equivalent to an extra 43% in annual rainfall in 1977 and might be higher now (Florence et al, 1999). It has an accumulative effect of amalgamating small quantities of contaminants over a large area. Seepage from septic systems contributes to this also. Due to the expansive nature of diffuse source pollution, it is relatively difficult to identify and manage at the end point, especially for substances that are sufficiently small to be dissolved or entrained in stormwater runoff. However for larger and bulkier contaminants, devices like gross pollutant traps are useful to control the distribution of pollution.

With the various water quality parameters identified and discussed in this report, diffuse source pollution are generally recognised as the predominant source of pollution for most of these parameters in the Georges River. Diffuse source pollution became the major pollution source since the construction of the effluent diversion from Glenfield STP to Malabar (Rish, 1992). Moreover, this pollution source was exacerbated by the increasing urbanisation within the Georges River catchment area. This was predominantly represented by pollution washed down by stormwater from urban runoff after storm events. Nutrients like phosphorus and nitrogen would be leached from gardens, parks and sports fields, while particles or sediments bound with heavy metals and chemicals would be flushed from the paved surfaces of the catchment area into the river through overland or sheet flow. Stormwater runoff is a fundamentally central pollution issue for the Georges River as its catchments are so heavily urbanised with continual increases in population density and escalating use of major roads and motorway corridors. The cumulative effect of this pollution in conjunction with intermittent events of rainfall often equates to substantially poorer water quality in the river after each storm event until it gets sufficiently flushed and diluted from tidal flows.

Data from the monitoring of stormwater quality was sourced from a number of Local Governments adjacent to Botany Bay and the average concentrations of pollutants from stormwater discharges from urban areas of the Botany Bay catchment are summarised in Table 6.1 below.

Table 6.1 - Average concentrations of pollutants from stormwater discharges from urban areas of the Botany Bay catchment (WBM, 2003)

Variable	Average	ANZECC/ARMCANZ (2000)
Ammonia (mg/L)	**1.26**	0.015[A]
Arsenic (mg/L)	0.86	N/A
BOD (mg/L)	6.77	N/A
Cadmium (mg/L)	**0.05**	0.0055[B]
Chromium (mg/L)	**0.19**	0.0274[B]
Conductivity (mS/cm)	5.85	N/A
Copper (mg/L)	**0.06**	0.0013[B]
Dissolved Oxygen (mg/L)	10.7	N/A
Faecal Coliform (cfu/100mL)	42855086.3	1000[C]
Faecal Streptococci (cfu/100mL)	2227.5	N/A
Lead (mg/L)	**0.02**	0.0044[B]
Mercury (mg/L)	0.001	N/A
Nitrate (mg/L)	1.09	N/A
Oil & Grease (mg/L)	5.95	N/A
Orthophosphorus (mg/L)	0.07	N/A
Oxidised Nitrogen (mg/L)	**1.07**	0.015[A]
pH	7.40	7.0-8.5[A]
Phenol (mg/L)	0.03	0.4[B]
TKN (mg/L)	2.28	N/A
Total Nitrogen (mg/L)	**3.65**	0.3[A]
Total Phosphorus (mg/L)	**0.39**	0.03[A]
Total Suspended Solids (mg/L)	28.5	N/A
Zinc (mg/L)	**0.36**	0.015[B]

A = default trigger values for physical and chemical stressors (south-east Australia); B = trigger values for toxicants (95% protection of species); C = Secondary recreational contact.

6.2.2 Point Source

Point source pollution commonly refers to a single identifiable localised source of pollution, usually discharging into a waterway via a pipe or culvert. Traditionally in the Georges River, point sources would have included any discharge from industrial areas or factories, sewage discharge from a treatment plant or waste material from dredging. As such, they are typically easier to identify and subsequently manage than diffuse sources. However due to much stricter regulations and legislation, point source pollution is currently much more tightly controlled and their impacts on the general water quality of the Georges River would be considered negligible.

Presently, point source pollution in the Georges River could be linked to discharge points such as sewer overflow pipes, stormwater pipes and gross pollutant traps. While these discharge at a discrete point, they are technically diffuse source pollution as they do not originate from a single source, but rather are collected from the whole catchment before being directed through open channels, pipes, pits and culverts to the discharge point.

6.3 Physical, Chemical and Biological Parameters

The consideration of water quality is multifaceted and encompasses physical, chemical and biological factors. As such, a number of specific parameters were adopted from the ANZECC 2000 Water Quality Guidelines to help describe and define the state of the water in more detailed, concrete and measurable terms. Table 6.2 below briefly summarises these parameters with their corresponding environments and trigger values. Tables 6.3 and 6.4 describe the Water Quality Objectives (WQOs) from the DECCW website (http://www.environment.nsw.gov.au/ieo/georgesriver/report-03.htm) and their trigger values.

Table 6.2 – ANZECC 2000 Guidelines for Water Quality

Parameter	Ecosystem type	ANZECC (2000) Trigger Value
Dissolved Oxygen	Lowland Rivers	85-110% sat
	Estuaries	80-110% sat
Turbidity	Lowland Rivers	6-50 NTU
	Estuaries	0.5-10 NTU
Total Phosphorus	Lowland Rivers	50 µg L-1
	Estuaries	30 µg L-1
Total Nitrogen	Lowland Rivers	500 µg L-1
	Estuaries	300 µg L-1
Chlorophyll-a	Lowland Rivers	5 µg L-1
	Estuaries	4 µg L-1
Faecal Coliforms	Recreational Waters	Primary human contact – median of 150 CFU/100mL
		Secondary human contact – median of 1000 CFU/100mL
Copper	Freshwater (99% Species)	1.0µg L-1
Lead	Freshwater (99% Species)	1.0µg L-1
Zinc	Freshwater (99% Species)	2.4µg L-1

Table 6.3 – Water Quality Objectives for Aquatic Ecosystems in the Georges River

Parameter	Ecosystem type	WQOs Trigger Value
Total Phosphorus	Upland Rivers	20 µg/L
	Lowland Rivers	25 µg/L
	Lakes & Reservoirs	10 µg/L
	Estuaries	30 µg/L
Total Nitrogen	Upland Rivers	250 µg/L
	Lowland Rivers	350 µg/L
	Lakes & Reservoirs	350 µg/L
	Estuaries	300 µg/L
Chlorophyll-a	Upland Rivers	N/A
	Lowland Rivers	5 µg/L
	Lakes & Reservoirs	5 µg/L
	Estuaries	4 µg/L
Turbidity	Upland Rivers	2-25 NTU
	Lowland Rivers	6-50 NTU
	Lakes & Reservoirs	1-20 NTU
	Estuaries	0.5-10 NTU
Salinity	Upland Rivers	30-350 µS/cm
	Lowland Rivers	125-2200 µS/cm
Dissolved Oxygen (Derived from daytime measurements)	Upland Rivers	90-110%
	Lowland Rivers	85-110%
	Lakes & Reservoirs	90-110%
	Estuaries	80-110%
pH (changes of more than 0.5pH units from the natural seasonal maximum or minimum	Upland Rivers	6.5-8.0
	Lowland Rivers	6.5-8.5
	Lakes & Reservoirs	6.5-8.0

Parameter	Ecosystem type	WQOs Trigger Value
should be investigated)	Estuaries	7.0-8.5

Table 6.4 – Water Quality Objectives for primary and secondary contact recreation and Aquatic foods (cooked).

Parameter	Activity	WQOs Trigger Value
Faecal Coliform	Primary Contact Recreation	Beachwatch considers waters are unsuitable for swimming if: • the median faecal coliform density exceeds 150 colony forming units per 100 millilitres (cfu/100mL) for five samples taken at regular intervals not exceeding one month, or • the second highest sample contains equal to or greater than 600 cfu/100mL (faecal coliforms) for five samples taken at regular intervals not exceeding one month.
	Secondary Contact Recreation	Median bacterial content in fresh and marine waters of < 1000 faecal coliforms per 100 mL, with 4 out of 5 samples < 4000/100 mL (minimum of 5 samples taken at regular intervals not exceeding one month).
Enterococci	Primary Contact Recreation	Beachwatch considers waters are unsuitable for swimming if: • the median enterococci density exceeds 35 cfu/100mL for five samples taken at regular intervals not exceeding one month, or • the second highest sample contains equal to or greater than 100 cfu/100mL (enterococci) for five samples taken at regular intervals not exceeding one month.
	Secondary Contact Recreation	Median bacterial content in fresh and marine waters of < 230 enterococci per 100 mL (maximum number in any one sample: 450-700 organisms/100 mL).
Protozoans	Primary Contact Recreation	Pathogenic free-living protozoans should be absent from bodies of fresh water. (Note, it is not necessary to analyse water for these pathogens unless temperature is greater than 24 degrees Celsius).
pH	Primary Contact Recreation	5.0-9.0
Temperature	Primary Contact Recreation	15°-35°C for prolonged exposure.
	Aquatic Food (cooked)	<2 degrees celsius change over an hour
Turbidity	Primary Contact Recreation	A 200 mm diameter black disc should be able to be sighted horizontally from a distance of more than 1.6 m (approximately 6 NTU).
Chemical contaminants	Primary & Secondary Contact Recreation	Waters containing chemicals that are either toxic or irritating to the skin or mucous membranes are unsuitable for recreation. Toxic substances should not exceed values in tables 5.2.3 and 5.2.4 of the ANZECC 2000

Parameter	Activity	WQOs Trigger Value
		Guidelines.
Visual clarity and colour	Primary & Secondary Contact Recreation	Natural visual clarity should not be reduced by more than 20%. Natural hue of the water should not be changed by more than 10 points on the Munsell Scale. The natural reflectance of the water should not be changed by more than 50%.
Surface films	Primary & Secondary Contact Recreation	Oils and petrochemicals should not be noticeable as a visible film on the water, nor should they be detectable by odour. Waters should be free from floating debris and litter.
Algae & blue-green algae	Primary & Secondary Contact Recreation	< 15 000 cells/mL
Nuisance organisms	Primary & Secondary Contact Recreation	Macrophytes, phytoplankton scums, filamentous algal mats, blue-green algae, sewage fungus and leeches should not be present in unsightly amounts.
Copper	Aquatic Food (cooked)	<5 µgm/L
Mercury	Aquatic Food (cooked)	<1 µgm/L
Zinc	Aquatic Food (cooked)	<5 µgm/L
Chlordane	Aquatic Food (cooked)	<0.004 µgm/L
PCBs	Aquatic Food (cooked)	<2 µgm/L

6.3.1 Water Temperature

Water temperature is a fundamental water quality parameter that can directly affect certain species of flora and fauna that are sensitive to minor changes in water temperature for breeding behaviours or movement patterns. It can also enhance or hinder certain chemical and biological processes that occur in the water, such as levels of dissolved oxygen, chemical transformations of substances, and growth of bacteria and phytoplankton. Since there are no additional or artificial sources of heating or cooling of the natural waters in the Georges River, it is assumed that water temperatures taken in the early 1990's remain valid for today's conditions and will not have changed substantially.

A very similar pattern of water temperature variation occurs throughout the whole river for different times of the year. There is a clear trend that in summer months water temperatures reach 28-29℃, while during winter months, the water temperature drops down to 12-14℃. Moving downstream, the range of temperatures toward Botany Bay becomes narrower, typically within 1℃ lower and higher of the maximum and minimum seasonal temperatures respectively. This is most likely due to the dampening effect that the large body of ocean water exerts on the freshwater flow from its relatively constant temperature. All the water temperature data reviewed was consistent and well correlated with the seasons, setting out a distinct pattern of temperature variation. This can be seen for the different sections of the river in Figure 6.2 – Botany Bay, Lower Estuarine Zone and Upper Estuarine Zone.

Figure 6.1.1 - Botany Bay: Temporal profile plot of mean temperature (+/- one standard error) at two sites in Botany Bay from the 28/01/93 to the 31/03/94.

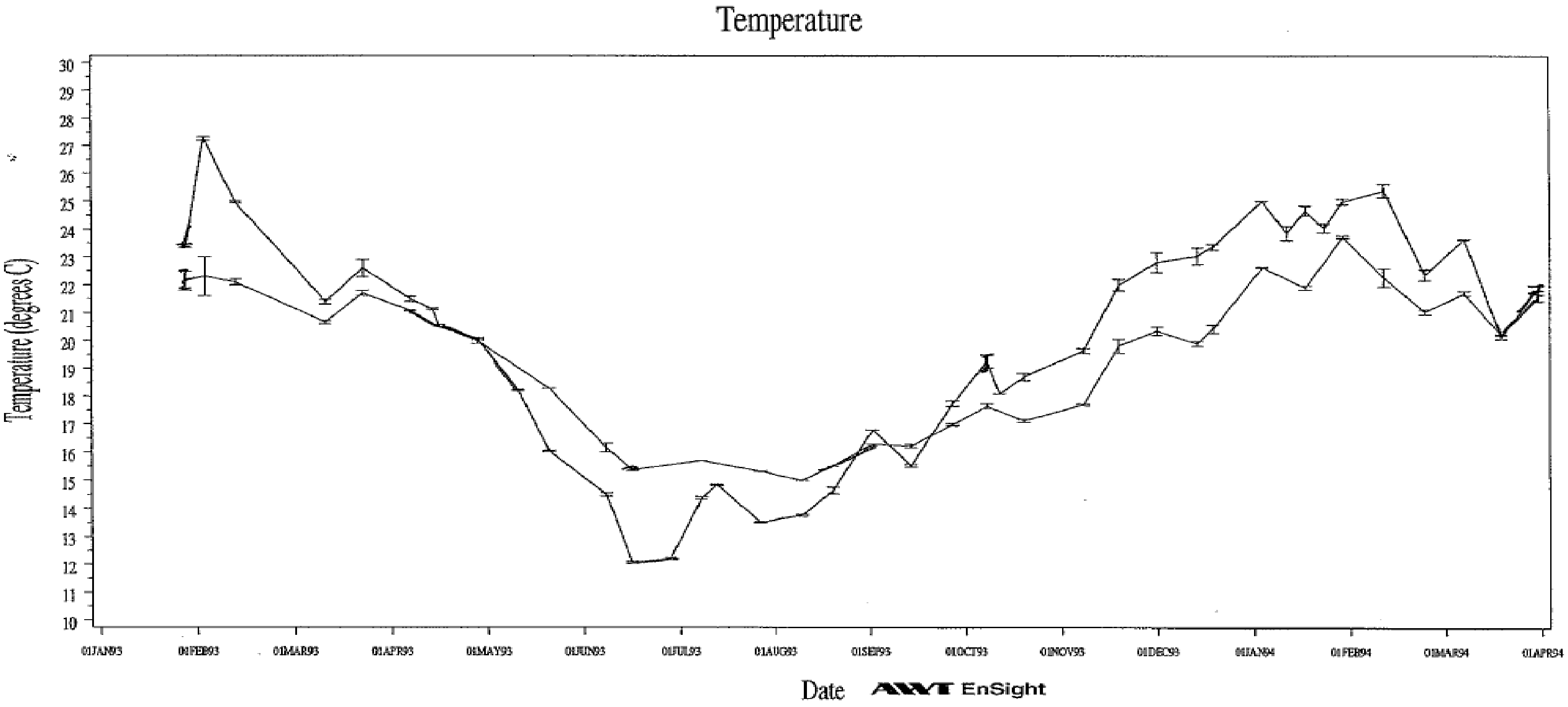


Figure 6.1.2 - Lower estuarine zone: Temporal profile plot of mean temperature (+/- one standard error) at three sites in the lower estuarine zone from the 28/01/93 to the 31/03/94.

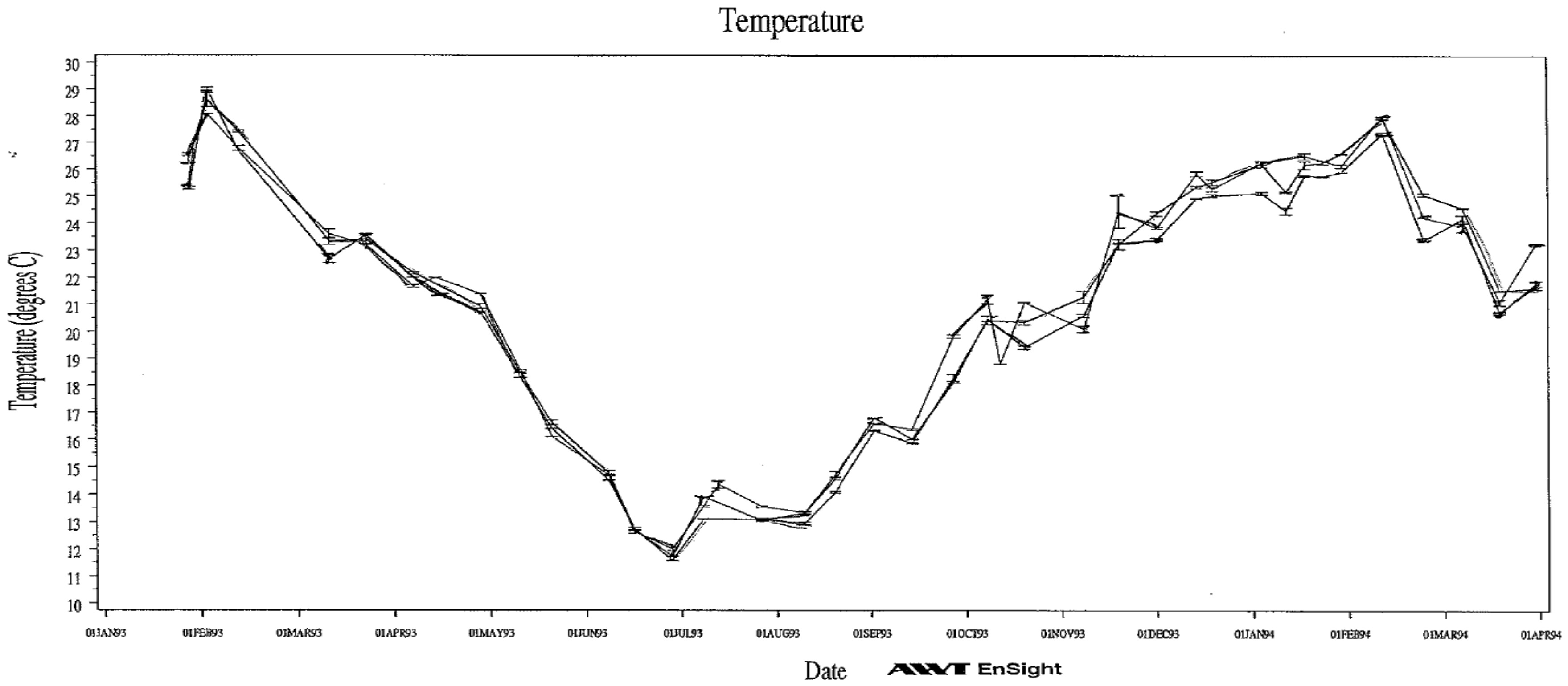


Figure 6.1.3 - Upper estuarine zone: Temporal profile plot of mean temperature (+/- one standard error) at three sites in the upper estuarine zone from the 28/01/93 to the 31/03/94.

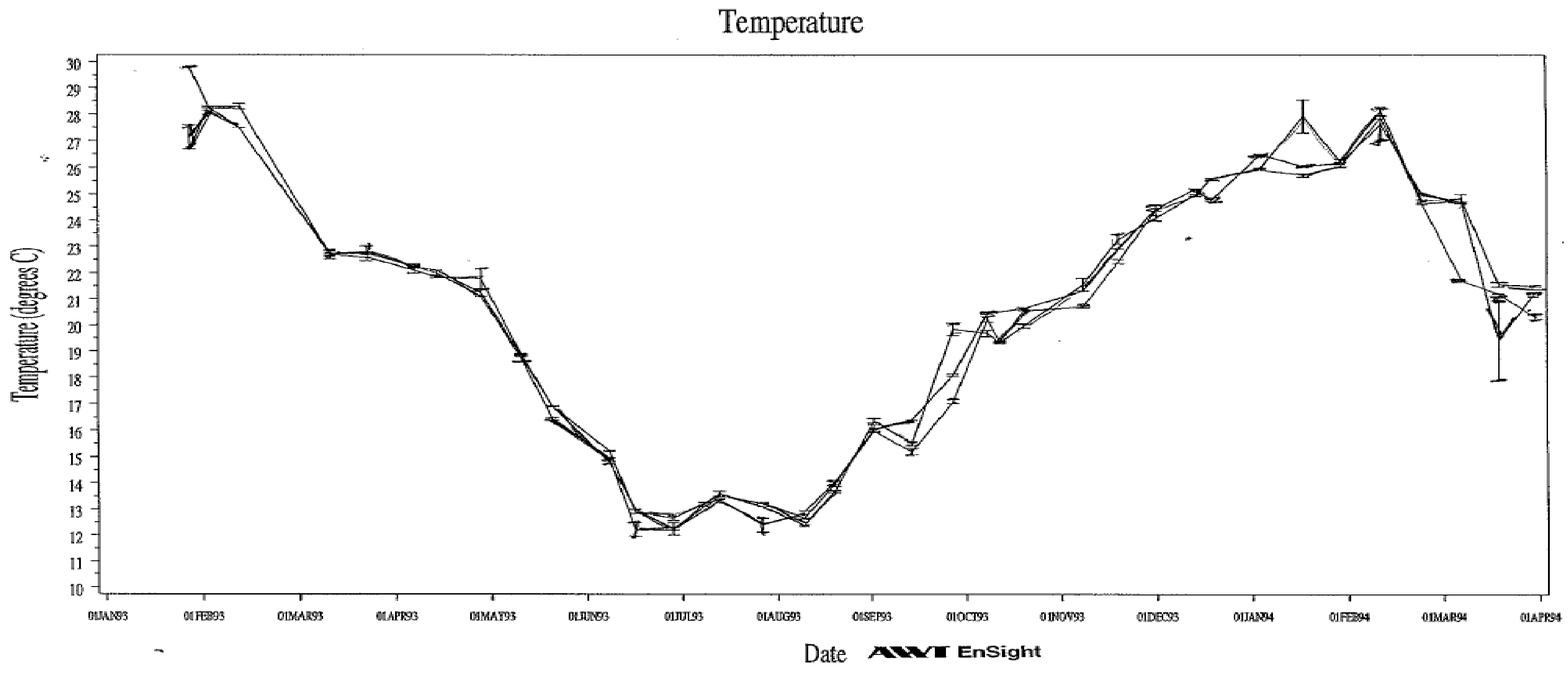


Figure 6.2 – Eutrophication Study Report - Interpretive Report Georges River 01 January 1993 to 31 March 1994

6.3.2 Salinity and Stratification

Salinity is a measure of the amount of dissolved salts in water, with sea water usually having a salinity level of 35 parts per thousand (ppt). In an estuary, salinity tends to vary according to the dilution achieved between seawater and freshwater, the concentration of salts in the freshwater, and in response to the extent of evaporation of poorly flushed saline areas.

