THE UNIVERSITY OF NEW SOUTH WALES
water research laboratory
Manly Vale N.S.W. Australia

BROOKLYN ESTUARY PROCESS STUDY (VOLUME I OF II)

by

Water Research Laboratory
Manly Hydraulics Laboratory
The Ecology Lab
Coastal and Marine Geosciences
The Centre for Research on Ecological Impacts of Coastal Cities

Edited by

B M Miller and D Van Senden

Technical Report 2002/20
June 2002 (Issued October 2003)

THE UNIVERSITY OF NEW SOUTH WALES
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING
WATER RESEARCH LABORATORY

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The work reported herein was carried out at the Water Research Laboratory, School of Civil and Environmental Engineering, University of New South Wales, acting on behalf of the client.

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1. EXECUTIVE SUMMARY

1.1 Background

The Brooklyn Estuary Processes Study was commissioned by Hornsby Shire Council. The Water Research Laboratory (WRL) of the University of New South Wales was commissioned by the council to undertake this study in association with Manly Hydraulics Laboratory (MHL), The Ecology Lab (TEL), Coastal and Marine Geosciences (CMG) and the Centre for Research on Ecological Impacts of Coastal Cities (CREICC). This report summarises the historical data and studies that have been completed in the Brooklyn Estuary study area or similar estuarine systems. It provides a comprehensive basis for the latter stages of the processes study.

The study area encompasses a complete estuarine section of the lower Hawkesbury River downstream of the Sydney-Newcastle Freeway Bridge to an imaginary line that joins Parsley Bay to Croppy Point across the river. Consideration is also given to the wider catchment and waterway area in so far as it affects water quality, sewage effluent, and urban runoff that may be contributing to increased surface flows and input of sediment and nutrients within the study area.

1.2 Objectives and Scope

The main objectives of this study were to:

a) Review and analyse existing data and reports available on the study area;
b) Assess and quantify issues raised by the community as stipulated by the Council;
c) Develop an understanding of the water quality, hydraulic, sedimentary and ecological processes of the Brooklyn waterway and define the interactions between the different processes;
d) Determine the extent to which human activities have modified or disrupted the estuarine processes;
e) Define the relative health of the various ecosystems present in the estuary;
f) Determine the pressures applied by both commercial and recreational fishing;
g) Determine the location and nature of significant natural, cultural, physical, and scientific sites in the estuary and its foreshores;
h) Undertake any further data collection or monitoring system to aid the subsequent stages of an estuary management study and formulating a management plan for the estuary.

To achieve these objectives the scope of the study included:

- Water Quality Processes
- Hydrodynamics and Flushing Processes
- Sedimentary Processes
- Ecological Processes
- Human Usage and Activities

The study is based upon information available up to June 2002.

1.3 Relevant Findings

The findings from the above analysis were divided amongst 5 major chapters (3-7). The summary of these findings is presented below.

Catchment Characteristics

Introduction

Chapter 3 describes various components of the study area including the climatic, land use, runoff, fluvial sedimentation, sewage disposal, stormwater management, and groundwater characteristics. Findings within this chapter are based on various sources including a review of available literature, GIS analysis, analytical calculations and personal communication with relevant stakeholders.

Key Findings

The Brooklyn study area covers approximately 185 square kilometres including the Mooney Mooney Creek, Mullet Creek and Sandbrook Inlet catchments which comprise 75%, 15%, and 10% of the area, respectively. The climate is characteristic of temperate regions, with warm to hot summers and cool to cold winters and mainly reliable rainfall patterns. GIS mapping of land use indicates that over the past 42 years bushland has decreased by 13.3%, while unsewered semi-urban developments, orchards and unfertilised grazing increased by 7%, 1.7% and 1.6%, respectively. Catchment runoff pollutants are highly dependent on rainfall events and are dominated by total nitrogen loads (47000 kg/yr versus 8200 kg/yr for total phosphorus). Runoff nutrient load estimates from major road and railway lines indicate that for the three major transport networks annual nitrogen loading is 864 kg, total phosphorous loading is 45 kg, and suspended solid loading is 10,368 kg.

The sediment within the main river channel is composed primarily of coarse sediments such as sands, whereas the tributaries of the lower Hawkesbury are characterised by muds and sandy muds. Sediment transport events were most likely dominated by large scale construction events such as the development of roads, railways and associated bridges infrastructure. Extensive analyse of aerial photos of the study site indicate minor changes to the bathymetry between 1872 and 1952, and pronounced areas of accretion and erosion after the construction of the Sydney-Newcastle Freeway Bridge in 1973. Furthermore, significant accretion within Sandbrook Inlet (10 to 20 millimetres per year) is related to restricted tidal flows.

Previous reports identified that more than 50% of inspected sewage disposal units at Brooklyn and Danger Island experienced environmental problems such as leaking, odours, insects or weeds. Findings suggest that the proposed sewage management scheme, which incorporates a sewerage system for each town and a local centralised sewage treatment plant, would decrease the problems currently encountered especially during wet weather periods. Such schemes require the highest level of sewage treatment so that effluent does not increase total nutrient discharges into the study area. The installation of two vessel pump out facilities at Brooklyn will reduce nutrient and faecal coliforms concentrations within the waterways and provide a means of legal and environmentally safe waste disposal.