Due to the expansive stretch of the Georges River encompassed within the study area, a number of processes and elements affect the level of salinity within the river on a macro scale from section to section, and also on a more local scale within the water column; yearly fluctuations in local monitoring measurements presented in the PWD (1990) report on salinity and temperature data from the Georges River bears witness to this.

However in general terms, the river behaves as one would expect in terms of longitudinal salinity variation whereby salinity progressively decreases upstream. The Georges River exhibits the 3 distinct regions that define an estuary 1) the lower estuary which is primarily influenced by marine flux, 2) the middle estuary which experiences strong mixing between freshwater and salt water, 3) the upper estuary which is typically dominated by freshwater but is subject to daily tidal action. The strong tidal influences associated within the lower reaches of the estuary, towards Botany Bay, is reflected by the higher salinity levels, which can reach concentrations up to 34 – 37 ppt in Dolls Point, comparable to sea water. This gradually decreases with increasing distance upstream to 0-10 ppt at Liverpool Weir, depending on the time of year and antecedent climatic conditions from freshwater inputs. The pattern in which it decreases follow an S-shape curve, with the steepest change occurring upstream of Lugarno Ferry and downstream of Prospect Creek, while salinity concentrations plateau on either side of these locations. This is illustrated in Figure 6.3, below.

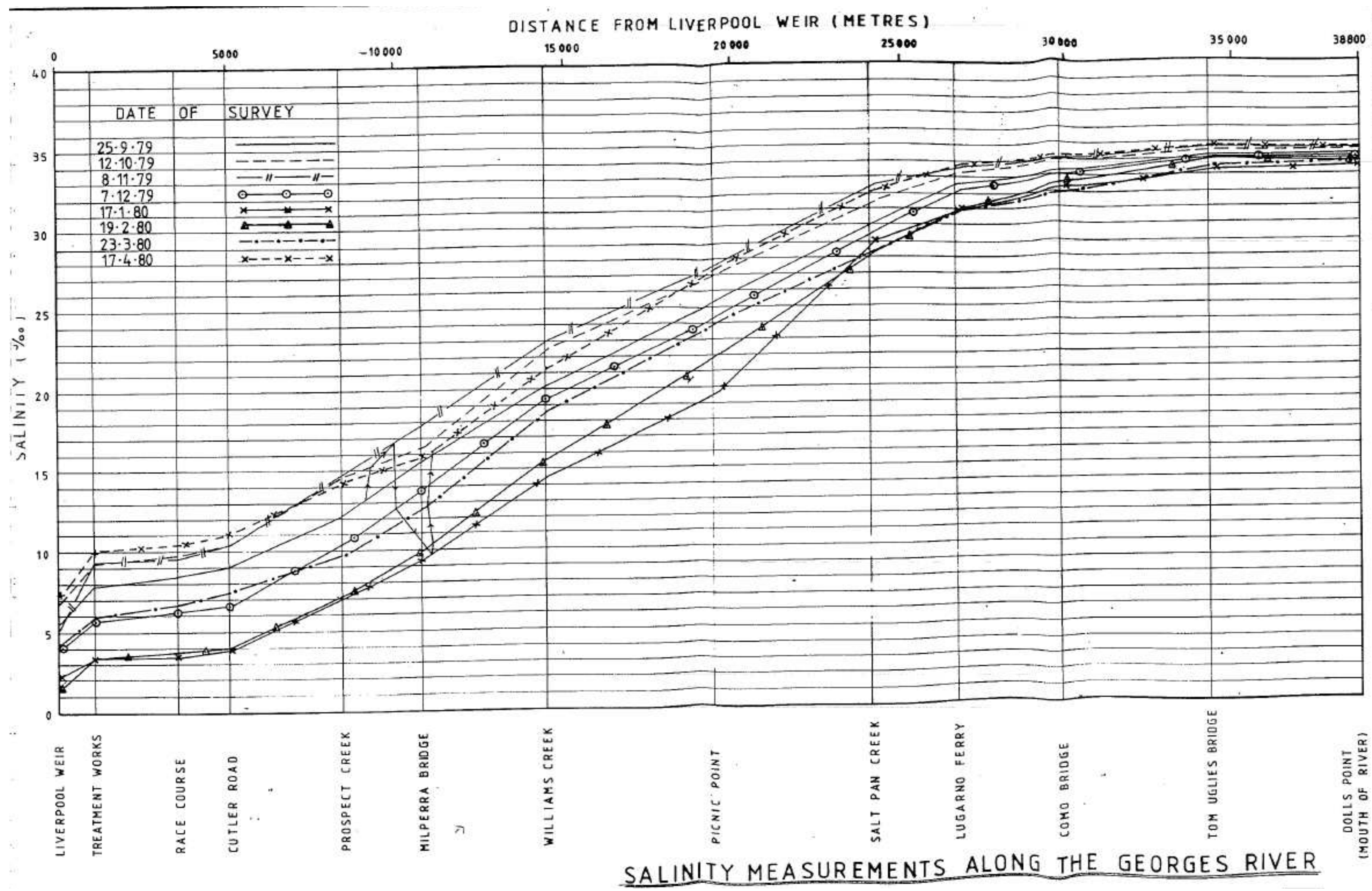


Figure 6.3 – PWD 1990, Georges River Salinity and Temperature Data

Salinity measurements taken at the surface, mid depth and near the bed of the river, indicate that the water column is well mixed with very little variation, and stratification rarely occurs. Measurements along the river indicate that variation in salinity over time is almost entirely dependent on freshwater inflow into the system. As such, depending on the magnitude of freshwater influx into the system from the upper catchment, such as after a large rainfall event or sewage overflow/discharge, salt water can be partially or completely flushed out of the estuary. Stratification in the lower reaches of the estuary may occur after a storm, forming a salt wedge, as the denser salt water entering from the sea is overlain by a more buoyant layer of freshwater river flow into the estuary. However this effect eventually disperses over time as tidal flows become predominant and equilibrium is re-established again. Further upstream, stratification which was observed for a handful of one-off instances in the deeper areas of the Chipping Norton Lakes Scheme were noted to similarly disperse after approximately one week, when normal tidal flows had mixed the entrained salt layer (PWD, 1990). These scenarios are presented in Figure 6.4 graphically, showing the formation of a salt wedge at the mouth of an estuary, the existence of stratification and thirdly, a well mixed water column with increasing levels of salinity towards the ocean.

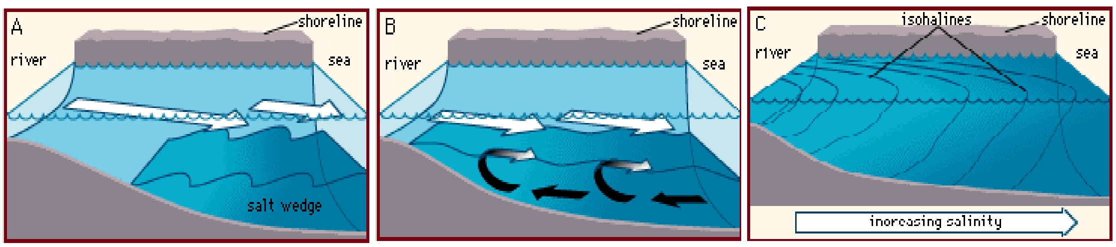


Figure 6.4 – Saline mixing in estuaries (Britannica http://cache-media.britannica.com/eb-media/75/6575-004-026E3142.gif)

The SPCC report on Water Movement and Salinity in the Georges River (1979) sheds light on the river's rate of response to re-establishing this equilibrium and found that the river exhibits a slow recovery rate of salinity levels after high rainfall or freshwater inflow, which indicates relatively poor longitudinal mixing characteristics in the river. As such, salinity may be used to indicate the water particle movement over a tidal cycle, although this approach may introduce small errors in the lower parts where bleed off into the embayments and subsequent increased mixing occurs.

6.3.3 Dissolved Oxygen

An adequate level of dissolved oxygen (DO) is critical for supporting life in all waterways. The level of dissolved oxygen is a complex interplay between a number of interacting physical, chemical and biological processes that influence the supply and uptake of DO. A source of DO may include aeration and photosynthesis, while DO can also be lost through aerobic respiration, chemical oxidation, nitrification and degassing.

Dissolved oxygen measurements are rarely static and regular fluctuations may occur in response to changing conditions of temperature, salinity, river flow, turbulence, hours of sunlight and consequent biological processes which feed off all these elements. This leads to diurnal and annual variations in measurements, which are impacted by changes in photosynthetic activity of submerged macrophytes, planktonic and benthic algae. Additionally, anthropogenic influences can also significantly impact the level of DO, and in the context of the Georges River, they primarily relate to the dredging of bottom sediments and disposal of sewage effluent into the waterway, in which both scenarios tend to cause DO depletion. DO levels ranged from 0 to 200% in the Chipping Norton Lake (according to Stacker) and value ranging from 13 to 201% were measured along Bankstown City

Council (Bankstown City Council, 2009). DO levels that are either too low or too high are undesirable as low values indicate eutrophic conditions and a presence of large oxygen demanding sinks, while high DO levels (reaching 150% saturation and over), indicate contributions by photosynthetic processes from algae or seagrass. Highly oxygen saturated water can lead to gas bubble disease in fish, which is characterised by small bubbles forming between layers of skin tissue, within vascular systems or in the gill lamellae in fish. This can lead to tissue death, restriction of blood flow, and in severe instances, can cause asphyxiation. Despite the fact that there has been no evidence of such disease in the Georges River, the effects of this high oxygen concentration can occur between levels of 105 and 140% saturation, and concentrations of 140% and higher increases the chances of fish kills from this disease. Examples of the effects of gas bubble disease are illustrated in Figure 6.5.

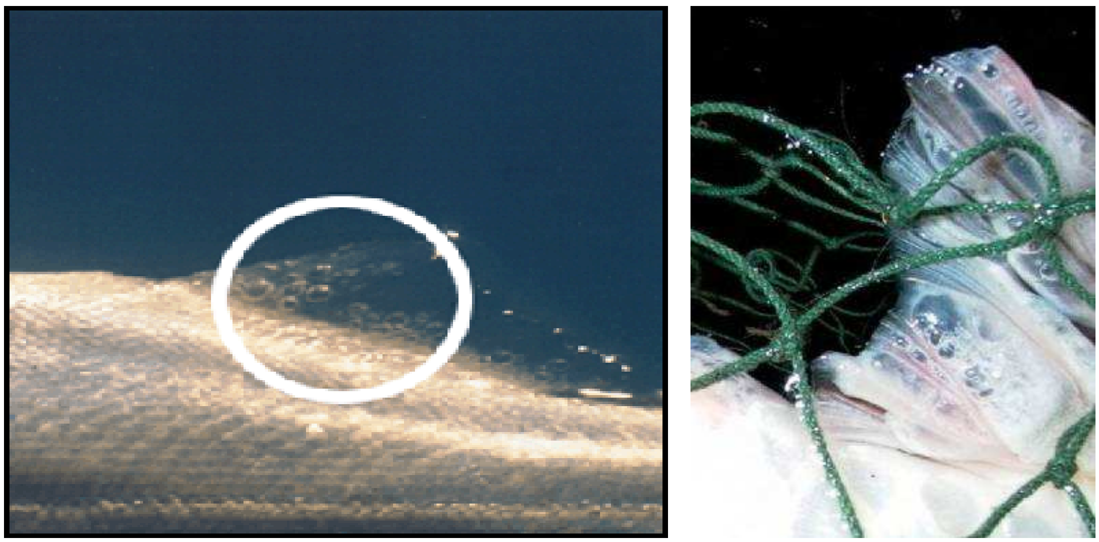


Figure 6.5 – Effects of gas bubble disease (http://www.lrf.org/TMDL2print/TMDL03print.gif and http://www.bonniesplants.com/sick_injured_fish/images/gas_bubble/Gas%20bubble%204.jpg)

In 1981, the SPCC reported on dissolved oxygen levels in the Georges River and Botany Bay for the period between 1971 and 1976. It was found that in Botany Bay mean levels of DO were consistently near saturation levels, with minimum levels usually returning above the 70% saturation mark; these readings were generally recorded near the northern foreshores of the bay and at the mouths of the Georges and Cooks Rivers.

It was found that the lower freshwater sections of the Georges River underwent large fluctuations in dissolved oxygen levels in surface layers due to the proliferation of algal blooms and/or duckweed, especially between October 1977 and March 1978. Generally however, this section of river saw DO levels vary diurnally with surface DO increasing during the day, peaking late afternoon before decreasing during the night to a minimum around sunrise (SPCC, 1981). This pattern directly correlated with changes in pH in the water, with maximum levels of pH 10 being reached during mid afternoon. Seasonally, stratification occurs in summer in which dissolved oxygen levels in bottom waters at Liverpool Rail Bridge may become entirely deoxygenated; the opposite is true for winter months.

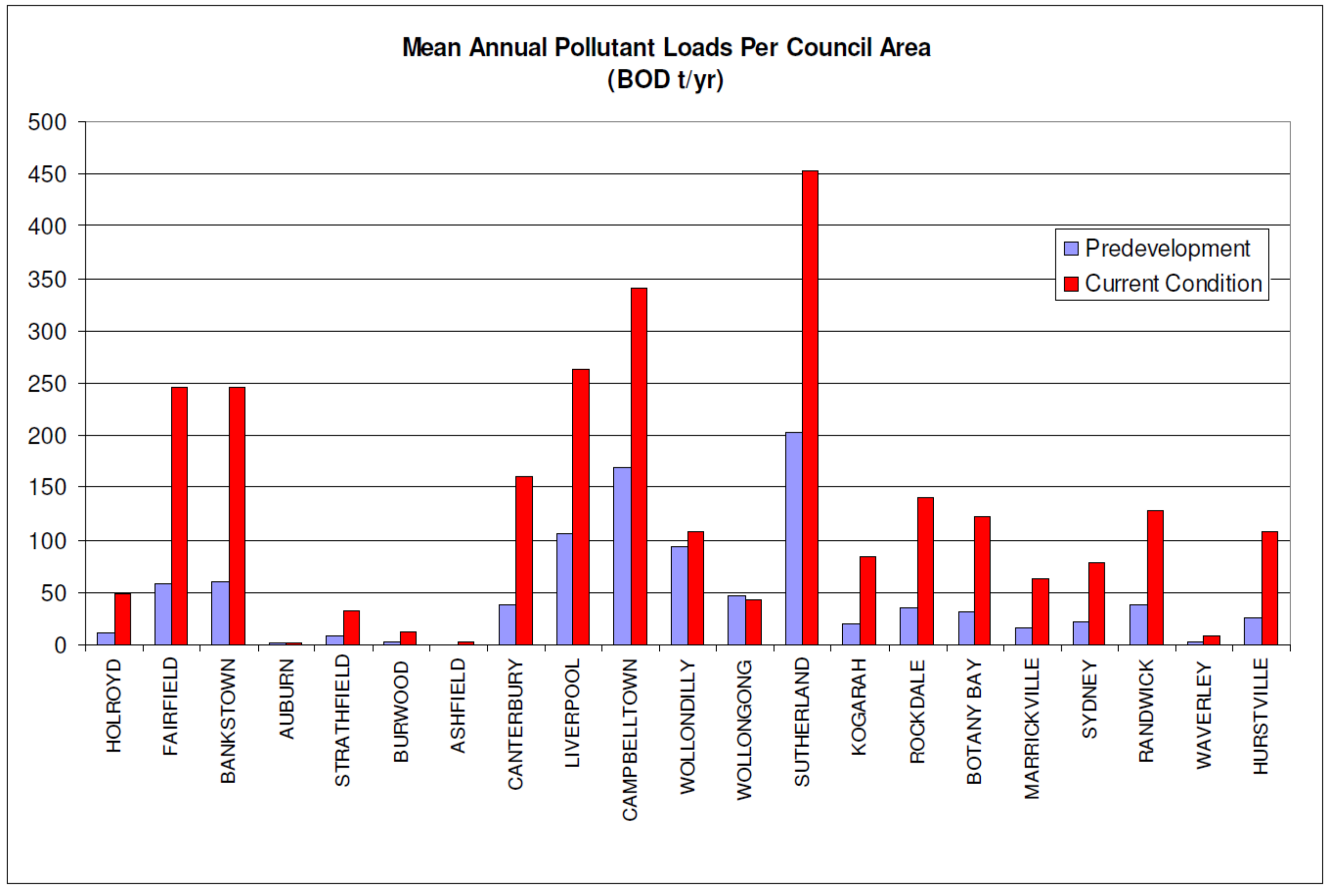
Further downstream in the estuarine section of the river, the impacts of effluent disposal from sewage treatment works played a role in increasing the demand for oxygen for all weather conditions up until 1986, when dry weather effluent was diverted to the ocean outfall. This increase in DO demand was due to the presence of ammonia and organic substances, in which DO is consumed by bacterial decomposition. However, DO demand is magnified after wet weather events due to increased levels of nutrients from effluent overflow and runoff, and increased organic matter in the waterway. Overall findings for this section of river shows a wide variation in DO readings, especially in the upper reaches where algal blooms are more likely. From the data available, it could be generally observed that upstream of Milperra and East Hills, DO varied through the day by up to 60% and did so inversely to changes in salinity. It was also found that the most sensitive areas to oxygen demanding inputs were the arms and smaller tributaries of the river's middle reaches, where the channels are narrow, shallow and poorly flushed.

This trend of large fluctuations in DO concentrations has continued through from the most recent water quality data set from Bankstown Council, although a notable downward shift towards lower DO concentrations was observed. In the mid estuarine section of the river, 60 – 70% of the readings fell below 85% saturation, which was the lower bound for DO levels as recommended by the ANZECC guidelines. A recognisable positive correlation pattern was detected for this data in terms of its percentage of DO saturation. The factors behind this downward DO shift could be driven by a number of reasons, some of which are mentioned above, or increased turbidity and bound nutrients, and the direct and indirect impacts of intensified urbanisation.

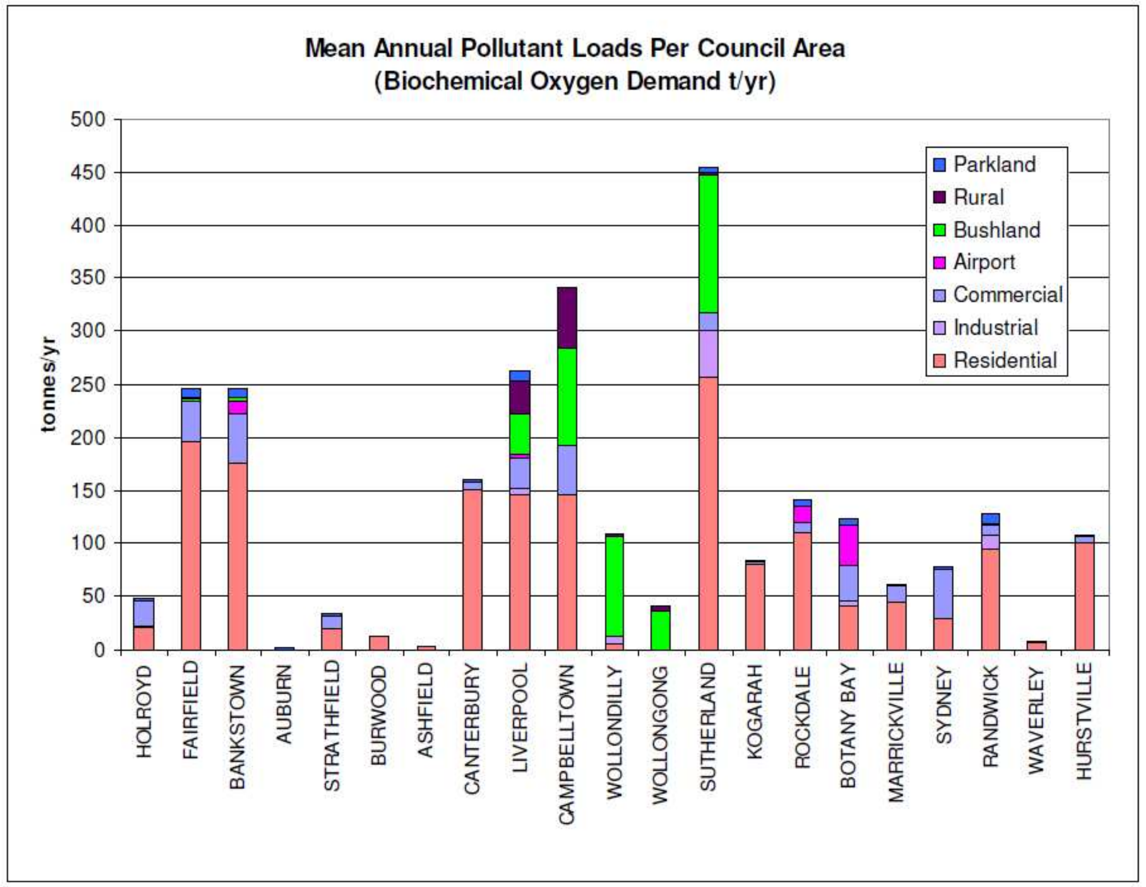
Pollutant modelling was undertaken by BMT WBM and the results were published by the BBCCI in 2008. The Biochemical Oxygen Demand (BOD) was studied as well as many other water quality parameters. The mean annual BOD per council and per landuse is provided in Figure 6.6.

The Council areas producing the most significant BOD load are Sutherland, Campbelltown and Liverpool due to their large area. The average production of BOD ranges between 15 and 60kg/ha/yr within the Georges River catchment.