A significant finding of this chapter is that the Brooklyn Estuary study area is strongly influenced by upstream processes and activities within the Hawkesbury-Nepean catchment. Particular interest should be addressed to upstream changes in land use, flow regimes, effluent disposal and/or recreational pursuits.

Hydrodynamics and Flushing

Introduction

Chapter 4 describes the flow regime within the estuary with particular reference to water level variability, water exchange and flushing, and sedimentation within the navigation channels. These processes are addressed using available literature, numerical modelling techniques, personal communication with involved stakeholders, and data acquired from on-site field investigations.

Key Findings

The study area for this Estuarine Processes Study covers a small fraction of the entire Hawkesbury-Nepean River catchment. Freshwater input to the study area include flows from the Hawkesbury River (286 ML/day in low flow conditions and greater than 1,000,000 ML/day in floods) and to a lesser extent from the local catchment (ML/day for low flow and 9000 ML/day for flood flow). Similarly, about 25% of the tidal prism entering the study area at the downstream boundary is captured within the study area, while the remaining 75% passes through to the upper Hawkesbury. As such, much of the conditions within the study area are determined by the conditions of the greater Hawkesbury River catchment.

The tidal range within the study area is very similar to oceanic tidal ranges with a slight tidal amplification towards the reaches of Mullet and Mooney Mooney Creeks. The tidal residuals within the study area show a good correlation with ocean residuals, indicating that the non-tidal water level oscillations are associated with oceanic phenomena such as coastal trapped waves and storm surges. Hydrodynamic simulations depicted that the removal of the causeway will not significantly affect flow even during 20% AEP peak flows.

Flushing times are relatively short, around 2 days for most of the study area increasing to around 8-15 days in Sandbrook Inlet and the upper Mullet and Mooney Mooney Creeks. Low energy sections of the estuary away from the influence of strong tidal currents are blanketed with fine grained muds, indicating areas of sediment accumulation and, in some areas, a build-up of metallic and organic contaminants. Selected chemical analysis of sediments at a majority of sites were found to be generally within the ANZECC (2000) guidelines for nutrients, metals and PAHs.

Tidal flows within Sandbrook inlet appear too low to remove fine grained sediments, leading to a build-up of contaminants from local sources. In view of this, future estuary management must consider enhanced tidal flushing to minimise the build-up of fine sediments. Contamination issues are not as pronounced in other regions of the estuary due to a combination of greater tidal flushing and/or the distance from anthropogenic pollution sources.

Water and Sediment Quality

Introduction

Chapter 5 addresses water and sediment quality issues including microbiological influences and the analysis of obtained sediment and water quality data. Though a literature review is incorporated within this chapter, findings and analysis from data acquired from field experiments comprises the bulk of this section.

Key Findings

While water quality conditions at the study site are largely determined by the Hawkesbury River, there are a range of local inputs and activities that are of concern at the smaller scale. Particularly, water quality within the study area can be divided into sections dependent on inflows and flushing characteristics. These sections include: (1) the main arm of the Hawkesbury River including Dangar Island; (2) Sandbrook Inlet; (3) the upper Mooney Mooney and Mullet Creeks; and (4) the lower Mooney Mooney and Mullet Creeks. Water quality in the study site is generally good however there are impacts from the main Hawkesbury River where sections consistently fail to meet standards. There is some evidence of algal blooms in the upper Mooney Mooney Creek but elsewhere there is little evidence of algal issues. Faecal contamination by septic overflows and boat use may also cause localised elevated faecal counts but these are generally shortlived and confined to small areas at the discharge point.

Water sampling results were predominately in line with water quality guidelines. Seventy-five percent of all dissolved oxygen samples were within aquaculture protection standards. pH readings were generally between 7.5 to 8.0 and did not detect significant acid sulphate soil leachate typical of other low-lying estuaries along the NSW coast. Salinity values fluctuated between 12-41 ppt indicating estuarine flushing and the inter mixing of freshwater and oceanic inputs. Suspended solids at all sites were well below the aquaculture protection guidelines except for within Sandbrook Inlet due to tidal flushing over shallow mud flats. Secchi depth measurements also exceeded recreational guideline values indicating potential problems from recreational use. Median turbidity, total phosphorous nutrient levels, and chlorophyll-a were all within the ANZECC (2000) criteria and indicate good water quality. Conversely, total nitrogen concentrations were often in excess of ANZECC criteria.

Within the study site a range of sediment textures were encountered, however, the majority of samples contained more than 50% mud (% <0.063 mm). The energy regime of the estuary influences the sediment type with coarse grained sediments, typically muddy sands, occurring in strong tidal area and finer grained sediments occurring in lower energy parts of the estuary. Sediment metal content indicated that the railway causeway (i.e. the eastern portion of Sandbrook Inlet) may trap contaminants such as copper, lead and zinc. PAH compounds concentrations were also highest within Sandbrook Inlet but all sediment samples were below ISQG-Low guidelines. These findings indicate that future issues of sediment contamination within Sandbrook Inlet warrant further investigation.