(a)



(b)



(c)

Name	Urban BOD (T/yr)	Industrial BOD (T/yr)	Commercial BOD (T/yr)	Airport BOD (T/yr)	Bushland BOD (T/yr)	Rural BOD (T/yr)	Parkland BOD (T/yr)	All Land Uses BOD (T/yr)
HOLROYD	21	1	25	0	0	0	2	48
FAIRFIELD	195	0	38	0	2	1	8	245
BANKSTOWN	177	0	46	12	3	0	8	246
AUBURN	0	0	1	0	0	0	1	2
STRATHFIELD	19	0	13	0	0	0	1	33
BURWOOD	12	0	0	0	0	0	0	12
ASHFIELD	2	0	0	0	0	0	0	2
CANTERBURY	150	0	8	0	0	0	2	160
LIVERPOOL	147	5	29	4	37	31	9	263
CAMPBELLTOWN	147	0	46	0	90	58	0	341
WOLLONDILLY	6	7	0	0	94	2	0	108
WOLLONGONG	0	0	0	0	36	7	0	43
SUTHERLAND	257	43	17	0	131	2	4	453
KOGARAH	81	0	2	0	0	0	0	83
ROCKDALE	110	0	9	16	0	0	5	141
BOTANY BAY	42	5	34	38	0	0	5	122
MARRICKVILLE	44	0	15	1	0	0	1	62
SYDNEY	30	0	45	0	0	0	3	79
RANDWICK	95	13	9	0	1	0	10	128
WAVERLEY	7	0	1	0	0	0	1	8
HURSTVILLE	101	0	5	0	2	0	0	108

(d)

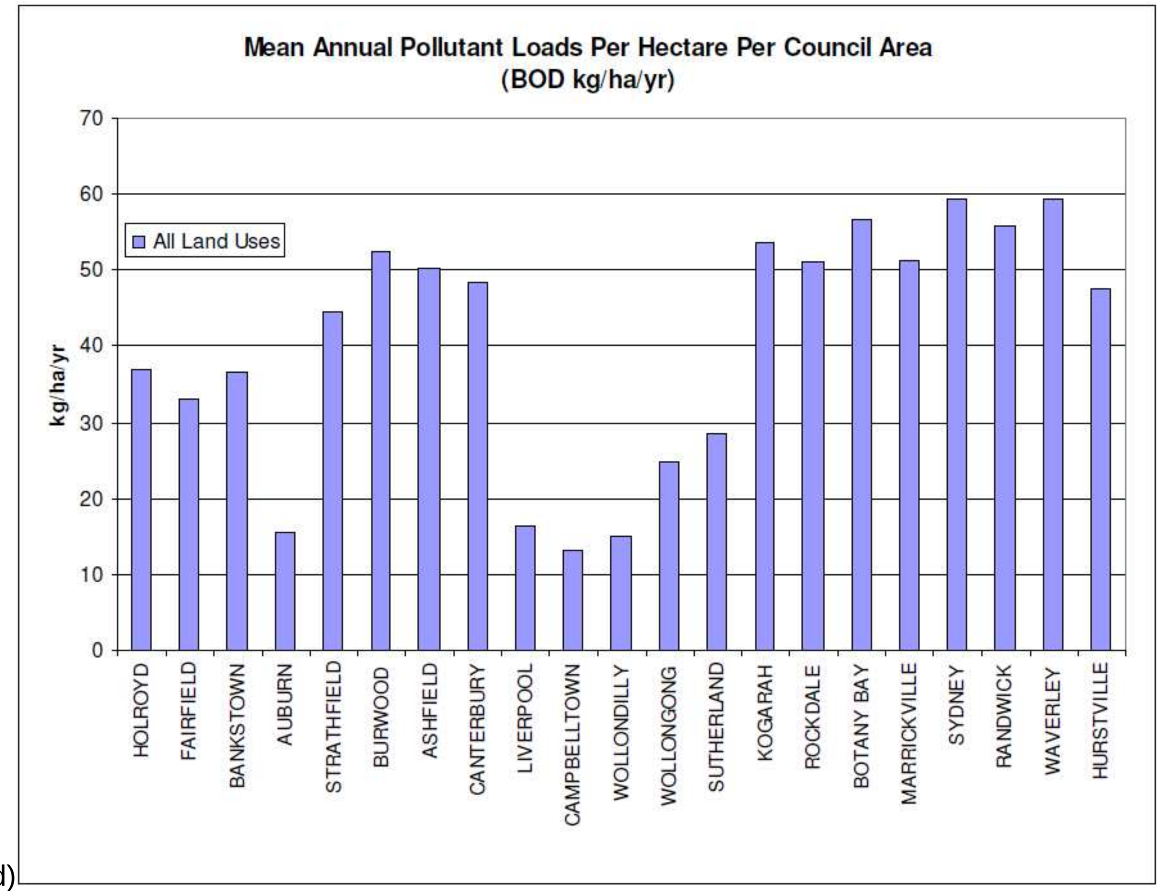


Figure 6.6 – Mean annual BOD load in 2008 conditions compared to predevelopment condition per council area (a),mean annual BOD loads per land use per council area (b) and (c), and mean annual BOD load per hectare per council area(d) (BBCCI, 2008)

6.3.4 Turbidity

Turbidity is a measure of the amount of suspended matter in water which causes light scattering and gives turbid water its murky appearance. The extent of turbidity in water can have far reaching implications for aquatic flora and fauna vitality, while also impacting on other water quality parameters like temperature, dissolved oxygen, and visual aesthetics. More specifically, highly turbid waters can:

- reduce photosynthetic potential for aquatic plants,
- alter the spawning and migration behaviour of certain fish,
- mechanically damage fish gills through clogging or tissue irritation,
- alter a local habitat to favour a particular species of flora or fauna,
- change water temperatures causing thermal stratification, and
- reduce dissolved oxygen, causing degradation in river aesthetics

Generally, the causes of turbidity are dependent on geology, topography, soils, climatic conditions, river flow, vegetation cover and anthropogenic activities. For the Georges River, the most pronounced contributors to turbidity in the past included the rapid increase in urbanisation which led to elevated levels of runoff and sediment loads, effluent discharge and overflow into the Georges River, and the dredging processes that occurred leading up to and during the construction of the Chipping Norton Lake Scheme in the 1980's. Additionally, rainfall and storm events can generally increase turbidity in a river system in two ways. Firstly, it contributes to additional flow into the system, which increases flow velocities and has the effect of increasing bank erosion and overland sediment transport. Secondly, with the increase in sediment load, more sediments remain entrained in the moving water body as the higher flow volumes and velocities encourages turbulent conditions, and prevents settling.

Today, the dominant contributors remain similar. The continual pressures of intensified urbanisation have increased population densities and areas of impervious surfaces, which when considered together, greatly enhance the magnitude of runoff and sediment loads especially after storm events. The Chipping Norton Lakes Scheme impact on the river's hydrodynamic behaviour has also begun to emerge as a contributor to turbidity. Higher flow velocities are now experienced entering and exiting the Lakes Scheme due to the larger tidal prism generated from the extra storage capacity made available from the sand mining operations that occurred up until the 1980's. This has produced the consequent effect of increased bank erosion and bank instability. Coupled with the geology of the upper section of the Georges River, between Liverpool Weir and East Hills which consists predominantly of dispersive clays and shales, the impact on turbidity is amplified. The influence of geology of the soils on turbidity is particularly evident at creek or tributary ends after storms, with the most water discolouration being observed in such areas. With a smaller water body volume in the creeks and tributaries compared to the main river channel, the potential of dilution of the fine clay particles that are washed in by stormwater is lessened, and thus, a heavier discolouration occurs despite the regular tidal flushing that the tributaries experience. Additionally, other recreational activities like dirt biking and four wheel driving near the foreshores of the river destabilises soil structure and removes vegetation, exacerbating the already high levels of turbidity in the tributaries and main river channel.

The upper sections of the Georges River, between Liverpool Weir and East Hills, experience higher turbidity levels, and recovery after rainfall is slower than less affected downstream areas towards the mouth of the river (SPCC, 1987). Increased turbidity levels in this area results from catchment runoff after precipitation through the various tributaries and stormwater drains. Recovery to dry weather turbidity levels occurs at a uniform rate along the intermediate section of river and was found to be independent of salinity recovery. Thus, tidal exchange especially in the upper reaches does not contribute strongly to the recovery rate; rather sedimentation is likely to be the primary mechanism for recovery.

Figure 6.7 shows the extent of turbidity in Harris Creek.

Figure 6.7 – Turbidity in Harris Creek

The processes contributing to turbidity in the intermediate section of the Georges River are more complex as the factors are multifaceted and interrelated at different stages and in different ways. Firstly, from the data it can be observed that the most turbid areas after a storm peak at Williams Creek, downstream of the Lakes Scheme. However, it was concurrently observed that the recovery rate here was much quicker than that of sections further upstream. The high levels of turbidity at this location suggest that the main sources of turbidity are upstream of this point. The faster rate of recovery here compared to other areas reflects the impact that catchment properties have on turbidity recovery. The catchment of Williams Creek is founded primarily on sandstone and is largely non-urbanised, thus any sediments entrained in runoff can be expected to be coarser and denser, thus, settling quickly.

In contrast, the Cabramatta and Prospect Creeks' catchment have similar properties and are characterised by much higher levels of urbanisation and underlain by shale derived soils. These soils are more erodible, finer in nature, and remain suspended in runoff for longer periods of time. This together with the higher sediment loads from urbanisation, compounds to yield these two catchments as the main contributors of turbidity in this section of river. It was concluded that the fine suspended solids are responsible for the observed slow rate of recovery, which also indicates the poor flushing that this section of river experiences (SPCC, 1979). For example, dry weather conditions near Prospect Creek can take up to four weeks before being restored after rainfall. This supports the notion that sedimentation processes dominate over tidal flushing mechanisms for turbidity recovery in this section of the river. The most current water quality data indicates that the extent of turbidity has worsened over time. While many of the measurements still lie within similar bounds that were observed in the early 1990's, the frequency at which higher turbidity levels are being measured at, up to 10 times the previously highest values, has increased dramatically. On the whole, 80 – 90% of the monitoring data supplied by Bankstown council fell under the upper limit of 50 NTU as suggested in the ANZECC 2000 water quality guidelines for aquatic systems. However the 10-20% of remaining measurements reached levels of up to 600 NTU at times.

While most parts of the river follow a similar pattern of turbidity intensification and recovery following wet weather, certain sections of the river exhibit particular features of recovery. A quicker recovery to low turbidity levels was observed at Liverpool Weir, Kelso Creek and Williams Creek (SPCC, 1979).

At Liverpool Weir, the structure has the function and capacity to retain a relatively large volume of impounded water, which acts as a settling pond for upstream flows entering the study area of the Georges River, particularly after storms. Thus, the weir overflow, which typically has lower levels of turbidity, acts to flush more turbid waters downstream from that local upper estuarine section. Kelso Creek's quick recovery rate was encouraged by the tidal exchange and sedimentation, while the geology and catchment properties were the primary drivers at Williams Creek.

6.3.5 Nutrients

Nutrients are typically represented by phosphorus and nitrogen in a river system and are commonly used to gauge water quality. They both occur in several forms in the environment and are foundational to the livelihood of an aquatic ecosystem, in particular, the sustenance of plants. These two elements are considered to be the limiting growth factors of plants in water bodies as they are predominantly greatest in demand but shortest in supply. Some forms of these elements are more readily absorbed by plants than others. For phosphorus, the most available forms include dissolved orthophosphate, present as HPO_4^{3-} or $H_2PO_4^{2-}$, and for nitrogen, nitrate and ammonium. While more complex forms of these are common in nature, further microbial breakdown is required before they can be easily utilised by plants.

Nutrients exist and are naturally cycled through the environment and waterways through a number of physical and biological processes, of which, surface runoff and erosion play an important part as pathways for nutrient enrichment in waterways. The sources and sinks of such processes for an estuary have been graphically illustrated in greater detail as shown in Figure 6.8. This figure briefly highlights the numerous factors that affect the amounts of nutrients in a river system and provides a sense of the complexity involved in the interplay between the sources and sinks (among other factors) which are behind the numbers obtained through water quality monitoring. Soil erosion is an important source of phosphorus into the river system through phosphorus bound to sediment particles. Anthropogenic sources act to further enhance the effects through the binding of additional nutrients from household fertilizers and chemicals onto soil and organic matter. These sediments are then carried into the waterways via stormwater drains or natural flow through the banks. Other major anthropogenic sources derive from sewage effluent or overflow, industrial waste discharge and stormwater runoff, all of which have a much more pronounced impact immediately after a rainfall event as it has a flushing effect.

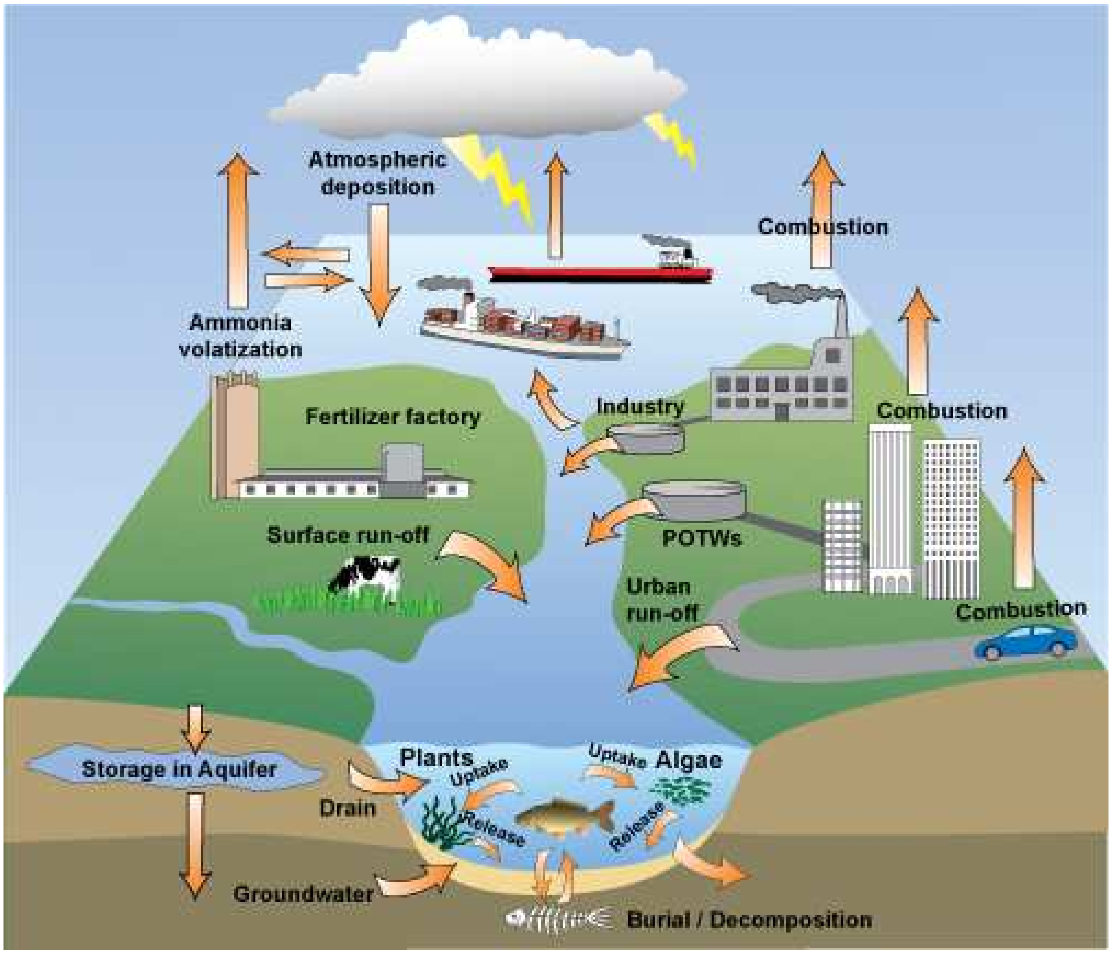


Figure 6.8 – Nutrient cycle in an estuary (http://www.sccwrp.org/images/ResearchAreas/Nutrients/NutrientCyclingInEstuaries/Background_NutrientCycle/Background_NutrientCycle.jpg)

To provide a further appreciation of the extent in which some of these natural sources contribute towards the nutrient concentrations in the Georges River, a section of the 2001 Australian Agricultural Assessment has been shown in the Table 6.5 below to highlight the attributes specific to the Georges River's nutrient flux.

Table 6.5 – Nutrient concentrations and pathways in the Georges River
http://www.anra.gov.au/topics/water/nutrients/nsw/basin-sydney-coast-georges-river.html

Attribute	Unit	Basin value	Median Australia-wide value
Phosphorus from fine sediments	%	72	76
Phosphorus from point sources	%	0	0
Phosphorus dissolved from diffuse sources	%	28	17
Phosphorus deposited on floodplain	%	35	30
Phosphorus deposited in reservoirs	%	0	0
Phosphorus delivered to estuaries	%	65	65
Phosphorus - total basin export	tP/y	10	46
Phosphorus - export rate	kgP/ha/yr	0	0
Phosphorus load - times pre-European	ratio	2	2
Phosphorus - dissolved to total	ratio	35	21
Nitrogen from sediments	%	40	44
Nitrogen from point sources	%	0	0
Nitrogen - dissolved from diffuse sources	%	60	51
Nitrogen deposited on floodplain	%	19	16
Nitrogen deposited in reservoirs	%	0	0
Nitrogen denitrified	%	5	4
Nitrogen delivered to estuary	%	76	76
Nitrogen - total basin export	t/y	114	451
Nitrogen - export rate	kg/ha/y	1	1
Nitrogen load - times pre-European	ratio	1	2
Nitrogen - dissolved to total	ratio	68	65

While nutrients are essential to sustaining an ecosystem, an excess can lead to severe environmental problems. Under the right conditions, the enrichment of nutrients in the waterways can produce excessive algal blooms which are unsightly and malodorous, and can subsequently result in the clogging of waterways and the proliferation of oxygen demanding bacteria during the algal decay process. As such, dead zones in water bodies are formed whereby the dissolved oxygen is depleted to such an extent that aquatic life becomes unsustainable. These conditions are largely dependent on flow conditions as high flows provide a flushing effect which dilutes and distributes any dissolved or suspended matter in the water body. Figure 6.9 depicts a severe case of algal growth on the water surface caused by eutrophic conditions.

Figure 6.9 – Eutrophication caused by algal growth
http://www.play-with-water.ch/d4/experiments/images/img_23.jpg

Based on historic SPCC water quality data over a 20 year period between 1969 – 1990 and a 1992 Scientific Services Branch report for Water Quality in the Georges River, an increase in total phosphorus (TP) was observed to peak around in the early 1980's, reaching concentrations well over 1000 µg/L. This was at a time when sewage effluent was still discharged directly into the river, and while it was well treated, it was still rich in nutrients, particularly phosphorus and nitrogen. However, TP levels significantly declined after 1983, when the Glenfield STP incorporated a Phosphorus removal process unit in the plant and furthermore after 1986 when the Glenfield and Liverpool dry weather sewage effluent was diverted to the ocean outfall system at Malabar. As a result, TP concentrations dropped rapidly at Liverpool Weir and dipped below the 2000 ANZECC recommended 50µg/L upper limit in the late 1980's and early 1990's and remained low until at least 1992.

Further down stream, at Cabramatta Creek, Milperra Bridge and Sandy Point, the benefits of the process improvement at Glenfield STP were not as evident and levels of phosphorus remained above the recommended 50µg/L trigger value, although a notable decline was still observed up until the late 1980's and early 1990's with levels generally remaining around 100µg/L. These higher values were observed downstream of Liverpool due to runoff from heavily urbanised areas of Liverpool, Cabramatta, and Fairfield. The accumulation of bound nutrients in this section of river is particularly severe because of the poor tidal exchange. This trend appeared to continue in the mid 1990's around this upper section of the river after analyzing data from a 1994 Interpretive Eutrophication Study completed by the PWD. The study showed that Prospect Creek continued to be a particularly troublesome area with regards to high nutrient concentrations, along with Picnic Point and Salt Pan Creek further downstream. Again the influence of the hydrodynamic and tidal processes were reflected in the water quality results, whereby measurements made in Botany Bay had consistently low levels of nutrients and rarely exceeded the recommended water quality criteria, while further upstream, the impact of urban flow and weaker tidal flows were indicated by the progressive increase in nutrient concentrations.

In comparing the most recent data from Bankstown Council and historical data, TP levels appear to have returned to the elevated levels experienced during the mid 1980's (Rish, 1992), with concentrations of TP well above the recommended 50µg/L mark. The pattern of TP distribution throughout the river from Liverpool Weir to Alfords Point Bridge near Salt Pan Creek remained relatively stable, with most values fluctuating between 50 – 500 µg/L for all river sections. From this parameter, it seems that water quality has regressed since the early 1990's, in particular near Liverpool Weir, where historical data suggests that TP levels went down to approximately 30µg/L. No appreciable pattern of this fluctuation could be observed for any of these sites and the variations in TP concentrations seemed to be evenly spread throughout the data series with respect to time and location.

Similarly for oxidized nitrogen measurements, improvements made in the late 1980's and early 1990's in suppressing nitrogen to levels below 1mg/L have since been reversed and a marked increase has been observed in all sections of the river. In particular, over the 5 years since 2004, nitrogen concentrations around the 2mg/L mark have become more frequent, whereas before 2000, concentrations would usually hover around 1.5 mg/L. Again, a relatively uniform pattern is observed through the different river sections with the exception of Kelso Park (northern arm), which consistently exhibited grossly elevated levels of nitrogen – typically between 10-25 mg/L, but up to 35 mg/L in some instances. The ANZECC guidelines recommend total nitrogen levels below 0.5 mg/L, which has been breached by the majority of water quality results. However, as these values are only recommended by ANZECC for slightly disturbed ecosystems, a more lenient threshold could be adopted to take into account of the highly urbanised environment along the Georges River.

The behavior of the two nutrient parameters in the Georges River tends to suggest that nutrient levels have generally increased throughout the river since the early 1990's to levels which were experienced in the mid 1980's. These increases were in the order of up to 10 times the early 1990's TP and oxidized nitrogen levels. A particularly excessive nitrogen loading at Kelso Park was also observed. While there is a 5-10 year gap in water quality data between the early 1990's and early 2000's, one possible factor leading to the increase may be related to the population increase experienced in the area. From ABS data, it was found that the population in Bankstown LGA increased by almost 13,000 between 1990 and 2001, which equates to a 0.8% per year growth. This however, needs to be considered with the aging sewerage infrastructure, which has not been upgraded since its conception. As sewage volumes increase with population growth, the capacity of the diversion pipelines and sub-mains will be exceeded more frequently under wet weather conditions with less intense rainfall events.