<u>Ecological Processes</u>

Introduction

Chapter 6 details the ecological processes within Brooklyn estuary including flora and fauna distribution, habitat mapping, intertidal invertebrate research, the impact of recreational and commercial fisheries, population and health of fish and mobile invertebrates, aquatic pollution and bioaccumulation issues. Findings were obtained from a comprehensive review of literature information, various on-site field experiments, statistical evaluation of field results, and personal communication with relevant stakeholders. This chapter concludes with a general review of the ecosystem health.

Key Findings

Ecological processes findings indicate that the general health of the entire estuary is stable and positive though individual areas may require attention. The medium level urban foreshore development at Brooklyn Harbour, Sandbrook Inlet and Dangar Island are likely to have a negative effect of the ecosystem health of the local vicinity. In contrast, the undeveloped aspect of Mullet Creek and Mooney Mooney Creek would have a low impact on ecosystem health.

Mangrove forests are abundant throughout the study area and have increased over the last 15 years since the construction of the freeway bridge near Mooney Mooney Creek and land reclamation. Mangrove stands near the west fringe of Spectacle Island and at Mooney Mooney Point have significantly increased in size which can be attributed to linear expansion of single trees along watercourses or marginal expansion of existing stands though trapping of sedimentation. The leaf biomass for common grey mangroves in the Hawkesbury River of 40 kg/m^2 is the highest recorded for temperate forest communities. The distribution of mangrove forest in the study area and their general state of health are stable and positive.

Seagrass beds are present in the study area at a number of locations including Sandbrook Inlet, Brooklyn Harbour, Dangar Island and the Head of Mullet Creek. The dominant seagrass was *Zostera capricorni* (eelgrass) and the cover of seagrasses has increased over the 16 years of available data. The seagrass bed in Brooklyn Harbour appeared healthy with a low epiphyte load (The Ecology Lab, 2002), while the beds in Mullet Creek have some epiphyte load.

Only recent information is available on the distribution of salt marsh habitats in the Brooklyn study area and hence, the stability of salt marsh areas could not be assessed. The largest stands of saltmarsh were located at the head of Mooney Mooney Creek, although small stands exist on both banks in Sandbrook Inlet. The saltmarsh species present were typical for the area being the samphire, *Sarcocornia quinqueflora*, rushes such as *Juncas Crausii* and the she-oak *Casuarina glauca.* It is possible that saltmarsh could be assessed through aerial photography in future studies.

Intertidal benthic assemblages from mangrove habitats were different between the eastern and western ends of Sandbrook Inlet (Lasiak & Underwood, 2002), and both locations were different to sites in Mooney Mooney Creek and Mullet Creek. Different taxa, rather than lower abundances, accounted for most of this difference. A study by Jones *et al*. (1986) found the benthos of Sandbrook Inlet to be depauperate compared to other locations in the Hawkesbury River. Generally, low species diversity is typical of highly disturbed environments. The intertidal rocky shore invertebrate communities were significantly different either side of the causeway. This difference could be the result of a number of natural factors as well as anthropogenic pressures.

The state of the Brooklyn region in terms of demersal fish species distributions and abundances is difficult to assess given the highly variable catch rates from beam trawling and beach seines studies. The Ecology Lab did find similar species of fish between this study and in 1988 which suggests some population stability. The assemblages of demersal fish and mobile invertebrates found in Sandbrook Inlet and Brooklyn Harbour were not different to other parts of the estuary. Therefore, factors other than proximity to urban developments (e.g. habitat cover or food availability) could be affecting the distribution of demersal fish and mobile invertebrates in the Brooklyn area. No information is available on the health of fish populations in the region.

Gobies were the most abundant group of fishes (Gehrke & Harris, 1996; The Ecology Lab 1988), while shrimps were the most abundant demersal invertebrate group (The Ecology Lab 1988; 2002). Fish of economic importance collected in the Brooklyn area included mullet, bream, whiting, tailor, flounder, leatherjackets, mulloway, sandy sprat (Booth & Schultz 1997; Gehrke & Harris, 1996; The Ecology Lab, 2002). Demersal invertebrates of economic importance included eastern king prawn, school prawn, greasyback prawns and king prawns (The Ecology Lab, 1988; 2002).

Significantly greater concentrations of zinc, copper, selenium and arsenic were detected in Sandbrook Inlet or/and Brooklyn Harbour wild oysters compared to remote locations. The significantly higher concentration of copper found in oysters from Brooklyn Harbour is likely due to the larger number of boats in the Harbour and the use of copper based anti fouling paints.

<u>Human Usage and Activities</u>

Introduction

Chapter 7 summarises the influence of human usage and activities on the study area including waterway usage, the history of human development, and important cultural and heritage values. Results were obtained for this chapter primarily from literature review, field surveys and personal communication with relevant stakeholders.

Key Findings

Public access is limited in many regions of the study area due to large areas of National Park and undeveloped land in the catchment, lack of road access in most areas, environmental features and private ownership of the foreshore in developed areas. In several areas public and commercial wharves provide public access to the waterway, however there is a lack of wheelchair access via these facilities. Field inspections of Brooklyn boat ramp facilities indicated that Parsley Boat ramp experiences 62% more cars and trailers than the Mooney Mooney Boat ramp. The boat ramp at Kangaroo Point public wharf is less utilised than the other ramps but the high number of vehicles at this site may be due to pickup and drop off for the charter and cruise boat passengers or for residents living upstream.

Waterway usage is constrained within the study area by the inaccessibility of the foreshore due to existing developments and natural barriers, water depth and wave climate, environmental factors, social issues and funding availability. Increased development may compromise water quality which is vital to the major industries of the area including oyster farming, commercial and recreational fishing and tourism. Mangrove areas should be maintained as they play a vital role in the estuarine ecosystem. Conflicts between waterway users are compounded by similarities among seasonal trends in activities.

Since settlement human activities have had an impact on estuarine processes. Major civil works have altered the flow regime and increased sediment transport and/or erosion. Reduced upstream flows such as dams moderate water flows and reduce the large natural variability. Agricultural use increases nutrient loads and faecal coliform contamination from animal waste. Unsewered and sewered treatment facilities have increased nitrogen and phosphorous nutrient levels in the receiving waters from natural levels. Other indirect impacts include changes to the scenic amenity, disposal of waste from marinas, impact of dredging and fishing sustainability.

The Hawkesbury River served as a social nexus for various tribal groups, and as such, the study area contains a number of Heritage protected sites. Furthermore, several European heritage sites, which depict the history of European settlement have been listed within the study area. The care and protection of these sites must be considered during any further developments. Additional consideration should also be given to the scenic amenities of the study area.

Additional Information

A response to issues outlined by the brief and pertaining to estuarine management are given in Chapter 8. Individual issues were divided amongst nine management themes: (1) Water Quality, (2) House Boat and Pump Out Facilities, (3) Marina Management, (4) Land Use, (5) Navigation, Dredging and Siltation, (6) Contaminants in Sediments, (7) Flushing through Causeway, (8) Sewage, and (9) Habitat and Land Management. Chapter 9 describes a reliability assessment of the data. Finally, Chapter 10 highlights the key findings presented throughout the study.

2. INTRODUCTION

2.1 Background

The Hawkesbury River system is a highly valued ecological, sociological and economical resource due to its variety of uses. However, population increases and changes in land use have contributed to increased impacts upon the health of the river and its tributaries. In order to reduce the detrimental human impacts on river systems in New South Wales, the New South Wales Estuary Management Policy aims to ensure estuaries are managed in an ecologically sustainable manner. One of the steps set out in the Estuary Management Manual (NSW Government, 1992) is to undertake an estuary processes study to enable development of a responsible management plan.

The Brooklyn Estuary Processes Study was commissioned by the Hornsby Shire Council. The Water Research Laboratory (WRL) of the University of New South Wales was commissioned by the council to undertake this study in association with the Manly Hydraulics Laboratory (MHL), The Ecology Lab (TEL), Coastal and Marine Geosciences (CMG) and the Centre for Research on Ecological Impacts of Coastal Cities (CREICC).

This report summarises the historical data and studies that have been completed in the Brooklyn Estuary study area or similar estuary systems. It provides a comprehensive basis for the latter stages of the processes study.

A detailed review of the literature for each of the aforementioned categories follows the initial summarised section. The detailed sections cover information about the quality and coverage of the available literature and datasets. Where possible, conclusions regarding the current state of the Brooklyn Estuary in reference to the particular categories have been made. Furthermore, where applicable, recommendations have been made as to what future monitoring would be required for individual categories in order to make informed and responsible decisions regarding the management of the estuary.

2.2 Study Area

Brooklyn Estuary is a region of the Hawkesbury River that is perceived to be particularly vulnerable to impacts due to the diverse range of ecological, estuarine and commercial and recreational human activities in the area.

The Brooklyn Estuary study area is part of the Hawkesbury River and is situated north of Sydney, NSW as shown in Figure 2.1. The boundaries of the study area are from downstream of the freeway bridge to an imaginary line from Parsley Bay to Croppy Point and encompasses the waterbody and its interacting catchment areas. This area includes Sandbrook Inlet and both Mullet and Mooney Mooney creeks, which are significant due to their potential population increases and subsequent development and commercial fishing industries. The study area is flanked by the Kuring-gai Chase National Park to the south, Muogamarra Nature Reserve to the west and Brisbane Water National Park to the North. The study area also includes the Spectacle Island and Long Island Nature Reserves.

The more densely populated areas of the Brooklyn Estuary study area are located at Brooklyn, Dangar Island and on the banks of Mooney Mooney Creek. The main industries in the area are tourism, recreational and commercial boating and fishing. A large number of oyster leases also exist within the estuary. Sandbrook Inlet differs to other estuaries in the region as it has been blocked at one end by the Main Northern Railway causeway. This is one of the attributes of the study area that makes it subject to unique and significant environmental impacts.

The most pressing issues facing Brooklyn Estuary as identified by the Estuary Management Committee and the public are:

- catchment runoff and discharges from boats;
- leachates and sewage disposal;
- boating and tourism development;
- aquaculture and fishing;
- marine and catchment ecology and diversity;
- heritage and cultural value;
- the effects of marina management; and
- wharf, jetty and shoreline development.