Total annual mean load of nutrients (TN and TP) and suspended solids in 2007 in the Georges River are provided in Figure 6.10. It can be seen that most significant loads occur usually in winter and spring except in the upper reaches of the Georges River where it occurs in spring and summer.

Pollutant modelling was undertaken by BMT WBM and the results were published by the BBCCI in 2008. The TN and TP loads were studied as well as many other water quality parameters. The mean annual TP and TN per council and per landuse was provided in Figure 6.11 and 6.12.

The Council areas producing the most significant TP and TN loads are Sutherland, Campbelltown and Liverpool due to their large area. The average production of TN ranges between 2.5 and 7kg/ha/yr while the production of TP ranges between 0.25 and 0.857kg/ha/yr within the Georges River catchment.

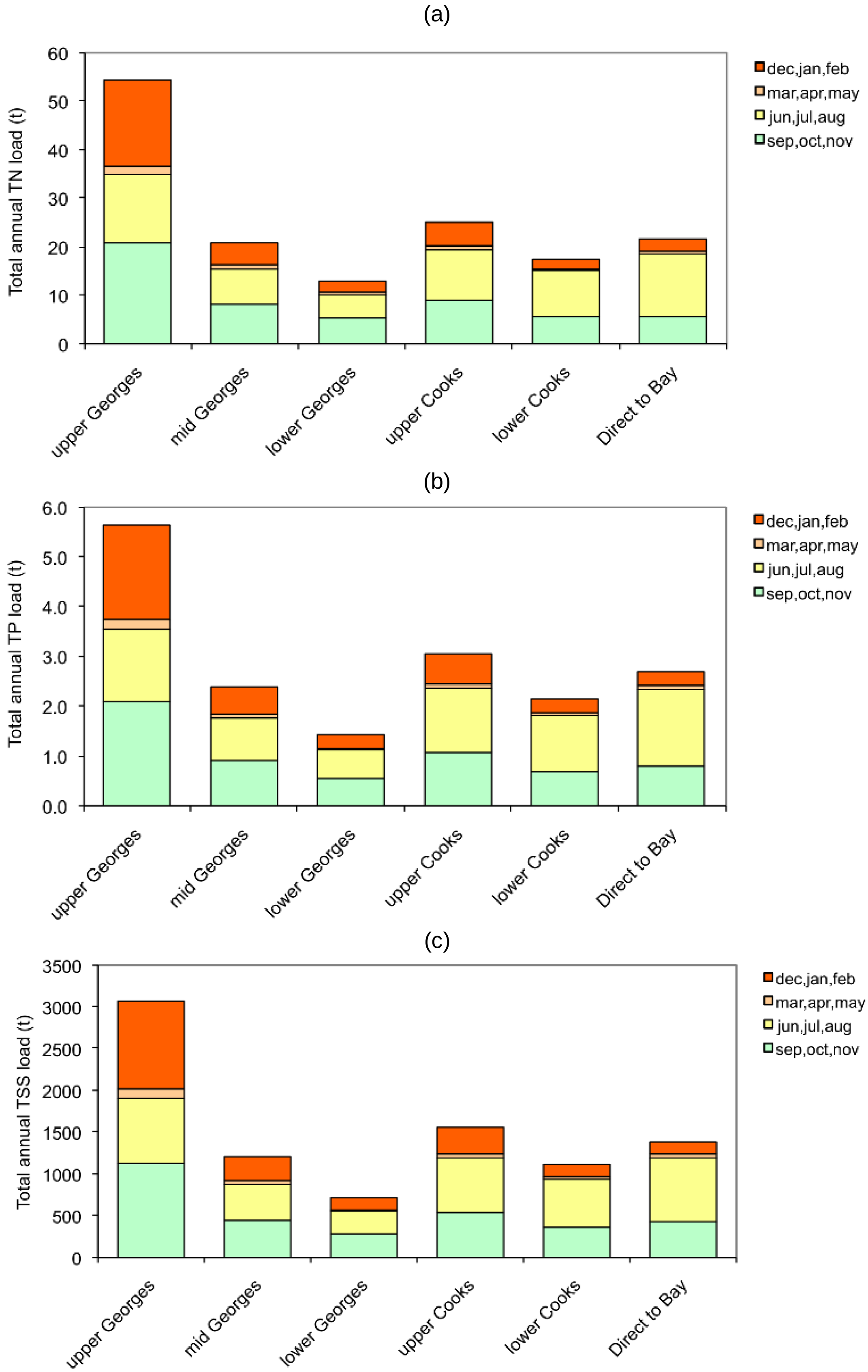
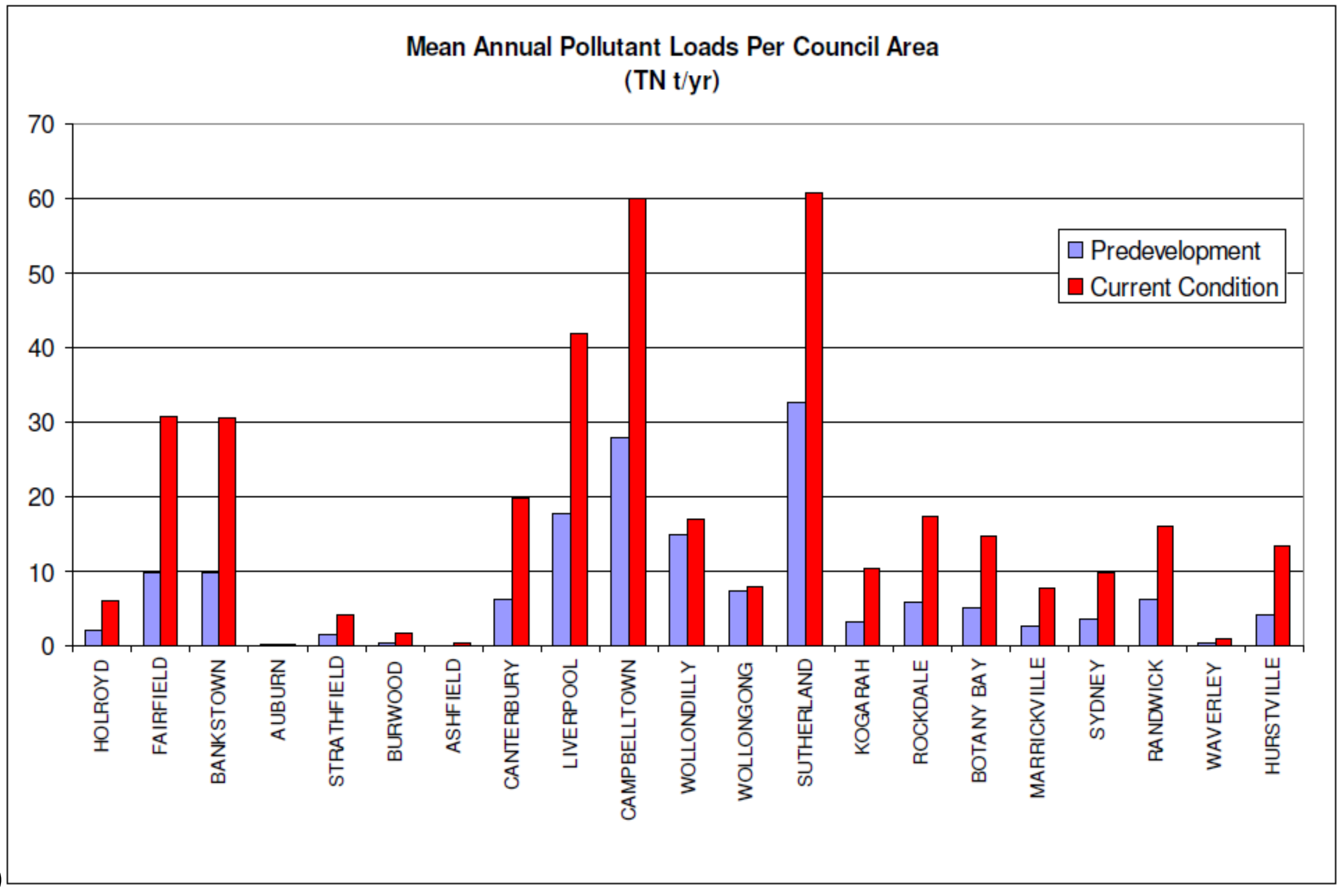
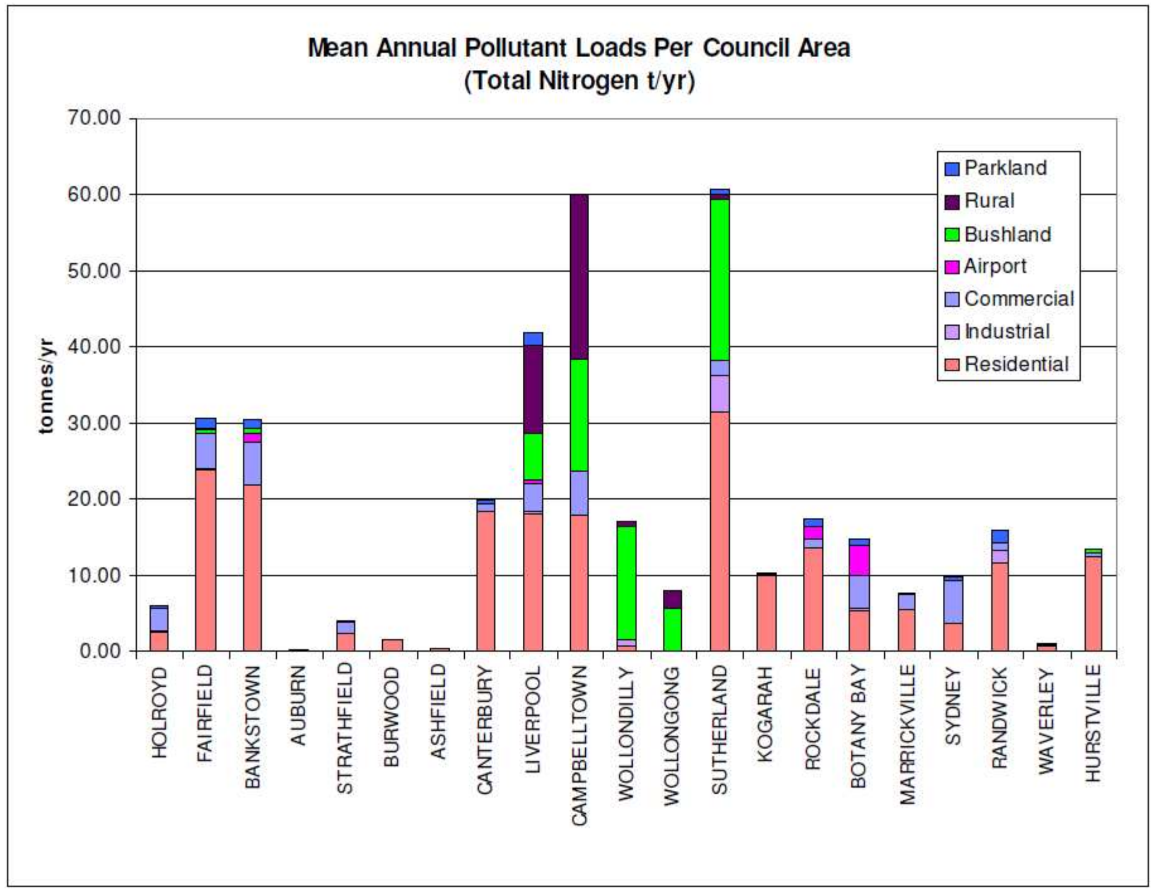


Figure 6.10 – Total annual loads of total nitrogen (a), total phosphorus (b) and total suspended solid (c) in 2007 in the Botany Bay catchment (BBCCI, 2009)

(a)



(b)



(c)

Name	Urban TN (T/yr)	Industrial TN (T/yr)	Commercial TN (T/yr)	Airport TN (T/yr)	Bushland TN (T/yr)	Rural TN (T/yr)	Parkland TN (T/yr)	All Land Uses TN (T/yr)
HOLROYD	2.59	0.12	3.02	0.00	0.00	0.00	0.30	6.03
FAIRFIELD	23.97	0.05	4.73	0.00	0.32	0.27	1.39	30.73
BANKSTOWN	21.76	0.00	5.68	1.35	0.48	0.00	1.27	30.54
AUBURN	0.00	0.00	0.07	0.00	0.00	0.00	0.17	0.24
STRATHFIELD	2.39	0.00	1.57	0.00	0.00	0.00	0.14	4.10
BURWOOD	1.51	0.00	0.00	0.00	0.00	0.00	0.00	1.51
ASHFIELD	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.30
CANTERBURY	18.51	0.00	0.96	0.00	0.00	0.00	0.33	19.80
LIVERPOOL	18.01	0.56	3.50	0.47	6.18	11.54	1.55	41.81
CAMPBELLTOWN	17.98	0.00	5.68	0.00	14.88	21.48	0.00	60.01
WOLLONDILLY	0.71	0.76	0.00	0.00	15.01	0.56	0.00	17.05
WOLLONGONG	0.00	0.00	0.00	0.00	5.62	2.38	0.00	8.00
SUTHERLAND	31.54	4.73	2.09	0.00	21.00	0.68	0.68	60.73
KOGARAH	10.00	0.00	0.20	0.00	0.00	0.00	0.08	10.28
ROCKDALE	13.59	0.00	1.16	1.77	0.00	0.00	0.79	17.31
BOTANY BAY	5.17	0.51	4.16	4.16	0.00	0.00	0.74	14.75
MARRICKVILLE	5.46	0.00	1.85	0.12	0.00	0.00	0.23	7.65
SYDNEY	3.66	0.00	5.58	0.00	0.00	0.00	0.55	9.79
RANDWICK	11.73	1.41	1.17	0.00	0.16	0.00	1.56	16.04
WAVERLEY	0.84	0.00	0.10	0.00	0.00	0.00	0.13	1.07
HURSTVILLE	12.36	0.00	0.62	0.00	0.34	0.00	0.00	13.32

(d)

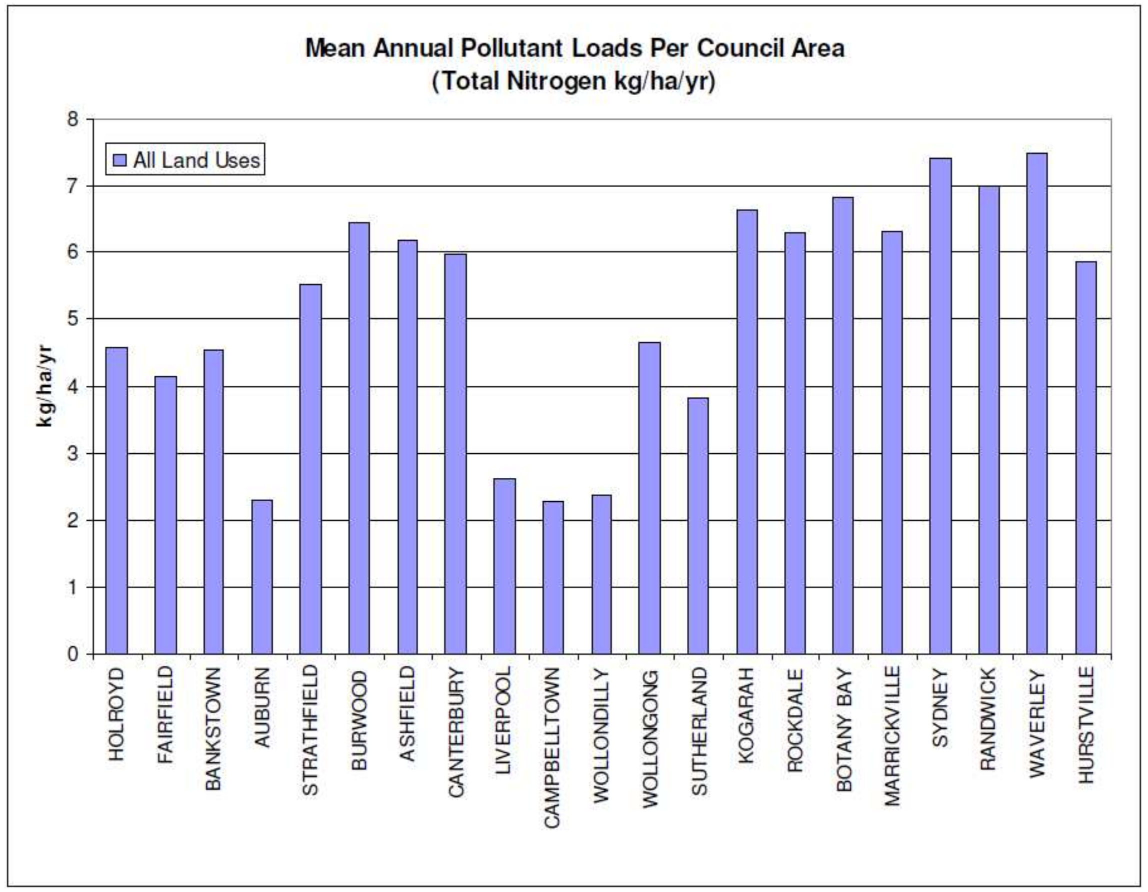
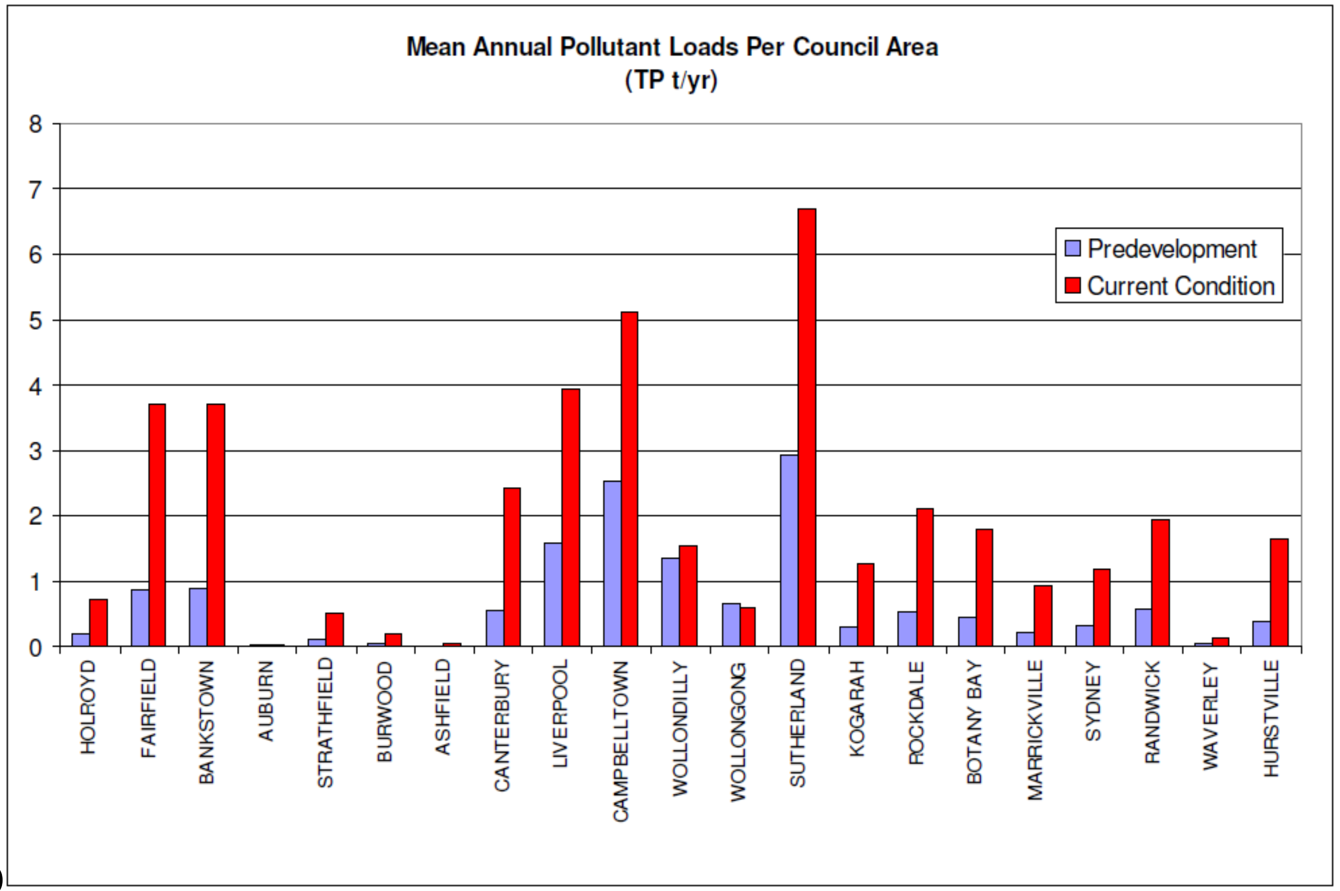
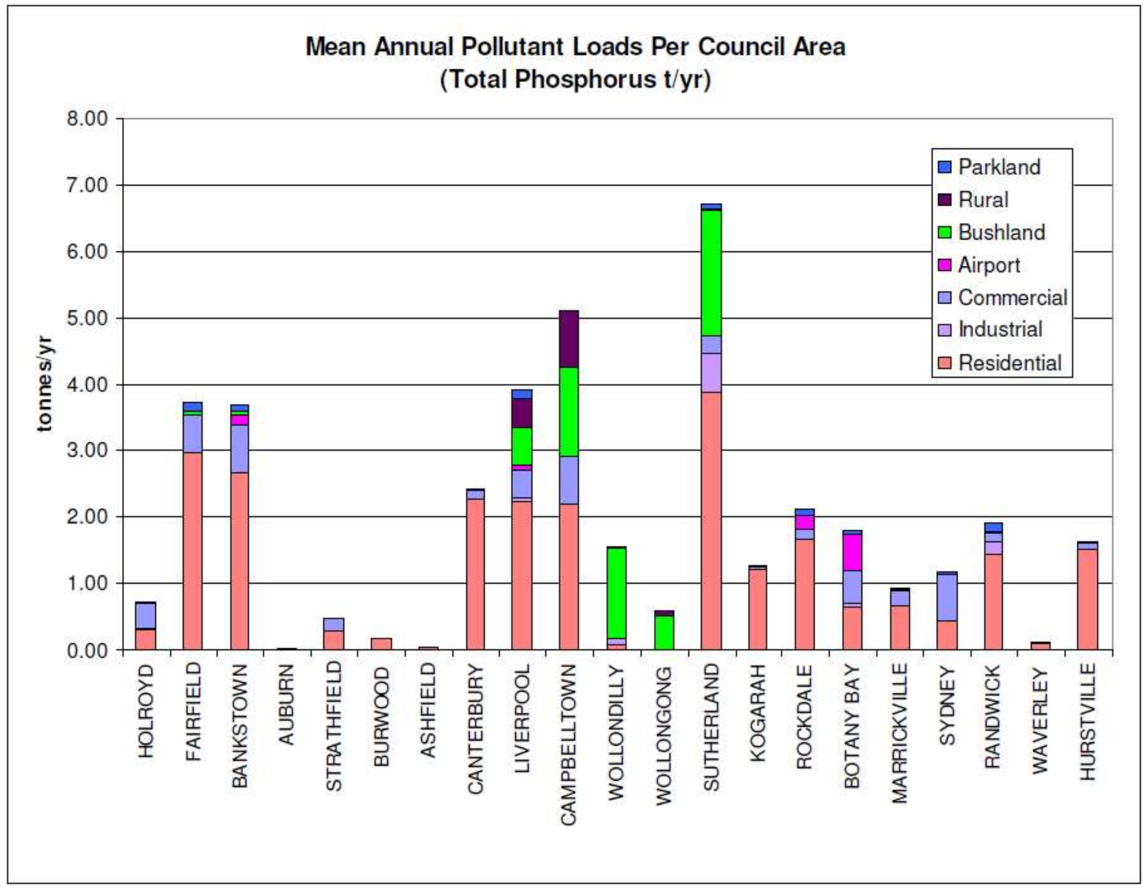