The study is based upon information available up to June 2002.

2.3 Study Team

The Study Team who undertook this project was lead by the **Water Research Laboratory** (WRL).
The other study team organisations were:

- Manly Hydraulics Laboratory (MHL)
- The Ecology Lab Pty Ltd (TEL)
- Coastal and Marine Geosciences (CMG)
- Centre for Ecological Impacts of Coastal Cities (CEICC)

In particular, the following key people have had major involvement with this study.
Brett Miller (WRL), David van Senden (MHL), William Glamore (WRL), Ainslie Fraser (WRL), Matt Chadwick (WRL), Peggy O'Donnell (TEL), Michele Widdowson (MHL), Bronson McPherson (MHL), Sophie Dillon (TEL), Charmaine Bennett (TEL), John Hudson (CMG), Theresa Lasiak (CEICC) and Tony Underwood (CEICC).

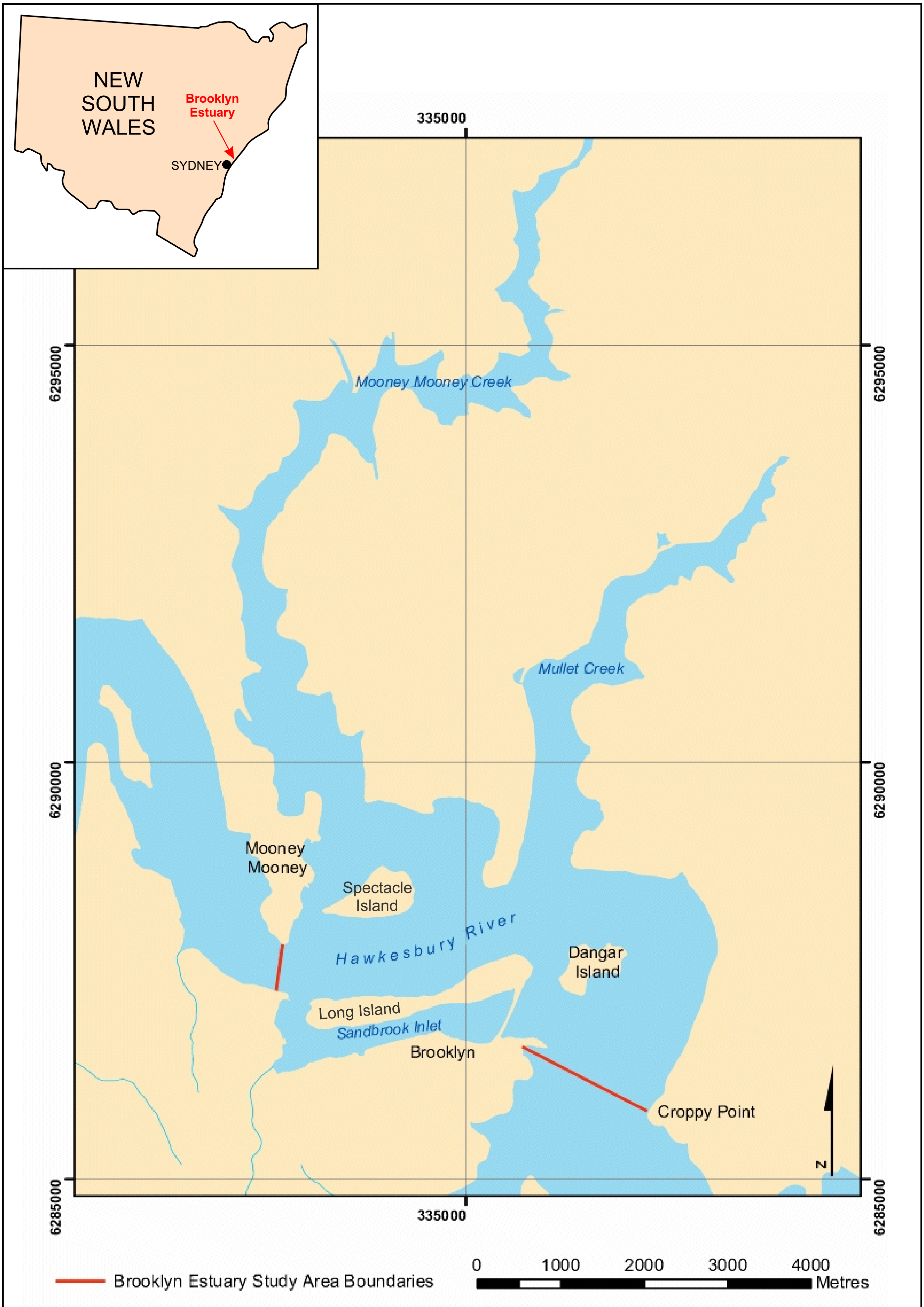
The study team would like to thank all assisting experts, agencies and reviewers for their efforts on this study.

2.4 Report Structure

This report is structured in five main study groups:

- Catchment Characteristics
- Hydrodynamics and Flushing
- Water Quality
- Ecological Processes
- Human Usage and Activities

There are many issues which pertain to more than one of the main study groups. The report summarises issues pertaining to management and a summary of key issues for various parts of the Brooklyn estuary.



WRL Report No. 2002/20	BROOKLYN ESTUARY STUDY AREA	Figure 2.1 00758-02-01.cdr

3. CATCHMENT CHARACTERISTICS

This chapter summarises the available catchment information within and adjacent to the study area. The chapter commences with a description of the catchment including its size, population, and climate. Land use and land use changes are described using GIS mapping techniques and historical data. Catchment runoff and pollutant loads are then estimated to determine the quantity and source of nutrient loading within the estuarine system. Fluvial sedimentation sources and rates are given and aerial photographs are used to highlight areas of accretion and erosion over time. Both land based and marine sewage disposal issues are then discussed, including current contaminants and suggested remediation techniques. The chapter concludes with discussions on stormwater management, the groundwater regime and the influence of the Hawkesbury-Nepean River system on the study area.

3.1 Catchment Description

The Brooklyn Estuary catchment covers an area of approximately 185 square kilometres, including the subcatchments of Mooney Mooney Creek (~75 %), Mullet Creek (~15 %) and Sandbrook Inlet (~10%) (Figure 3.1). The majority of the catchment is steep bushland lying within the national park boundaries of Kuring-gai Chase National Park on the southern shore and Brisbane Water National Park on the northern shore. The Brooklyn Estuary is part of the larger Hawkesbury River Estuary and is strongly influenced by activities and processes occurring upstream in the Hawkesbury River.

Sandbrook Inlet is a centre for boating activity in the lower Hawkesbury River. The inlet was formed in the mid 1880's by the construction of a railway causeway between Long Island and the mainland, which blocked the link with the river at the eastern end (Figure 3.1). Seymours Creek flows into the inlet at its western end. The town of Brooklyn, with a population of 672 (Table 3.1), is spread across the southern shoreline of Sandbrook Inlet and provides services and facilities for the large number of tourists who access the river at this point (see Section 7.2). Major expansion of the town occurred around the time of the Main Northern Railway construction in the 1880's and Brooklyn is an area of significant heritage value due to its history as a fishery, tourism and railway base (see Section 7.4). The majority of Long Island, which forms the northern boundary of the inlet, is a nature reserve with limited access to the public. Sandbrook Inlet is tidal for its full length (MHL, 2002).

Mooney Mooney Creek is approximately 35 km in length and originates to the south of Mangrove Mountain. Its main tributaries are Little Mooney Mooney Creek, Floods Creek, Piles Creek and Calverts Creek. There are two dams on Mooney Mooney Creek, the lower of which supplied Gosford City with water until 1962 when the Upper Mooney Dam was constructed with an increased storage capacity. While the majority of the Mooney Mooney Creek catchment is dominated by bushland there are a number of urban and periurban centres within the study area, including Mooney Mooney and Mt White in the south, Kariong and Somersby in the east and portions of Peats Ridge and Mangrove Mountain in the north (Figure 3.1). Population figures for these centres are presented in Table 3.1. The tidal influence in Mooney Mooney Creek extends 2.2 km upstream from Floods Creek (MHL, 2002), approximately 20 km from the confluence of Mooney Mooney Creek and the Hawkesbury River.

Table 3.1
Population figures for urban centres in the Brooklyn Estuary catchment

Urban centre	Population *
Brooklyn	672
Mooney Mooney	561
Kariong	5859
Somersby	691
Mt White/Bar Point	288

* 1996 census

Mullet Creek is approximately 6 km in length and its catchment lies entirely within the Brisbane Water National Park. A major feature in the catchment is the Main Northern Railway track, which crosses the Hawkesbury River at Cogra Point and then follows the western bank of Mullet Creek past Wondabyne and across a wetland at the northern end of the creek towards Woy Woy. The tidal limit in Mullet Creek occurs in the wetland upstream of the railway embankment (MHL, 2002).

In addition to the Main Northern Railway, which is a major feature of both Brooklyn and Mullet Creek, the major transport infrastructure of the F3 Sydney to Newcastle Freeway and the Old Pacific Highway are significant features in the Brooklyn Estuary catchment. Through the railway, freeway and highway, the study area is a vital link in the connection between Sydney and areas to the north of the Hawkesbury River. However, catchment processes including water quality and erosion/sedimentation rates have undoubtedly been affected by their construction and use, and are discussed further in Sections 3.4.2 and 3.5.

On the Hawkesbury River, and within the study area, are two river settlements accessible only by boat, Little Wobby and Cogra Bay, as well as a larger settlement on Dangar Island, which has a regular ferry service from Brooklyn. Spectacle Island, near the mouth of Mooney Mooney Creek, is a nature reserve with limited public access.

3.2 Climate

Brooklyn Estuary is located within a temperate zone, with characteristically warm to hot summers, and cool to cold winters with mainly reliable rainfall (Lee and Gaffney, 1986). The closest Bureau of Meteorology (BoM) stations to the study area are at the Narara Research Station, Gosford, for which data is available from 1916 to 2001, and the Pennant Hills station, for which data is available from 1900 to 1969. These stations measure a number of weather and climate variables, including rainfall, temperature and humidity.