Figure 6.11 – Mean annual TN load in 2008 conditions compared to predevelopment condition per council area (a),mean annual TN loads per land use per council area (b) and (c), and mean annual TN load per hectare per council area(d) (BBCCI, 2008)



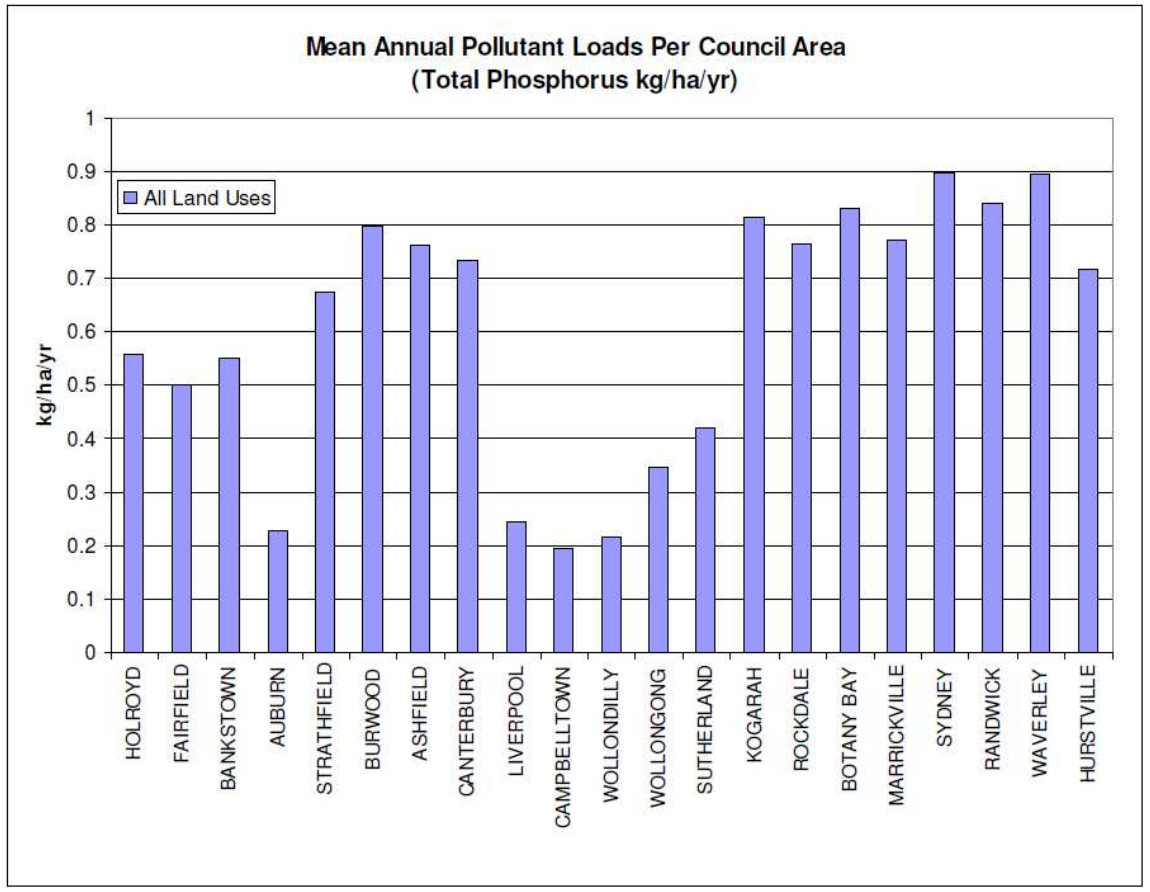
(a)



(b)

Name	Urban TP (T/yr)	Industrial TP (T/yr)	Commercial TP (T/yr)	Airport TP (T/yr)	Bushland TP (T/yr)	Rural TP (T/yr)	Parkland TP (T/yr)	All Land Uses TP (T/yr)
HOLROYD	0.32	0.01	0.37	0.00	0.00	0.00	0.03	0.73
FAIRFIELD	2.96	0.01	0.58	0.00	0.03	0.01	0.13	3.71
BANKSTOWN	2.68	0.00	0.70	0.17	0.04	0.00	0.11	3.71
AUBURN	0.00	0.00	0.01	0.00	0.00	0.00	0.02	0.02
STRATHFIELD	0.29	0.00	0.19	0.00	0.00	0.00	0.01	0.50
BURWOOD	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.19
ASHFIELD	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.04
CANTERBURY	2.28	0.00	0.12	0.00	0.00	0.00	0.03	2.43
LIVERPOOL	2.22	0.07	0.43	0.06	0.56	0.45	0.14	3.93
CAMPBELLTOWN	2.22	0.00	0.70	0.00	1.34	0.84	0.00	5.10
WOLLONDILLY	0.09	0.09	0.00	0.00	1.35	0.02	0.00	1.55
WOLLONGONG	0	0	0	0	1	0	0	0.60
SUTHERLAND	3.88	0.58	0.26	0.00	1.89	0.03	0.06	6.70
KOGARAH	1.23	0.00	0.03	0.00	0.00	0.00	0.01	1.26
ROCKDALE	1.67	0.00	0.14	0.22	0.00	0.00	0.07	2.11
BOTANY BAY	0.64	0.06	0.51	0.51	0.00	0.00	0.07	1.79
MARRICKVILLE	0.67	0.00	0.23	0.01	0.00	0.00	0.02	0.93
SYDNEY	0.45	0.00	0.69	0.00	0.00	0.00	0.05	1.19
RANDWICK	1.45	0.17	0.14	0.00	0.01	0.00	0.14	1.92
WAVERLEY	0.10	0.00	0.01	0.00	0.00	0.00	0.01	0.13
HURSTVILLE	1.52	0.00	0.08	0.00	0.03	0.00	0.00	1.63

(c)



(d)

Figure 6.12 – Mean annual TP load in 2008 conditions compared to predevelopment condition per council area (a),mean annual TP loads per land use per council area (b) and (c), and mean annual TP load per hectare per council area(d) (BBCCI, 2008)

6.3.6 Chlorophyll-a

Chlorophyll-a (Chl-a) is a water quality parameter which has been used as a surrogate indicator for phytoplankton growths, namely algal blooms and other similar algal infestations found during eutrophication. Chlorophyll-a is a photosynthetic pigment found in all green plants and while it cannot be easily related directly to cell numbers or total cell volume, due to variations in species, stage of cell development, cell size and other factors, it is nonetheless an empirically useful index to estimate distribution and density patterns of phytoplankton. This parameter is closely associated with nutrient loads, subsequent dissolved oxygen levels in the water, turbidity and the colour of water. There is often a direct positive correlation between nutrients, chlorophyll-a, and subsequent algal blooms, with high levels of nutrients acting as a precursor to such blooms (SPCC, 1979). Turbidity is perceived to be a particularly crucial parameter affecting chlorophyll-a concentration as phytoplankton growth is largely influenced by light availability and highly turbid waters can severely diminish light penetration. Like many of the other water quality parameters, there is a high level of interdependence and relevance between its presence and the attributes of the surrounding environment.

The concentrations for chlorophyll-a are highly sensitive to flow conditions, which has been highlighted by water quality monitoring done by the SPCC in the mid and late 1980's. The results show a substantial decrease in chlorophyll-a concentrations under high flow conditions, as phytoplankton is flushed downstream by freshwater inflows after storms. This means the residence time and chance for phytoplankton to grow and become established, especially in upstream areas, is dramatically diminished. Further ramifications of high flow conditions include changed levels of salinity and increased turbidity which are unfavourable conditions for effective phytoplankton growth. As such, under low flow conditions, chlorophyll-a concentrations were distinctively higher, progressively increasing upstream, with consistently higher values being observed at Liverpool Weir in excess of 20µg/L. Downstream of Milperra Bridge, the concentrations notably dropped off, although under high flow conditions this trend was unclear. Other hotspots also found with elevated chlorophyll-a measurements were at Prospect Creek, and at the junction of Williams and Harris Creek. Towards the mouth of the river, close to Botany Bay, chlorophyll-a concentrations were consistently low, presumably due to the presence of strong tidal flow providing effective flushing.

During warmer months of the year in the 1970's, typically around February, the distribution of chlorophyll-a showed significant algal growth around Liverpool Weir, Prospect Creek and Salt Pan Creek. The upper estuary during this period was dominated by sections of phytoplankton merging from Prospect Creek to Liverpool Weir. This proliferation of phytoplankton was fuelled by increased amounts of sunlight, higher water temperatures and low flow conditions. This phenomenon was similarly observed for later sets of water quality monitoring data done in the early 1990's by the AWT and PWD.

Ecological condition targets (ECT) for the Georges River Chl-a concentration are 5 μg/L for the upper reaches, 4.2 μg/L for the middle reaches and 2.2 μg/L for the lower reaches (BBCCI, 2009). Mean annual chlorophyll-a concentration measured between 1994 and 2006 are illustrated in Figure 6.13. From this figure, it can be noted that the Chl-a in the lower Georges estuary exceeded the target 9 years out of 13. Error bars shows the maximum and minimum concentration during the year. The maximum concentration of less than 10 μg/L shows that the lower Georges is protected by a larger flushing volume of the river and wider opening to the bay avoiding nutrients concentration. Chl-a in the mid-Georges estuary at Salt Pan Creek only exceed the ECT slightly while the target was met only 3 times over the 13 years of measurements in the upper reaches.

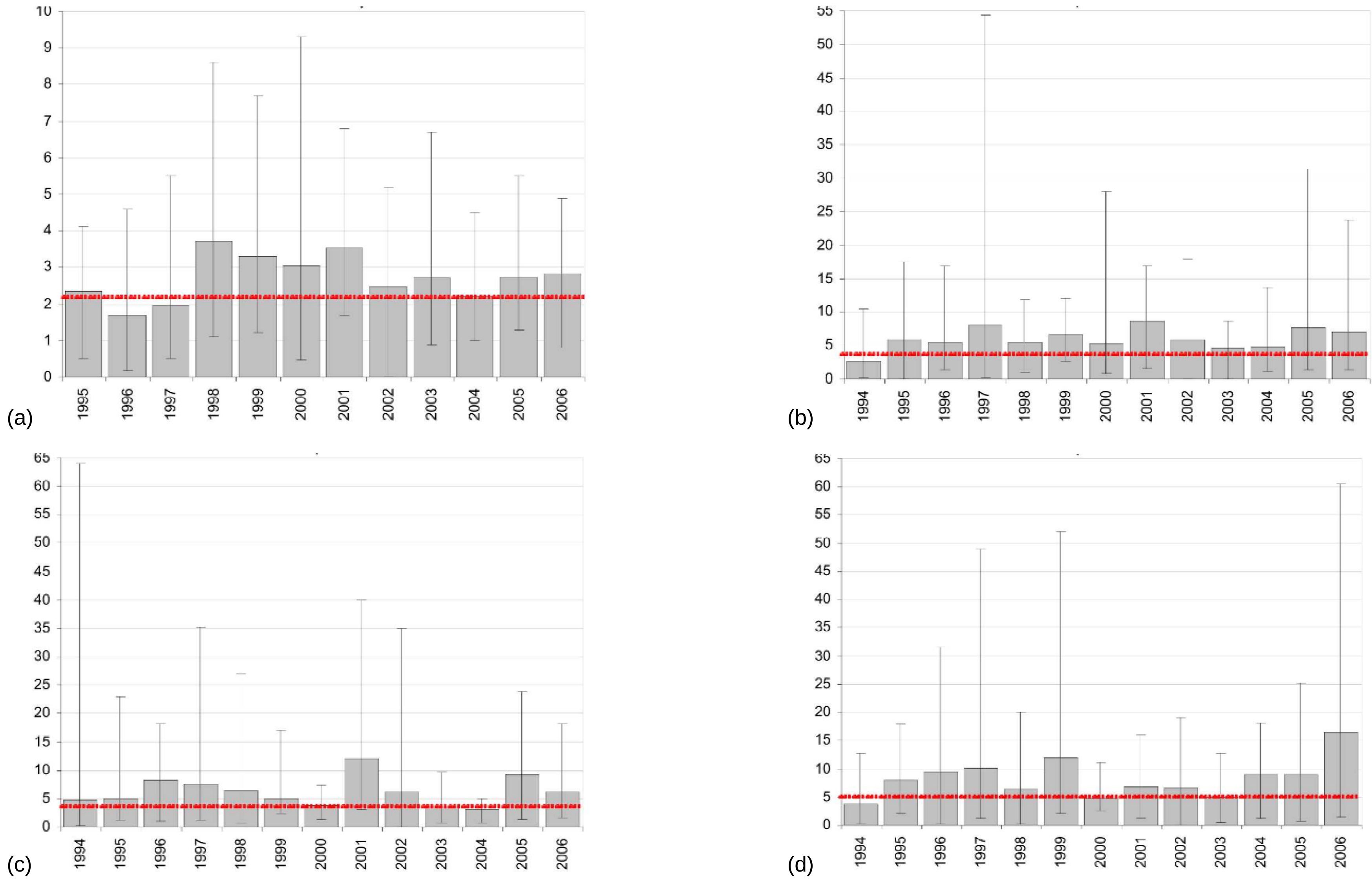


Figure 6.13 – Mean annual chlorophyll-a concentration at Woolooware Bay (a), Salt Pan Creek (b), Lower Prospect Creek (c) and Liverpool Weir (d) (BBCCI, 2009)

6.3.7 Bacteria and Pathogenic Contamination

There are hundreds of thousands of bacteria and pathogens which exist in the environment at any one time, and despite the stigma attached to them, they hold an important and foundational role in a functioning ecosystem. While many bacteria colonies are not disruptive to humans, there is a range of pathogens including viruses, bacteria, parasitic protozoa and helminths that are harmful and can cause serious illness. Due to the low numerical incidences and wide variation of pathogenic species in the environment, it was not only impractical but also uneconomical to continually test for a large number of pathogenic indicators. Instead, a general indicator of faeces, *Escherichia coli* (E.coli), was considered as a measure of bacteria and pathogenic contamination. However, this simplification of implementing a representative measure for such a large scope of pathogens means that the absence of E.coli does not automatically equate to water being completely free of pathogens, nor does a decrease in faecal coliform levels necessarily correspond to a decrease in pathogen levels. Although faecal coliforms are not intrinsically pathogenic, a high concentration is usually a good indication of possible exposure to other pathogens. Faecal coliforms are measured by the number of colony forming units (cfu) per 100mL of sampled water. Secondary treated sewage faecal coliform typically has densities of 100,000 cfu/100mL, so levels approaching this would indicate recent sewage pollution. The persistence of faecal organisms in the waterways are dependent upon factors such as dilution (rain or tidal), osmotic effects, solar radiation, salinity, turbidity and predation by other organisms. With the frequent use of the river for recreational purposes and the large population it serves, this water quality parameter is of particular interest as it has a direct impact on human health.

For the Georges River, the primary sources of bacteria and pathogenic contamination arise from sewage treatment plant effluent and sewer overflow predominantly, and to a lesser extent, urban stormwater runoff, which may contain faecal material from pets, animals and possibly humans too. Since sewage is the highest single source of faecal coliforms, it is important to briefly review its pathways of movement and the ways in which it may come in contact with the environment and humans.

There are three Sewage Treatment Plants (STPs) in the Georges River area which occasionally discharge into the river and its tributaries - Liverpool, Fairfield and Glenfield. Liverpool and Glenfield STPs are secondary treatment plants which discharge to the Northern Georges River sub-main then onto Malabar via the Southern and Western Suburbs Ocean Outfall Sewer (SWSOOS). Fairfield STP is a storm flow plant and provides primary treatment and disinfection before discharge to Orphan School Creek when the NGR is at capacity (Sydney Water Corporation, 2008). The current sewerage system transports sewage through the SWSOOS to Malabar, where it is processed and expelled via the ocean outfall. Part of this network collects and carries sewage from the North Georges River submain which covers areas from the Cooks River to Lansdowne via Salt Pan Creek and Hurstville. Several other smaller submains contribute to this from the Georges River, Bankstown, Smithfield and the Lansvale area around Chipping Norton. The distribution of these overflows in the Georges River catchment is depicted in Figures 6.14 to 6.16. Within this network of pipes, a number of sewage overflow points are located in the system as a preventative measure to infrastructure damage by acting as stress relief points under high flow conditions, where the flow exceeds the pipe's carrying capacity. This occurs during periods of wet weather when infiltration of stormwater into the sewerage system takes place due to illegal connections from properties to the system and infiltration via cracked or broken pipes and joints. This greatly adds to the volume of sewage that the pipes need to carry, thus overflows are common in the Georges River catchment during wet weather and effluent ends up in the river either by direct discharge or being washed in by stormwater runoff, depending on the location of the overflow. Figure 6.17 shows both the operation of a sewer overflow pipe schematically and a picture of an overflow in operation, discharging into a river.

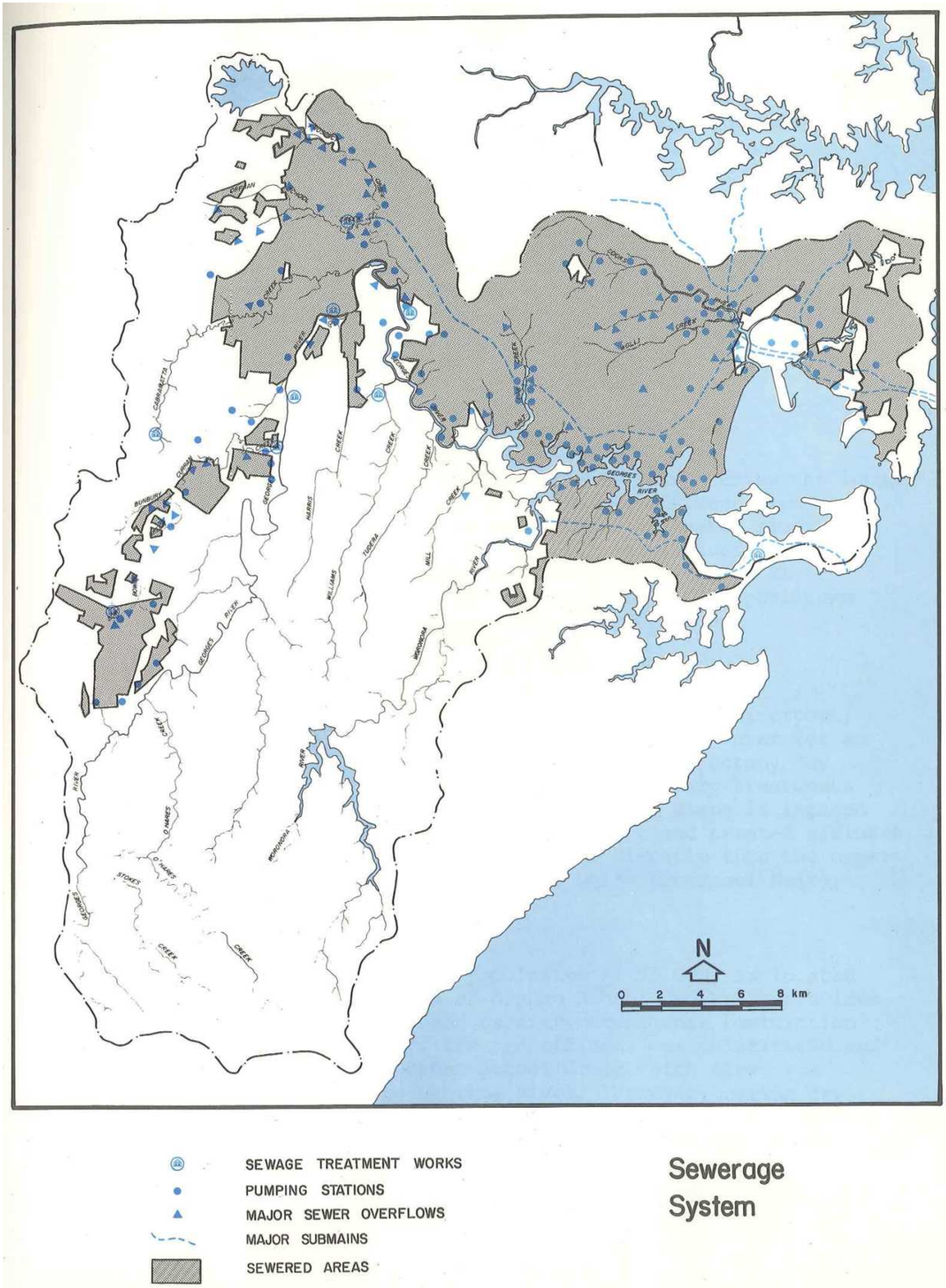


Figure 6.14 – Sewerage system in the Georges River catchment (SPCC, 1979)

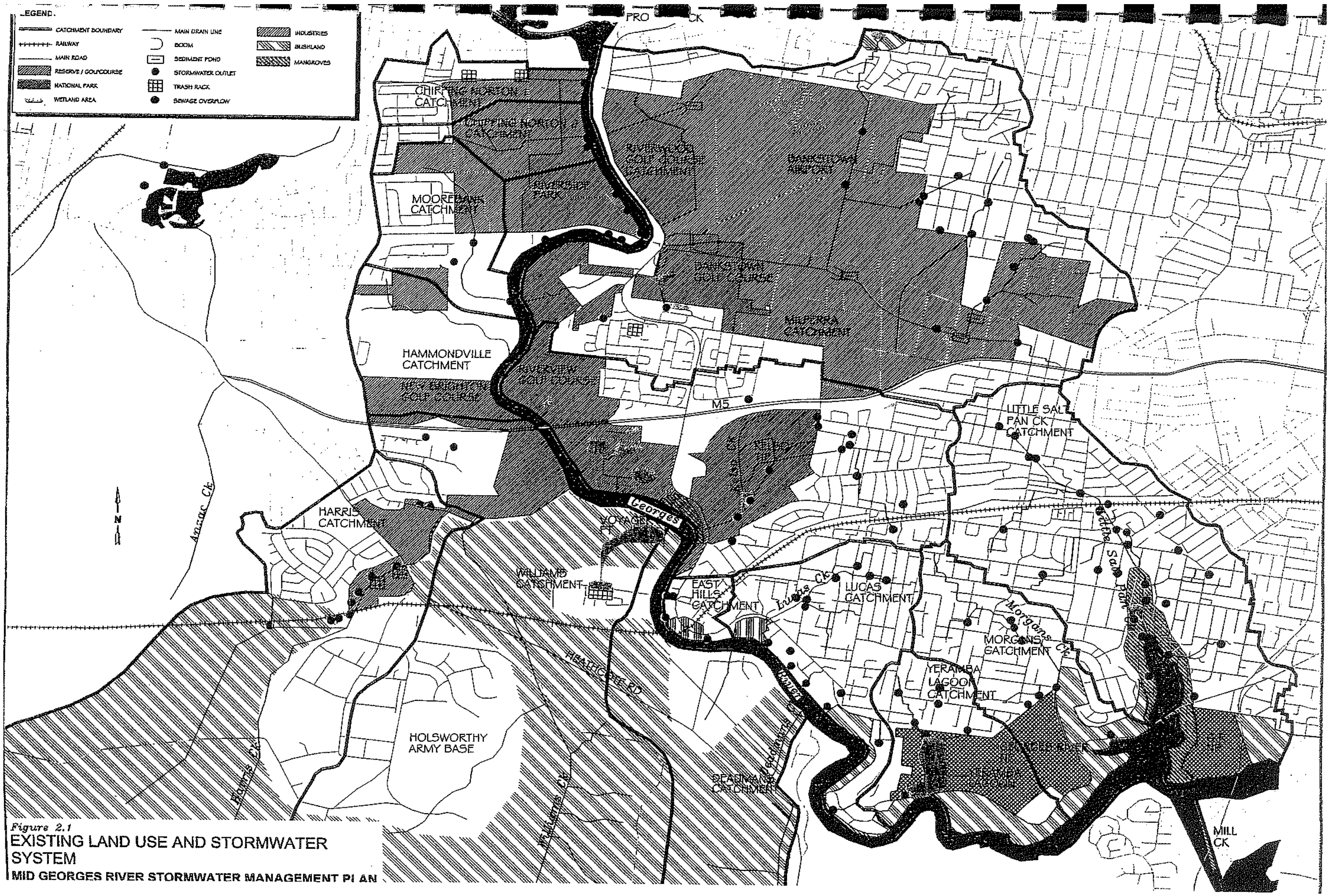


Figure 6.15 – Stormwater Outlet and sewage overflows in the Mid-Georges River (Kinhill Engineers, 1999)

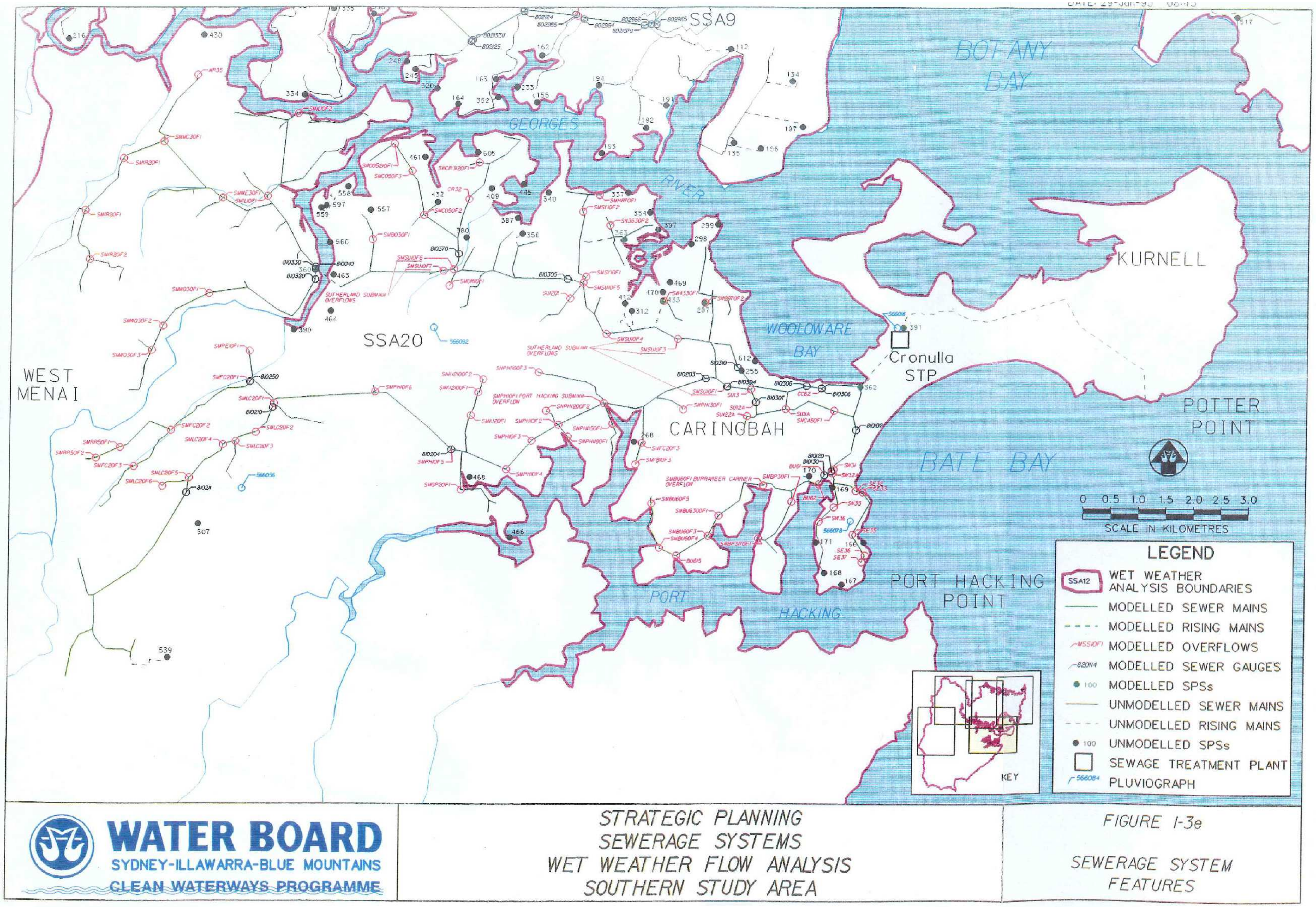


Figure 6.16 – Sewerage System in the Lower Georges River (Water Board Sydney-Illawarra-Blue Mountains Clean Waterways Programme, 1993)

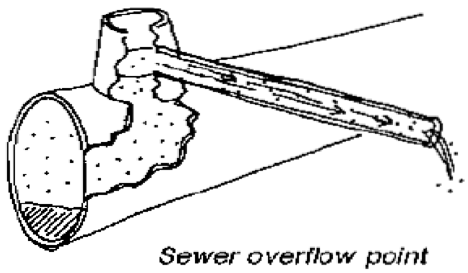


*Figure 6.17 – Sewer overflow (*http://www.johnstown-redevelopment.org/RAW/overflow.jpg)

Sewer overflows in the lower Georges River catchment area together with stormwater outlet locations are shown in Figure 6.18 (Harbourwatch 2008).

A number of water quality studies done between the early 1970's to the early 1990's reveal a general trend of increasing faecal coliform concentration moving upstream. Problem areas that were characterised by a poor performance for other water quality parameters, such as areas surrounding Prospect Creek, Cabramatta Creek and Salt Pan Creek, were again highlighted as areas that had high counts of faecal coliforms. From water quality data collected by the SPCC between 1971 and 1976, mean values of faecal coliform counts increased from 4 cfu/100mL at the mouth of the Georges River in Botany Bay, to 933 cfu/100mL just downstream of Liverpool Weir, with the majority of values at all locations falling under the 150 cfu/100mL threshold, as recommended in the ANZECC guidelines for primary recreational contact. The influence of the strong tidal processes can be clearly seen in the consistently low faecal coliform measurements.

Correlating coliform levels with salinity, it was generally found that higher faecal coliform levels were accompanied by lower salinity levels at all locations along the river except for Liverpool Weir, where the reverse scenario was true. This corresponds well with the known and measured high counts of faecal coliforms which regularly occur after wet weather events, where large influxes of freshwater enter the river via sewage overflow points or through stormwater runoff from the catchment, both sources of faecal coliforms. Similarly, while lower parts of the river are better flushed than the upper reaches, major sewer overflows from the NGR submain are located at Salt Pan creek, Lime Kiln bay and Gungah Bay, and after heavy rainfall, these areas were observed to contain much higher levels of faecal coliforms. This can be clearly seen from some water quality data from 1990 showing faecal coliform levels both in dry weather and wet weather conditions in Figure 6.19.

Seasonality appears to also have an influence on the concentration of faecal coliforms whereby summer readings were notably lower than those in winter months as seen Figure 6.20. This is well explained by the known effects of the sun's ultraviolet radiation on the mortality of faecal coliforms with daily average summer radiation levels typically being twice that of winter. Additionally, the warmer water temperatures in summer may encourage a more dominant presence of bacteriophages and similar predators in the water which consume faecal coliforms, and thus result in a faster recovery of water quality. However as noted before, a decline in faecal coliforms does not necessarily equate to less pathogens in the water.

Figure 6.18 – Water quality sampling sites, sewer overflows and stormwater drains in the lower Georges River catchment (Harbourwatch, 2008).

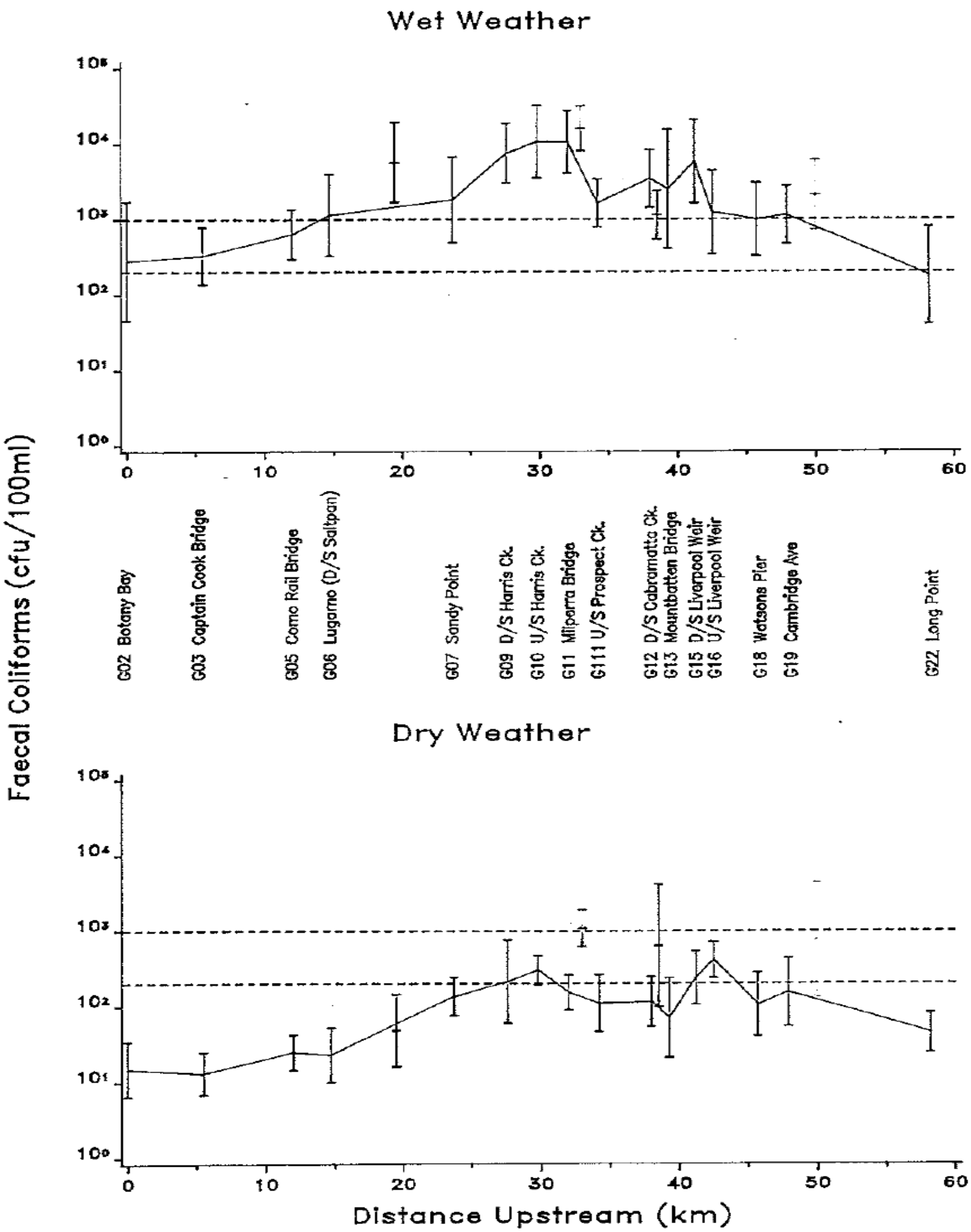


Figure 6.19 – Georges River 1990 Water Quality Monitoring - Preliminary Report February to August

Table 15. Levels of Faecal Coliforms Observed at Eight Stations along Georges River during May/June 1977

Date	Rainfall* (mm)	Faecal coliforms (FC/100 mL)** Liverpool (400)	Prospect Creek (320)	Milperra (300)	East Hills (240)	Picnic Point (210)	Salt Pan Creek (160)	Lugarno (120)	Como (90)
May									
2		160	72	64	28	40	16	4	8
3		240	120	160	48	0	8	0	0
4		340	110	100	52	4	12	12	8
6	5.5								
7	1.0								
9		180	72	80	64	8	16	4	20
10		312	240	400	52	16	4	32	0
11		120	320	210	80	32	0	12	4
14	3.5								
15	35.0								
16	37.5	560	1 200	800	720	560	240	100	88
17	0.7	400	480	400	480	320	240	88	68
18	7.0	550	1 100	740	350	400	30	20	80
19	10.5								
23		-	180	160	210	160	40	0	0
24	0.1								
25		170	140	150	180	30	10	10	0
28	10.5								
29	5.0								
30	5.5	360	2 000	>2 000	480	320	320	40	16
31	0.1								
June									
1		110	290	200	64	96	24	16	0
Range		110-560	72-2 000+	64-2 000+	28-720	0-560	0-320	0-100	0-88

Table 16. Levels of Faecal Coliforms Observed at Eight Stations along Georges River during December 1977-January 1978

Date	Rainfall* (mm)	Faecal coliforms (FC/100 mL) Liverpool (400)	Prospect Creek (320)	Milperra (300)	East Hills (240)	Picnic Point (210)	Salt Pan Creek (160)	Lugarno (120)	Como (90)
Dec.									
1	12	-	-	-	-	-	-	-	-
2	3	184	96	92	12	4	0	4	0
5		60	20	20	20	0	0	0	0
6		170	64	24	0	0	0	-	0
11	0.5								
12		140	40	28	-	20	0	0	0
13		52	24	0	4	0	0	-	-
14		350	48	20	16	800	4	8	0
16	1								
20	1.5								
23	0.5								
26	3.5								
Jan.									
3	2								
4	12.5	40	80	10	460	340	380	88	90
5	30								
6	12								
9		140	290	28	24	8	12	0	8
11		60	20	0	0	0	0	0	0
16	2.5	200	10	10	50	0	0	0	0
17	2								
18	28.5	420	400	0	0	0	0	0	0
19	30								
23		190	80	160	20	4	56	0	0
Range		40-420	20-400	0-160	0-460	0-800	0-380	0-88	0-90

Figure 6.20 – Level of faecal coliform along the Georges River in 1977-1978 (SPCC, 1979)

Despite the general correlations made above, there was a considerable amount of scatter in the data. Regardless of the sampling point's location, the range of faecal coliform concentrations remained similar across all the monitoring stations, all exhibiting some high levels of faecal coliforms of up to 100,000 cfu/100mL in the SPCC data as shown in Table 6.6; although the frequency of this decreased moving downstream.

Table 6.6 – Percentage distribution of faecal coliform levels at Georges River sampling stations (SPCC, 1979)

Range of Faecal Coliforms (FC / 100 mL)	Station						
	0	120	180	240	300	360	390
0 - 10	81	63	40	20	10	5	0
10 - 100	10	20	35	40	27	16	14
100 - 1 000	3	10	15	30	47	58	52
1 000 - 10 000	3	7	5	7	13	16	28
10 000 - 100 000	3	-	5	3	3	5	7

This scatter is also somewhat mirrored in the recent water quality monitoring data supplied by Bankstown Council where values would jump between 0 and 300,000 cfu/100mL on any given day. It is clear from the data that faecal coliform levels have increased significantly in the last two decades for the middle section of the river, easily eclipsing the highest values from the most recent data presented in the early 1990's by over 10 times in some instances. In the absence of more data upstream and downstream of Bankstown's boundary, it is difficult to ascertain whether similar patterns of longitudinal distribution still occur spatially within the Georges River, increasing in concentration when travelling upstream. However, the data did show that for 60 – 70% of the time, faecal coliform concentrations were over 150 cfu/100mL as recommended by the ANZECC guidelines for primary recreation use between Salt Pan Creek and Prospect Creek. And similarly, 25 – 50% of the time faecal coliform concentrations were over 1000 cfu/100mL as recommended by the ANZECC guidelines for secondary recreation. The worst areas with the highest concentrations were in the proximity of Salt Pan Creek. Like the other water quality parameters, the impacts of urban density and consequent stormwater runoff from these areas are likely to result in lower water quality, and indeed this has been true for faecal coliforms too.

Concentrations of Faecal Coliforms and Enterococci were studied in 2007-2008 by Harbourwatch along the lower Georges River (i.e. between Jewfish Bay and Botany Bay) and compared to the WQOs of 150CFU/100ml for the FC and 35CFU/100ml for the Enterococci described in Table 6.6. Results of the sampling are given in Table 6.7 and in Figure 6.21.

The pollutant modelling undertaken by BMT WBM (BBCCI, 2008) describes the load of Faecal Coliforms within the Botany Bay catchment. The mean annual FC load per council and per landuse was provided in Figure 6.22.

The Council areas producing the most significant FC loads are Sutherland, Bankstown and Fairfield due to their large area. The average production of FC ranges between 1×10^{10} and 6×10^{10}/ha/yr within the Georges River catchment.