Weather and climate impact upon hydrodynamic, geology, geomorphological and ecological processes, and are therefore important forcing factors driving many of the estuarine processes. The weather and climate variability is also important for the interpretation of natural versus anthropogenic changes in ecosystem variables.

3.2.1 *Rainfall*

Rainfall is significant for several estuarine processes as it is a driving force for fresh water flushing of the estuary (direct rainfall and runoff), erosion by runoff and the conveyance of catchment-derived constituents.

Mean annual rainfall recorded at the Narara BoM station is 1,320 mm and 1,068 mm at the Pennant Hills station to the south-west. Table 3.2 presents the mean monthly rainfall for each of these stations and shows that the driest months are July to November and the wettest months are January to April.

Table 3.2
Mean monthly rainfall (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Narara [1]	139	148	150	136	119	128	79	76	69	83	92	102
Pennant Hills [2]	104	106	123	105	87	101	86	67	54	70	75	89

[1] Narara Research Station, Gosford (BoM Station no. 61087), 81.6 years of data.
[2] Pennant Hills (BoM Station no. 66047), 63.5 years of data.

The Southern Oscillation Index (SOI) is a measure of the air pressure difference between Tahiti and Darwin. It is used as a climatic indicator and long periods of negative values of the SOI indicate periods of drought (Chiew *et al.*, 1996).

Long drought periods can have implications for the reduced flushing of the estuary, as well as for the geomorphology of the drainage paths. Reduced rainfall results in decreased flows to the estuary and natural reduction of the flow channels. Return of higher rainfalls after a drought results in channel erosion and delivery of sediment to the estuary (MHL, 1998).

The monthly SOI is plotted in Figure 3.2, including a five month average trend line. Sustained values of less than -10 indicate an El Niño Southern Oscillation (ENSO) event and dry weather across northern and eastern Australia. It can be seen that major ENSO events have occurred in 1986-87, 1991-92, 1992-93, 1993-94 and 1997-98, and that 1998 to 2001 have been wetter than average years.

3.2.2 *Temperature and Humidity*

Air temperature is a driving force for water temperature and many ecological processes. Humidity is a component of the driving force for the evaporation of water from an estuary.

Mean daily maximum and minimum temperatures for the Narara and Pennant Hills stations are presented in Table 3.3 and mean 9am and 3pm relative humidity for the Narara station is tabulated in Table 3.4.

Table 3.3
Mean daily maximum and minimum temperature (°C)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean daily maximum												
Narara [1]	27.2	27	26	23.6	20.3	17.5	17.3	18.7	20.9	23.5	24.8	26.8
Pennant Hills [2]	27.6	27.3	25.5	22.2	19.1	16.3	15.8	17.9	20.9	23.4	25.1	27
Mean daily minimum												
Narara [1]	16.5	17.1	15.4	11.8	8.1	6.3	4.4	5.4	7.5	10.7	12.6	15.1
Pennant Hills [2]	16.1	16.1	14.8	11.8	8.6	6.3	5.2	6.1	8.1	10.8	13.1	15

[1] Narara Research Station, Gosford (BoM Station no. 61087), 19.5 years of data.
[2] Pennant Hills (BoM Station no. 66047), 31.5 years of data.

Table 3.4
Mean relative humidity (%) [1]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
9 a.m.	71	78	78	78	81	81	80	72	66	62	63	66
3 p.m.	60	60	65	63	63	66	61	57	59	57	58	62

[1] Narara Research Station, Gosford (BoM Station no. 61087), 18.5 years of data.

3.2.3 Wind

Wind speed and direction data is useful for assessing mixing in the estuary. No local wind data is available within the catchment and the steep nature of the catchment may result in wind funnelling through the valleys. The nearest stations are Sydney Airport and Parramatta (Bureau of Meteorology) and also at the Ocean Reference Station (ORS) (AWT/MHL) (approximately 1.5kms offshore of Bondi Beach, Sydney), operated for the assessment of the deepwater ocean outfalls. Wind roses compiled from data from the ORS indicating wind speed and direction on a seasonal basis are shown in Figure 3.3.

At the ORS, summer wind speed and direction is predominantly from the north-east and south. Autumn experiences less dominant directional occurrences, however westerly and southerly winds are common. Winter is dominated by westerly winds and spring experiences a range of winds dominated by southerly, north-easterly and northerly winds.

3.2.4 Evaporation

Evaporation data is useful when assessing heat flux variations in the estuary as well as assessing water losses from the estuary. Pan evaporation data for the region is derived from data collected at Mascot (Sydney Airport) and shown here as a monthly mean in Table 3.5 (Chapman and Murphy, 1989). This information highlights the strong evaporation rate in summer in comparison to winter levels (i.e. more than double mean monthly pan evaporation).

Table 3.5
Mean monthly pan evaporation (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sydney	217	177	157	126	94	85	93	116	141	168	193	252

3.2.5 Solar Radiation

Solar radiation data is important in the assessment of heat flux variations within the estuary, which has consequences for water density stratification and mixing and also for photosynthesis.