Table 6.7 – Compliance and ranking of Lower Georges River Sites during Summer 2007-2008 (Harbourwatch, 2008)

Site	Compliance (%) Faecal Coliforms	Compliance (%) Enterococci	Overall rank (out of 41)
Jew Fish Bay Baths	88	88	15
Como Baths	88	84	18
Oatley Bay Baths	88	72	27
Carss Point Baths	78	59	35
Sandringham Baths	88	94	9
Dolls Point Baths	88	91	12
Ramsgate Baths	87	100	7
Monterey Baths	88	100	6
Brighton-le-Sands Baths	88	100	6
Kyeemagh Baths	84	78	25
Foreshores Beach	63	44	40
Yarra Bay	100	66	22
Frenchmans Bay	72	56	37
Congwong Bay	100	91	4
Silver Beach	88	100	6

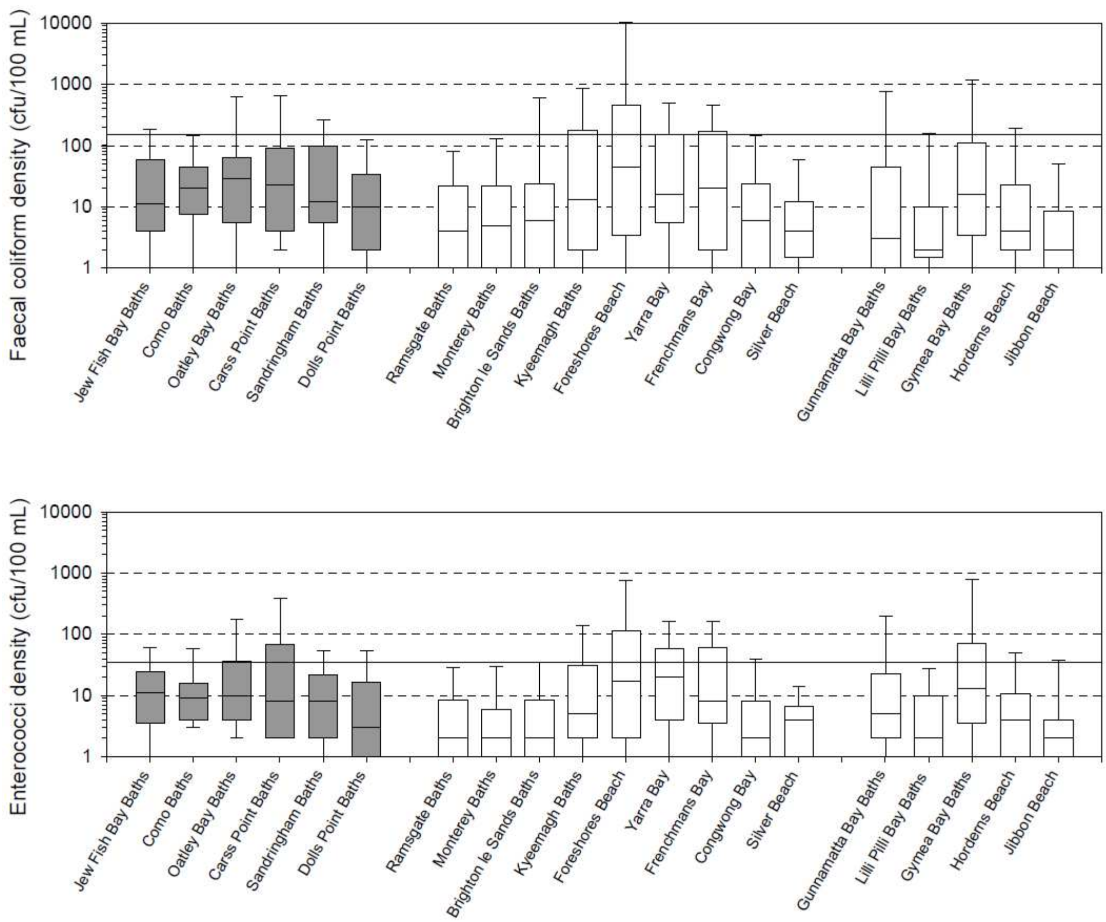
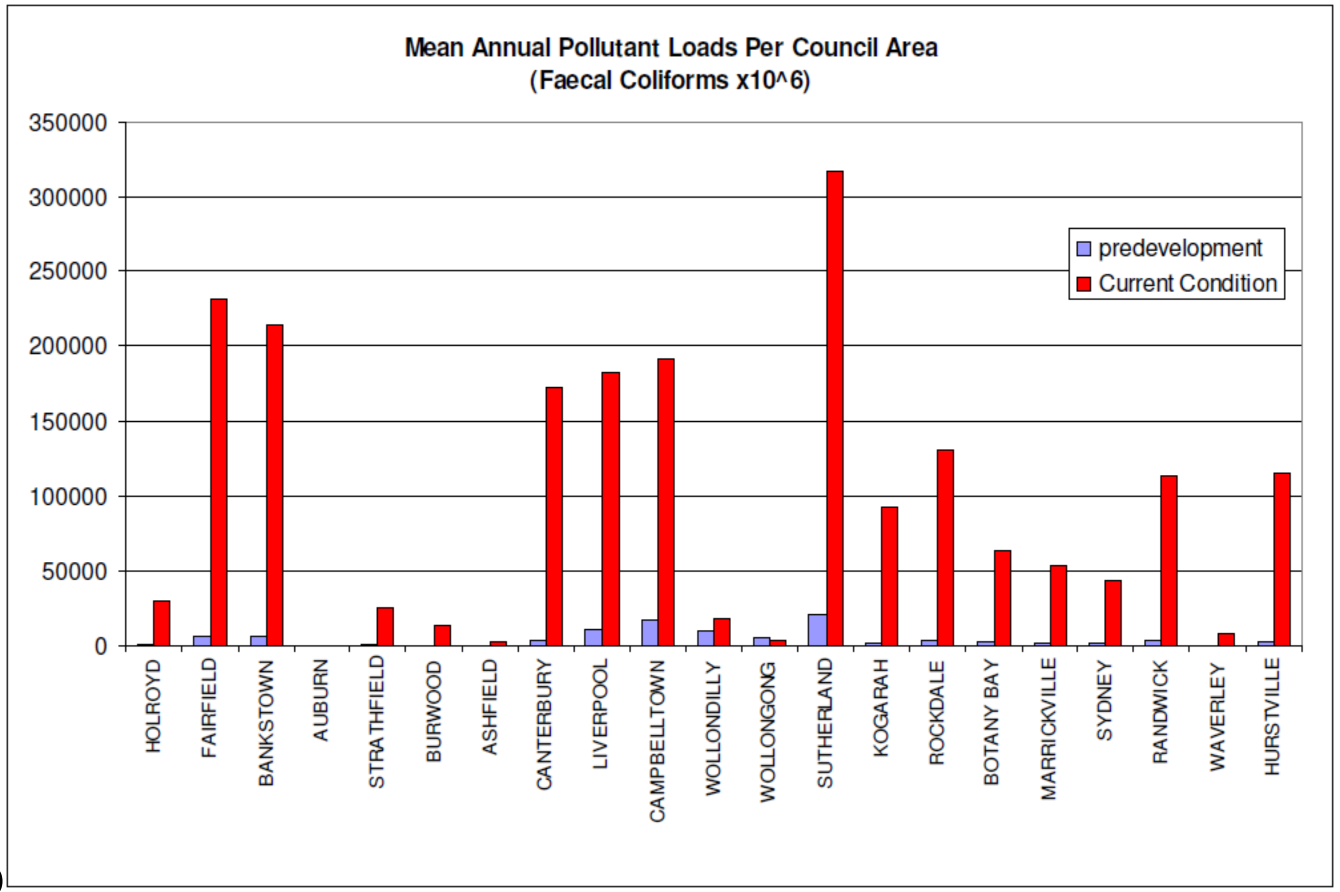
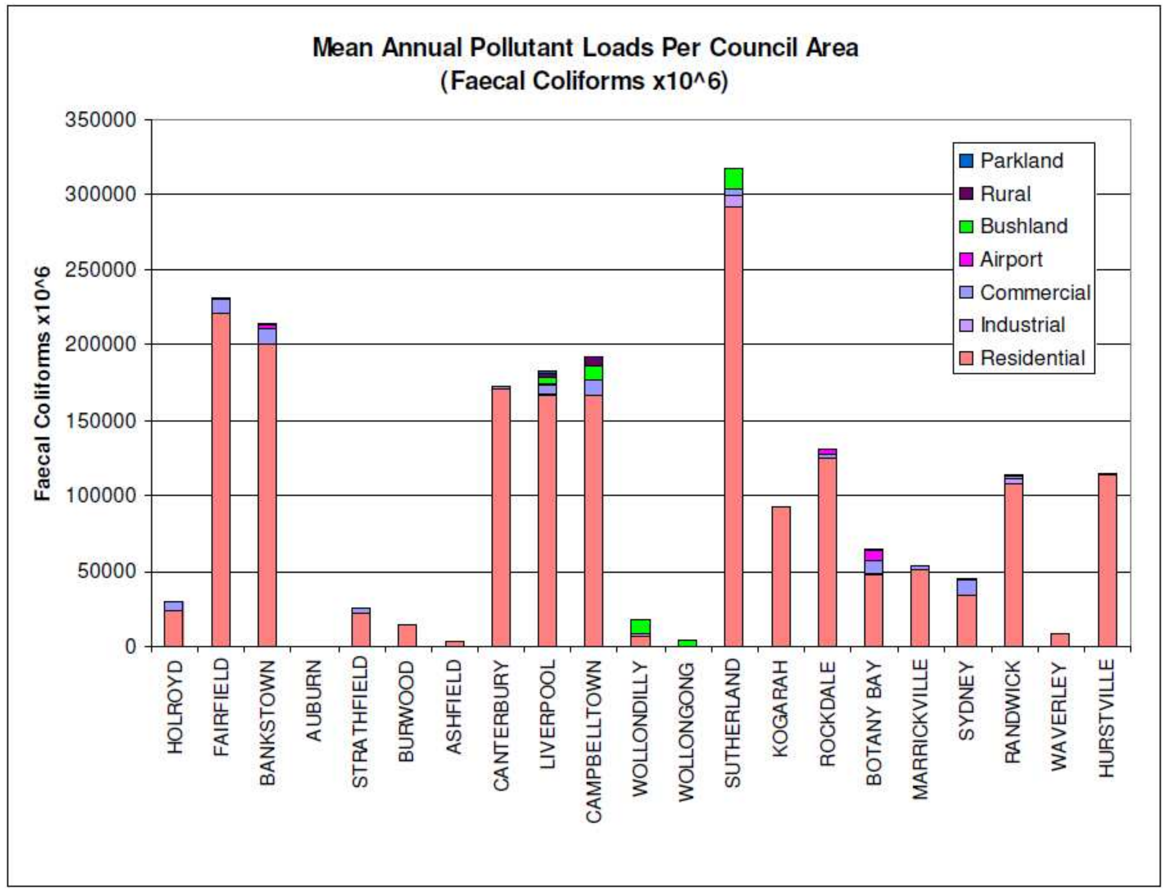


Figure 6.21 – Bacterial levels at Lower Georges River, Botany Bay and Port Hacking Sites during Summer 2007-2008 (Harbourwatch, 2008)

(a)


(b)


(c)

Name	Urban FC x 10^6	Industrial FC x 10^6	Commercial FC x 10^6	Airport FC x 10^6	Bushland FC x 10^6	Rural FC x 10^6	Parkland FC x 10^6	All Land Uses FC x 10^6
HOLROYD	23841	215	5550	0	0	0	188	29795
FAIRFIELD	221383	101	8704	0	200	74	870	231333
BANKSTOWN	200569	0	10375	2476	302	0	801	214523
AUBURN	0	0	123	0	0	0	109	231
STRATHFIELD	22012	0	2876	0	0	0	91	24979
BURWOOD	13907	0	0	0	0	0	0	13907
ASHFIELD	2788	0	0	0	0	0	0	2788
CANTERBURY	170610	0	1757	0	0	0	212	172579
LIVERPOOL	166510	1022	6433	855	3847	3185	971	182824
CAMPBELLTOWN	166195	0	10438	0	9303	5929	0	191865
WOLLONDILLY	6591	1407	0	0	9555	159	0	17712
WOLLONGONG	0	0	0	0	3608	675	0	4283
SUTHERLAND	291077	8672	3847	0	13308	191	432	317528
KOGARAH	92085	0	372	0	0	0	50	92507
ROCKDALE	125198	0	2126	3217	0	0	501	131042
BOTANY BAY	47619	930	7600	7632	0	0	470	64251
MARRICKVILLE	50142	0	3374	217	0	0	143	53877
SYDNEY	33744	0	10249	0	0	0	350	44343
RANDWICK	108168	2583	2135	0	103	0	997	113986
WAVERLEY	7758	0	181	0	0	0	85	8024
HURSTVILLE	113845	0	1138	0	216	0	0	115200

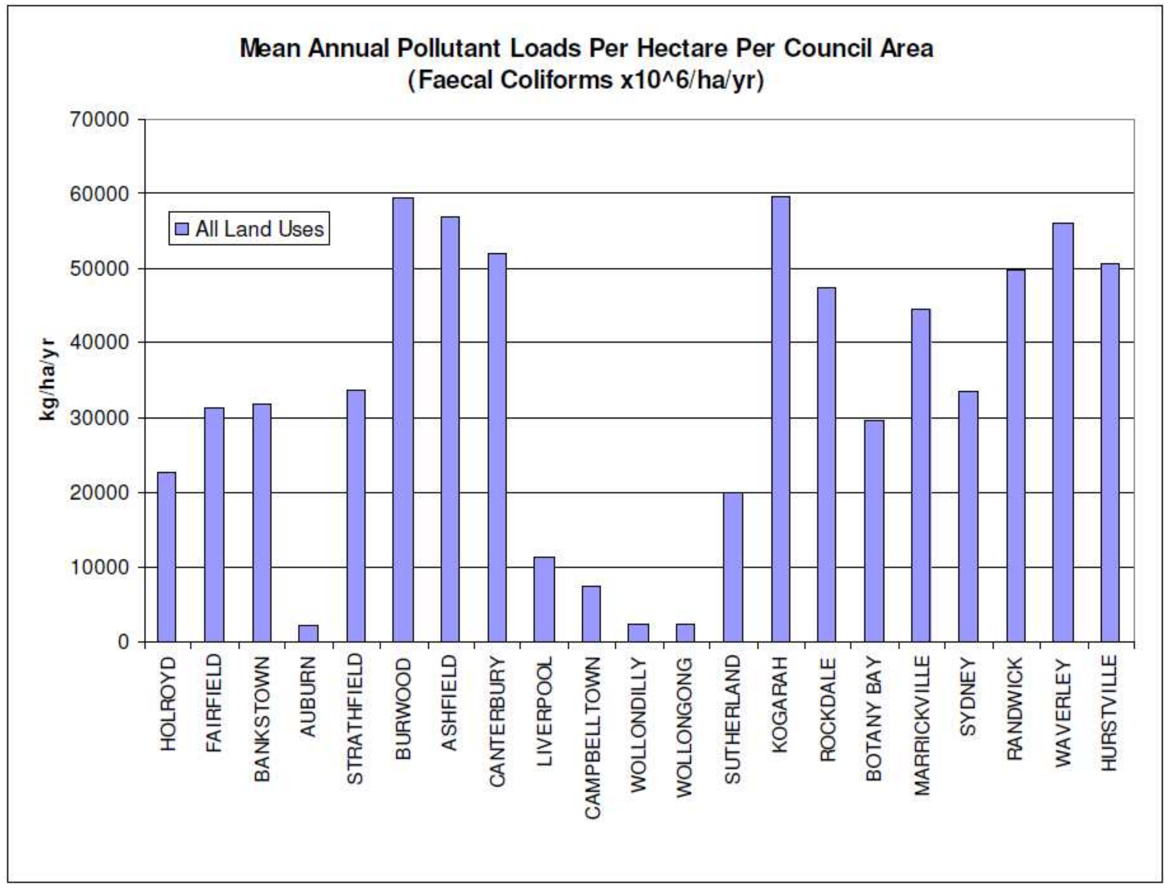
(d)


Figure 6.22 – Mean annual FC load in 2008 conditions compared to predevelopment condition per council area (a),mean annual FC loads per land use per council area (b) and (c), and mean annual FC load per hectare per council area(d) (BBCCI, 2008)

6.3.8 Heavy Metal Pollution

Heavy metals are an important aspect when considering water quality due to the potential health risks associated with coming in contact or consuming such substances in high doses. Heavy metals tend to refer to any metallic element that has a relatively high density. They occur naturally in the environment in very low concentrations and are essential to supporting life; however, in elevated concentrations, normally from artificial sources or anthropogenic activities, they become toxic and can cause many detrimental health issues to both animals and humans. One of the drivers behind their danger is their tendency to bioaccumulate when consumed, that is, they are retained in body tissue rather than being excreted. As such, moving up the food chain results in incremental increases of heavy metal levels as they continue to accumulate at every level of consumption. While there are thousands of metal compounds that are detrimental to human and animal health above a certain threshold, copper, zinc, nickel and lead are four heavy metals which are commonly found to occur in a river or estuary that has been disturbed by anthropogenic activities. Heavy metals may emanate from both point sources and diffuse sources such as industrial process wastes, sewage discharge, and perhaps most significantly but least controlled, urban runoff in stormwater. A substantial amount of heavy metals accumulate on street surfaces from sources like vehicle brakes, atmospheric fall out, exhaust emissions and galvanised iron roofs. All these are entrained and concentrated after a rainfall event, which effectively flushes the paved areas of the catchment to produce urban runoff that makes its way into the river system. Once there, they may be transported directly in suspension, in solution, or absorbed onto any sediments, organic matter or particulate matter. A portion of them may settle or become absorbed to the mud that mantles the estuary bed, and thus become immobile. Figure 6.23 below shows generically the various sources and sinks of heavy metals entering a river or estuary system.

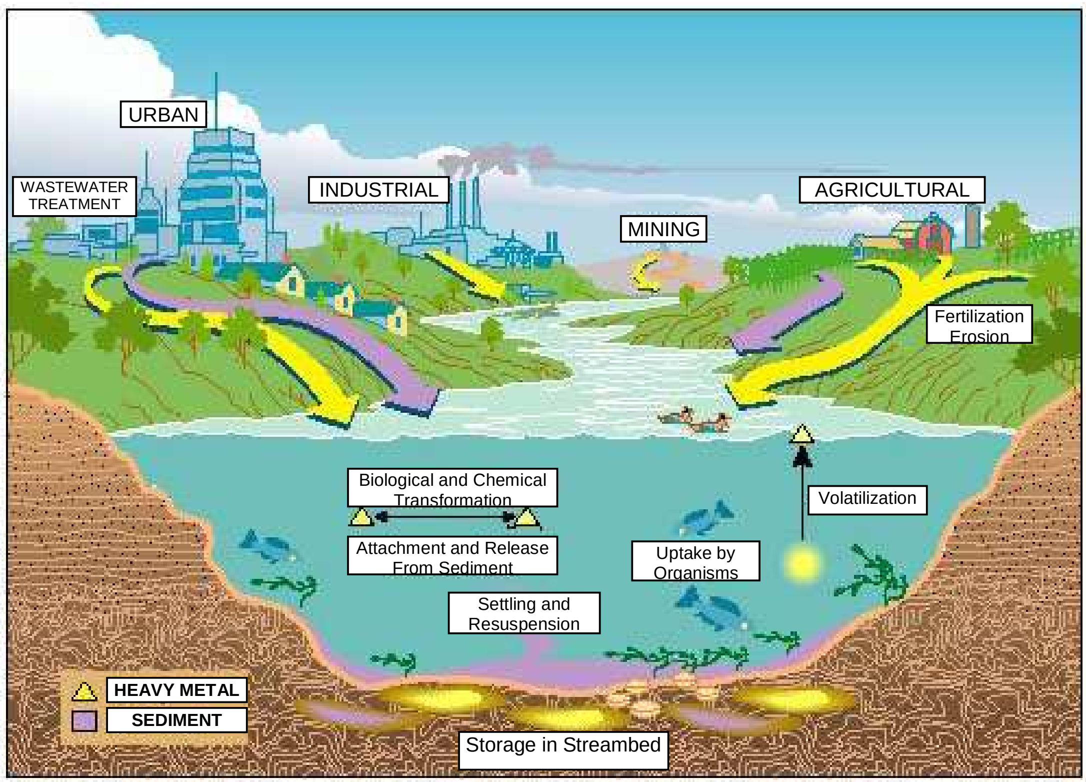


Figure 6.23 – Sources and sinks of heavy metals entering an estuarine system
http://altmed.creighton.edu/OrganicFood/heavy%20metals.jpg

Understanding the physical and biological properties of the river and surrounding environment is essential to understanding the distribution and temporal patterns of heavy metals. Two papers (Birch et.al, 1996 and Birch, 1993) in particular shed light to the state of heavy metal pollution within the Georges River and Botany Bay area, although neither of the studies extend further upstream than Salt Pan Creek. Generally, the majority of the estuarine areas greatly exceed background values, with the most elevated regions being the upper reaches of estuaries and bay ends. This was particularly so for Salt Pan Creek, where high metal concentrations of copper, zinc and lead were found to dominate this area; perhaps due to the extensive modifications resulting from the large waste dump in its headwaters. A substantial portion of metal enrichment in this upper section is a legacy of early uncontrolled dumping, although much stricter legislation has been placed on industrial discharges since then. It was found that baseline values for channel sediments had an enrichment factor of about 5 for copper, 6 for zinc and 3 for lead, while respective maximum enrichment values indicated enrichment factors of 33, 53 and 23. Botany Bay sediments did not fair much better with maximum enrichment factors of 45, 56 and 28 for copper, zinc and lead respectively, while baseline for all three elements were elevated by 4 times. Generally, sections of the main river channel have lower metal concentrations, although they are still above background values, while the lower reaches and particularly towards the mouth of the Georges River and Botany, some metals are closer to background values. A number of factors contribute to this, one being the stronger tidal flushing that occurs within the main river channel and the larger volume of water movement. Others result from the location of particular sources and sinks for the heavy metals.

Numerically, these equate to sediments containing 40-80 µg/g of copper in the upper estuary around the mouth of Salt Pan Creek, increasing to 300 µg/g for the end reaches of Salt Pan Creek and more than 100 µg/g for some bays like Lime Kiln and Jewfish Bay. These concentrations decrease noticeably near the mouth of the Georges River and Botany Bay. Zinc was found to range from 260 – 340 µg/g in the main river channel while off channel bays showed greater variance with a slightly wider range of 230-400 µg/g. Salt Pan Creek again showed much higher levels of zinc than baseline values, with a familiar trend of decreasing concentrations of zinc moving downstream. Interestingly, cross-sectional profiling of zinc in Salt Pan Creek showed mangrove sediments to be lower in zinc than adjacent channel sediments, 200 - <1000 µg/g compared to 340 – 1700 µg/g. Botany Bay sediments were found to generally have a uniform concentration of less than 300 µg/g of zinc. Concentrations of lead follow a very similar spatial distribution, where the main river channel ranges from 90 -110 µg/g, while off channel bays like Lim Kiln, Oatley and Neverfail Bay are elevated to more than 120 µg/g. Salt Pan Creek ranges from 100 – 300 µg/g in mangrove settlements but increase to more than 700 µg/g in the main channel, although again, a evident decline in lead concentrations are observed moving downstream (Birch et. al, 1996). These quantitative findings are summarised graphically in Figure 6.24, while Table 6.8 provides more detailed quantitative values of baseline and maximum metal concentrations.

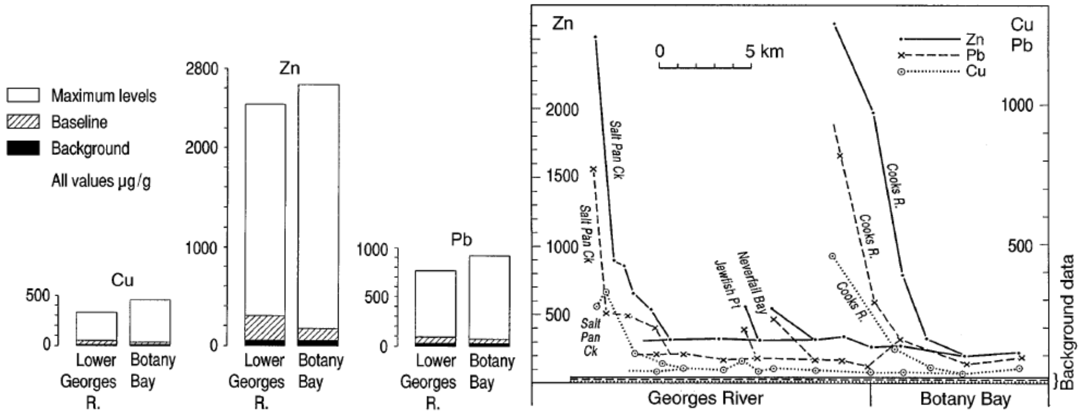


Figure 6.24 – Copper, Zinc and Lead concentration along the Georges River (Birch et.al, 1996)

Table 6.8 – Estuarine and marine metal concentrations (Birch, 1993)

	Cu	Zn	Ni	Pb
Parramatta River/Sydney Harbour				
Bay ends (max)	1078	2243	86	791
Harbour (baseline)	300–400	1000–600	42–50	500–700
Harbour mouth	50	200	28	200
Georges River/Botany Bay				
Bay ends (max)	457	2641	52	927
River (baseline)	100	340	—	200
Bay (baseline)	80	300	—	180
Offshore				
Max	135	249	109	70

As alluded to earlier, diffuse sources can contribute significantly to the distribution and accumulation of heavy metals in the Georges River and Botany Bay area, and while a number of potential metal diffuse sources are present, including the 786 sewage overflow structures, marinas, moorings and direct fallout within the area, it has been estimated that 95% of the total contaminant load to the Georges River/Botany Bay estuary is from stormwater runoff. It was concluded that the numerous diffuse sources in the estuary have led to increases in baseline levels of heavy metals to approximately four time background levels (Birch et.al, 1996). Strong associations between particular sources and elevated concentrations of specific heavy metals may be linked at times. For example, areas with a high density of boat use and boat moorings may experience elevated levels of copper and zinc. With the cessation of tributyltin based anti-fouling paints, copper contents in paints have increased as a substitute. Similarly, high zinc levels may result from contact with slipways, galvanised material and sacrificial anodes. The following figures (Figure 6.25) map out the distribution patterns respectively for copper, zinc and lead levels in the lower Georges River and Botany Bay area.

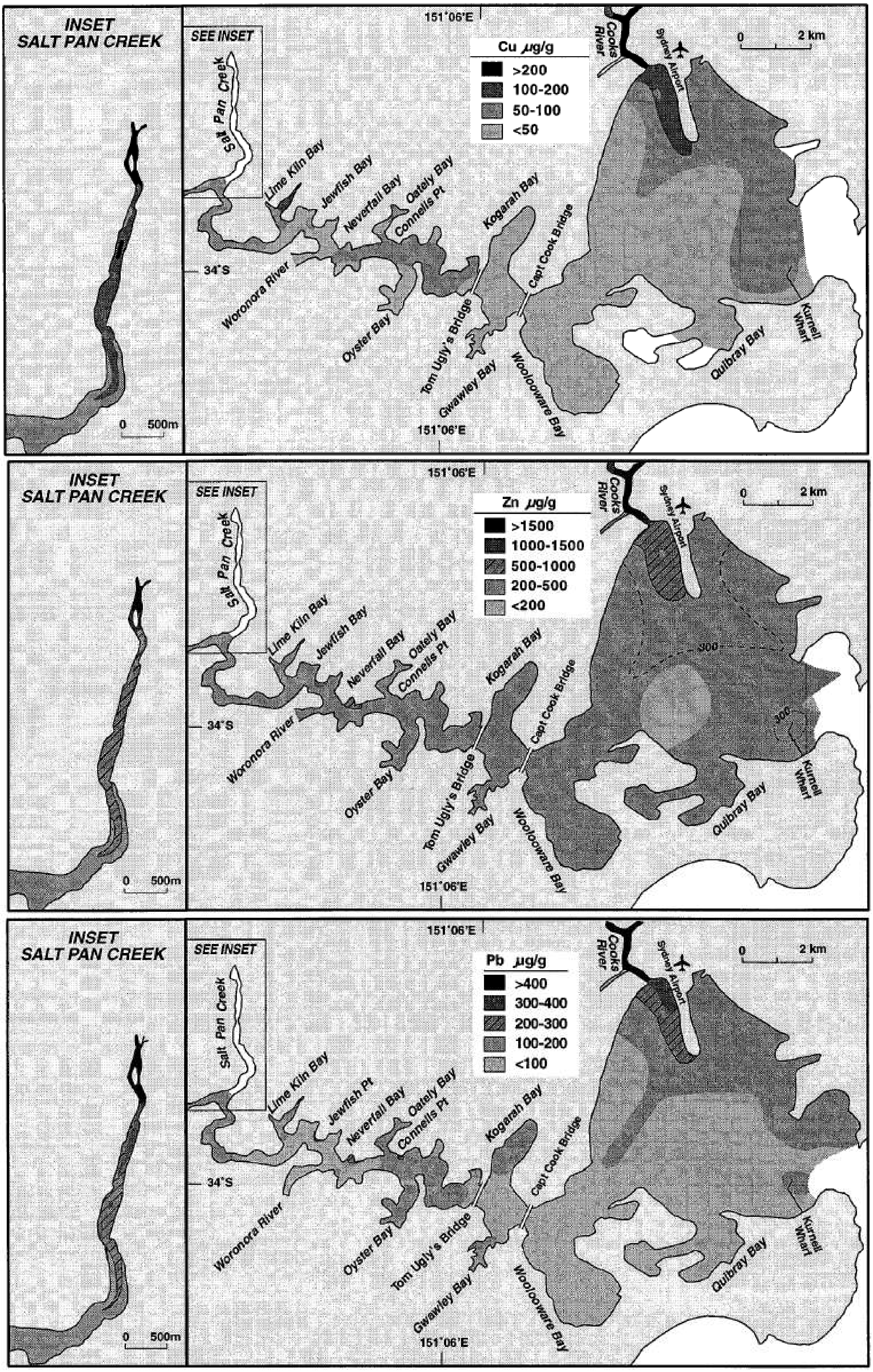


Figure 6.25 – Copper, zinc and lead concentration in the Georges River (Birch et.al, 1996)

6.3.9 Gross Pollutants

Gross pollutants and sediments are a significant pollution problem that extends throughout the entire reach of the river which can cause a considerable reduction in visual amenity. Gross pollutants includes any rubbish, litter, organic plant debris, or coarse sediment, although these usually take the form of packaging, plastic bottles, containers, fast food waste, plastic films and bags, leaves, branches, invasive plants, prunings, lawn clippings, and other miscellaneous refuse items. These pollutants are usually a result of careless litter disposal which gets washed into the river via stormwater from urban runoff after rainfall. As a diffuse source, the litter may then travel downstream or collect along the edges of the foreshore where flow velocities are slower and where riparian vegetation may act as a trap to retain the pollutants. This scenario was highlighted during the site visits, particularly within the smaller, narrower and shallower tributaries or bay areas away from the main river channel, such as the upper reaches of Salt Pan Creek and areas within the Chipping Norton lakes. Once there, the gross pollutants had little chance to escape into the main river channel as the force of the tidal flow was insufficient to flush the debris out, rather, the debris would only rise and fall with the tide, remaining stationary at their location. This has been highlighted from pictures taken on a site trip in Figure 6.26.

The GRCCC Riverkeeper Program is involved in works to halt pollution within the Georges River, such as rubbish collection, weeding and bushland regeneration. From 2006 to 2008, over 313,000 kg of gross pollutants were removed from the river under the Riverkeeper Program (GRCCC 2010c).

Figure 6.26 – Gross pollutants at Chipping Norton (top) and Salt Pan Creek (bottom)

6.4 Water quality predictions for 2030 and 2070

Various water quality parameters including TN, TP, FC, BOD and TSS were estimated for different scenarios of development by 2030 and 2070 (BBCCI, 2008). This was undertaken using the E2 model of Botany Bay catchments to calculate the flow durations and total pollutants load for future labnd use scenarios 2030 and 2070. Results of the modelling are shown in Table 6.9 below. It can be seen that pollutant exports can increase of 11-22% by 2030 and 24-46% by 2070 above current conditions. It is also highlighted that Water Sensitive Urban Design (WSUD) can have a very beneficial impact on the pollutant loads (Scenario 12). WSUD are further described in Section 7.5.2.

Table 6.9 – Total pollutant load percentage change results for the different modelled scenarios

Scenario	Scenario Description	Increase(+%)/Decrease (-%) from basecase					
		TOC	TP	TSS	TN	BOD	FC
	Predevelopment	-51%	-62%	-52%	-52%	-62%	-96%
Scenario 1	Basecase. Original 2006 Botany Bay E2 model.	-	-	-	-	-	-
Scenario 2	2030 Land use created from METRIX	+10%	+14%	+11%	+11%	+15%	+20%
Scenario 3	2030 Land use created from METRIX plus a large scale development in western region	+12%	+15%	+12%	+12%	+17%	+22%
Scenario 4	2030 Land use created from METRIX plus a large scale WSUD development in western region with 80% reduction in TSS, 45% reduction in TP and TN.	+12%	+14%	+11%	+11%	+17%	+22%
Scenario 7	2070 Land use	+23%	+29%	+24%	+24%	+32%	+41%
Scenario 8	2070 Land use plus a large scale development in western region	+26%	+33%	+27%	+27%	+37%	+46%
Scenario 9	2070 Land use plus a large scale WSUD development in western region with 80% reduction in TSS, 45% reduction in TP and TN.	+26%	+31%	+25%	+25%	+37%	+46%
Scenario 12	2070 Land use plus a large scale development in western region and all urbanised land uses characterised by WSUD pollutant reduction of 80% reduction in TSS, 45% reduction in TP and TN.	-	-18%	-59%	-19%	-	-

6.5 Water Quality Monitoring

Given the large gaps in the water quality data, the Botany Bay Water Quality Improvement Program (BBWQIP) has been formed to create a network of water quality monitoring stations within the Botany Bay Catchment. The locations of the monitoring stations are represented in Figure 6.27. These stations are expected to be constructed by May 2010. They would then start monitoring water quality parameters (i.e. temperature, salinity, turbidity, chlorophyll-A, dissolved oxygen and light) in real-time and the measurement will be published on the BBWQIP website. A decision support tool is also currently being developed as part of the BBWQIP.

The Harbourwatch program was set up in 1994 and monitors recreational water quality (faecal coliforms and enterococci) at 59 harbour locations throughout Sydney, including 15 in the lower Georges River and Botany Bay. Water quality monitoring stations administered by Harbourwatch within the study area are mapped in Figure 6.18.

Figure 6.27 – Location of the monitoring stations within the Botany Bay catchment (http://www.sydney.cma.nsw.gov.au/bbcci/monitoring-network.html)

The GRCCC has recently released the results of its Community River Health Monitoring program which provided an overall snapshot of river health for both the freshwater and estuarine areas of the catchment. This monitoring program sampled 42 sites concentrating on macroinvertebrates, water quality and vegetation to gain an overall picture of the health of the catchment (GRCCC 2010b). River health parameters at each site were given a grading ranging from degraded to excellent. The overall results of the scoring were that the estuary rated as being in fair health. Monitoring sites and results for both the upper and lower estuary are provided in Figure 6.28 (GRCCC 2010b).

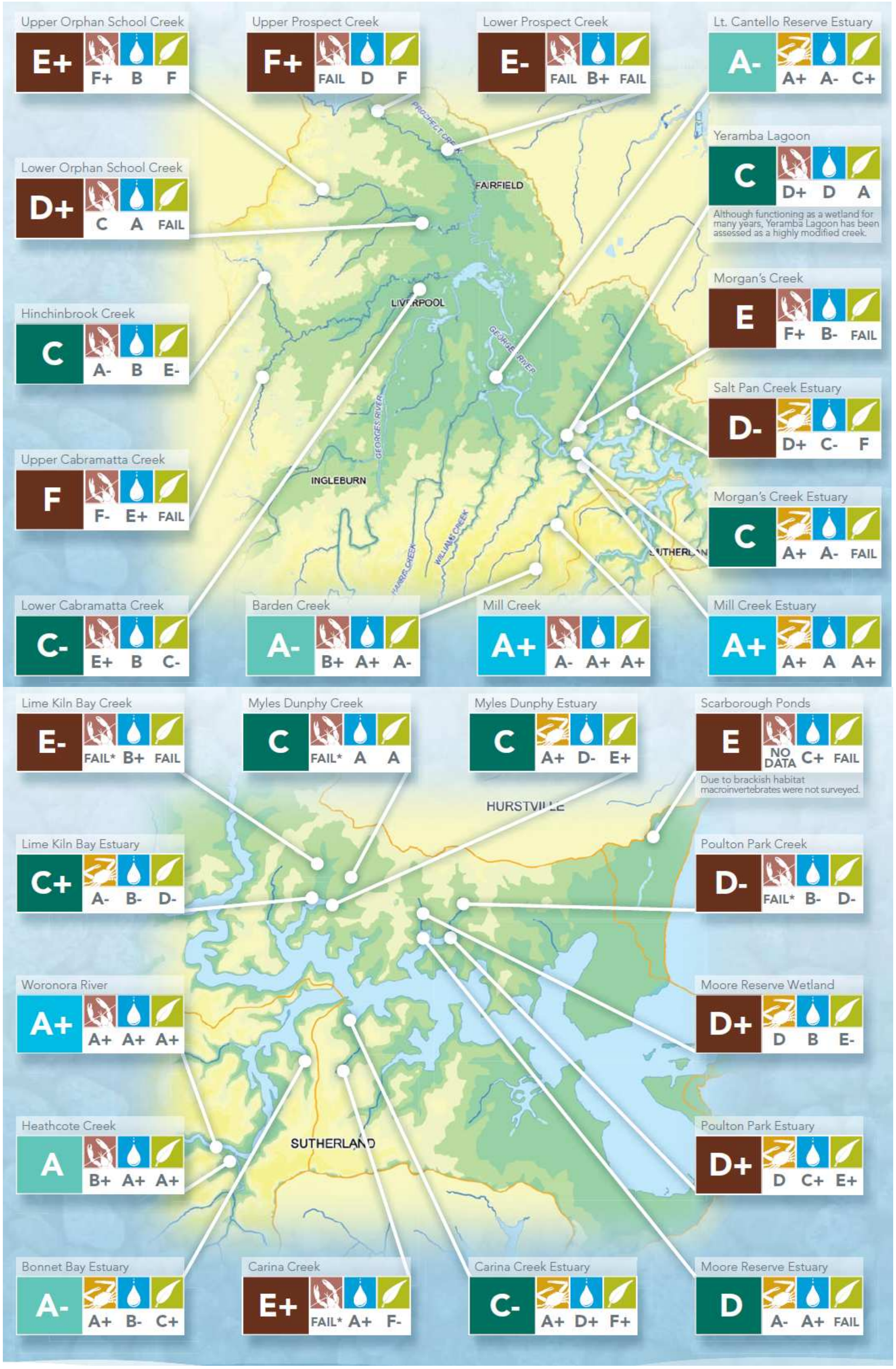

Upper Orphan School Creek
E+
F+ B F
Upper Prospect Creek
F+
FAIL D F
Lower Prospect Creek
E-
FAIL B+ FAIL
Lt. Cantello Reserve Estuary
A-
A+ A- C+
Yeramba Lagoon
C
D+ D A
Although functioning as a wetland for many years, Yeramba Lagoon has been assessed as a highly modified creek.
Lower Orphan School Creek
D+
C A FAIL
FAIRFIELD
LIVERPOOL
Hinchinbrook Creek
C
A- B E-
Morgan's Creek
E
F+ B- FAIL
Salt Pan Creek Estuary
D-
D+ C- F
Upper Cabramatta Creek
F
F- E+ FAIL
INGLEBURN
Morgan's Creek Estuary
C
A+ A- FAIL
Lower Cabramatta Creek
C-
E+ B C-
Barden Creek
A-
B+ A+ A-
Mill Creek
A+
A- A+ A+
Mill Creek Estuary
A+
A+ A A+
Lime Kiln Bay Creek
E-
FAIL* B+ FAIL
Myles Dunphy Creek
C
FAIL* A A
Myles Dunphy Estuary
C
A+ D- E+
Scarborough Ponds
E
NO DATA C+ FAIL
Due to brackish habitat macroinvertebrates were not surveyed.
Lime Kiln Bay Estuary
C+
A- B- D-
Poulton Park Creek
D-
FAIL* B- D-
Woronora River
A+
A+ A+ A+
Moore Reserve Wetland
D+
D B E-
Heathcote Creek
A
B+ A+ A+
SUTHERLAND
Poulton Park Estuary
D+
D C+ E+
Bonnet Bay Estuary
A-
A+ B- C+
Carina Creek
E+
FAIL* A+ F-
Carina Creek Estuary
C-
A+ D+ F+
Moore Reserve Estuary
D
A- A+ FAIL

Figure 6.28 – GRCCC monitoring stations within the upper and lower Georges River Estuary (GRCCC 2010b)

6.6 Water Quality Modelling and Data Analysis

A coupled hydrodynamic and biological numerical model has been built by DECCW to identify hot spots of poor water quality (where there are phytoplankton blooms) within the Botany Bay estuary and to identify regions where water quality improvement actions are required (BBCCI 2009). Management recommendations from this report include that actions are taken to improve water quality in the mid Georges River estuary and for reductions in total suspended solids (TSS) loads, TN loads and TP loads in the upper and mid Georges River estuary in event flows for all new redevelopments (BBCCI 2009).

For the Estuary Process Study, water quality data was obtained from Bankstown Council covering the following areas between 1997 and 2009:

- Prospect Creek catchment
- Georges River
- Salt Pan Creek catchment
- Kelso Creek catchment
- Milperra
- Little Salt Pan Creek catchment

For these areas, Tables 6.10 and 6.11 summarise the water quality analysis when compared with the ANZECC guidelines. It can be seen that most of the areas do not meet the guidelines, and for some parameters, the guidelines are exceeded more than 75% of the time.

Table 6.10 – Summary of the water quality data from Bankstown Council 1997-2009 compared to the ANZECC guidelines

Guidelines	Total P (mg/L)	Nitrogen (mg/L)	DO (%)	DO (mg/l)	pH	Turbidity (NTU)	Chl a	Faecal Coliform (cfu/100mL)
Prospect Creek								
Percentile (lower bound)	13.31%	32.90%	59.77%	51.25%	6.38%	52.95%	57.10%	38.99%
ANZECC guideline (lower bound)	0.05	0.50	80.00	6.70	6.50	6.00	5.00	150.00
Percentile (upper bound)	N/A	N/A	88.73%	85.84%	69.27%	85.80%	N/A	68.00%
ANZECC guideline (upper bound)	N/A	N/A	110.00	10.12	8.00	50.00	N/A	1000.00
Georges River Catchment								
Percentile (lower bound)	13.31%	42.85%	66.11%	57.59%	8.27%	44.43%	40.83%	39.56%
ANZECC guideline (lower bound)	0.05	0.50	80.00	6.70	6.50	6.00	5.00	150.00
Percentile (upper bound)	N/A	N/A	90.15%	86.66%	94.06%	84.18%	N/A	65.36%
ANZECC guideline (upper bound)	N/A	N/A	110.00	10.12	8.50	50.00	N/A	1000.00
Salt Pan Creek Catchment								
Percentile (lower bound)	8.74%	48.79%	62.98%	54.61%	4.64%	34.89%	41.59%	27.84%
ANZECC guideline (lower bound)	0.05	0.50	80.00	6.70	6.50	6.00	5.00	150.00
Percentile (upper bound)	N/A	N/A	88.85%	87.85%	85.60%	80.43%	N/A	52.75%
ANZECC guideline (upper bound)	N/A	N/A	110.00	10.12	8.00	50.00	N/A	1000.00
Kelso Creek Catchment								
Percentile (lower bound)	13.31%	40.90%	55.40%	53.40%	3.55%	42.93%	35.57%	45.41%
ANZECC guideline (lower bound)	0.05	0.50	80.00	6.70	6.50	6.00	5.00	150.00
Percentile (upper bound)	N/A	N/A	82.33%	81.72%	74.44%	84.73%	N/A	73.10%
ANZECC guideline (upper bound)	N/A	N/A	110.00	10.12	8.00	50.00	N/A	1000.00
Milperra								
Percentile (lower bound)	22.11%	55.67%	67.39%	60.87%	7.96%	44.41%	69.66%	43.18%
ANZECC guideline (lower bound)	0.05	0.50	80.00	6.70	6.50	6.00	5.00	150.00
Percentile (upper bound)	N/A	N/A	91.60%	88.34%	82.42%	79.68%	N/A	66.92%
ANZECC guideline (upper bound)	N/A	N/A	110.00	10.12	8.00	50.00	N/A	1000.00
Little Salt Pan Creek Catchment								
Percentile (lower bound)	13.31%	45.65%	66.15%	59.64%	3.83%	48.91%	63.38%	36.20%
ANZECC guideline (lower bound)	0.05	0.50	80.00	6.70	6.50	6.00	5.00	150.00
Percentile (upper bound)	N/A	N/A	89.06%	88.91%	85.32%	87.68%	N/A	63.69%
ANZECC guideline (upper bound)	N/A	N/A	110.00	10.12	8.00	50.00	N/A	1000.00

Table 6.11 – Summary of the water quality data from Bankstown Council 1997-2009 compared to the ANZECC guidelines

	Percent exceedence above ANZECC Water Quality (2000) Guidelines								
Catchment	**Total P (mg/L)**	**Nitrogen (mg/L)**	**DO (%)**	**DO (mg/l)**	**pH**	**Turbidity (NTU)**	**Chl a**	**Faecal Coliform (Primary)**	**Faecal Coliform (Secondary)**
Prospect Creek	86.69%	67.10%	71.04%	65.41%	37.11%	67.15%	42.90%	61.01%	32.00%
Georges River Catchment	86.69%	57.15%	75.95%	70.92%	14.21%	60.25%	59.17%	60.44%	34.64%
Salt Pan Creek Catchment	91.26%	51.21%	74.13%	66.76%	19.04%	54.47%	58.41%	72.16%	47.25%
Kelso Creek Catchment	86.69%	59.10%	73.07%	71.68%	29.11%	58.21%	64.43%	54.59%	26.90%
Milperra	77.89%	44.33%	75.79%	72.53%	25.54%	64.73%	30.34%	56.82%	33.08%
Little Salt Pan Creek Catchment	86.69%	54.35%	77.09%	70.72%	18.51%	61.23%	36.62%	63.80%	36.31%

Green: 0-25% Yellow: 25-50% Orange: 50-75% Red:75-100%