Daily solar radiation data in Watts/m^2 for the Sydney area is collected by the Bureau of Meteorology and is available from the Sydney Airport station (present only up until 1994) and Blacktown. The daily range is of the order of 0-1,000 W/m^2 in summer and 0-500 W/m^2 in winter. Daily cloud cover affects solar radiation and the Brooklyn Estuary area on average experiences 114 days per year of cloud cover more than 6/8ths of the sky.

3.3 Catchment Land Use

Land use within the Brooklyn Estuary catchment is summarised in Figure 3.4. As mentioned in Section 3.1, urban development is limited to the river settlements of Brooklyn, Dangar Island and Mooney Mooney, and the ridge top settlements of Kariong, Somersby and Mt White. Other small settlements accessible only by boat include Cogra Bay and Little Wobby, which contain approximately 30 and 50 dwellings respectively. Parts of Peats Ridge and Mangrove Mountain in the north of Mooney Mooney Creek catchment also lie within the study area.

Kariong and Somersby are located in the upper catchment of Mooney Mooney Creek and represent the highest level of development and industrialisation in the study area. The Mooney Mooney Creek catchment also contains areas of grazing, vegetable growing and orchards in its upper reaches. There is a dam in the upper reaches of Mooney Mooney Creek that contributes to the water supply of Gosford City. This dam has a capacity of 4,500 ML and was built in 1962 to replace a dam lower down the creek that had a capacity of 1,000 ML (GCC, 2000). The upper Mooney Dam was licenced in 1964 for town water supply purposes and is currently being reviewed for extraction volume licencing (W. Connors, DLWC, pers. comm.). The dam is part of the Stream Flow Management Strategy prepared by the Gosford-Wyong Councils' Water Authority to minimise environmental impact in its water supply catchments (GWCWA, 2001). The strategy includes the identification of environmental management outcomes for the four streams involved, development of an ecological and hydrological database, and specified field investigations and infrastructure modifications to protect biodiversity and restore habitat diversity. In addition, review of specific issues will be undertaken including the potential for ecological improvement through modification of redundant structures, which applies to the Lower Mooney dam (GWCWA, 2001). Options are also being evaluated to manage flow releases for environmental benefit in Mooney Mooney Creek (GCC, 2000).

Land use area in the catchment has been calculated from GIS land use maps provided by the Department of Land and Water Conservation, which are based on 1979-1981 topographic maps. Census data has been used to estimate the changes to land use areas by 1954 and 1996, with the assumption that bushland area has decreased linearly with population increase and other land uses have increased proportionately. Table 3.6 provides an overview of this land use information.

Table 3.6
Land use in the Brooklyn Estuary catchment in 1954, 1981 and 1996

Land Use	Area (ha)			% of Total Area		
	1954	1981	1996	1954	1981	1996
Bushland	14331	12338	11831	76.4	65.8	63.1
Established Sewered Urban	86	154	172	0.5	0.8	0.9
Established Unsewered Urban	32	58	65	0.2	0.3	0.3
Unsewered Semi-urban	1326	2380	2648	7.1	12.7	14.1
Industrial and Commercial	25	44	49	0.1	0.2	0.3
Built-up Miscellaneous	225	404	449	1.2	2.2	2.4
Intensive Vegetable Growing	55	100	111	0.3	0.5	0.6
Orchards	323	580	645	1.7	3.1	3.4
Fertilized Grazing	10	18	20	0.1	0.1	0.1
Unfertilized Grazing	302	543	604	1.6	2.9	3.2
Water	1909	1909	1909	10.2	10.2	10.2
Disturbed Land	99	177	197	0.5	0.9	1.1

Source: DLWC land use maps for 1981, with 1954 and 1996 data extrapolated using Census figures.

Hornsby Shire Council has provided aerial photographs for 1955, 1965, 1977, 1992 and 1997. These show the Brooklyn/Sandbrook Inlet area as far north as Mooney Mooney Point, and have been used to give an estimation of land use change over time in this area (Figures 3.5 and 3.6). Historical aerial photos of the northern part of the study area were not available for assessment at the time of report preparation.

The most obvious change over the period 1955-1997 is the addition of the F3 Freeway bridge, which appears in the 1977 photo having been constructed in 1973. Associated changes in land cover are obvious on both the northern and southern shores of the Hawkesbury River, near Kangaroo Point and at Mooney Mooney Point. The shape of Mooney Mooney Point has been altered, with the area between an existing boat ramp and the freeway reclaimed to form a carpark and reclamation is also evident on the eastern side to accommodate on and off ramps. Vegetation clearance is evident in this area and also on the southern shore. Further to the construction of the freeway, on the southern shore the Pacific Highway has been straightened and a substantial area of bushland has subsequently been removed. The 1990's photos show that this has largely recovered.

The town of Brooklyn does not appear to have changed substantially over the period 1955-1997. Steep terrain to the south and west, and the river to the north and east, restrict the boundaries of the town, so any changes relate solely to intensification of development. Housing construction on the southern hillside is apparent in the 1977 photo but overall there is little change in the form of the town over time. Census figures show that the population of Brooklyn has remained constant from 1950 (669 residents) to 1996 (672 residents). However, the marina areas and number of moorings have developed over time, indicating a greater usage by people through the area related to waterway activities. Reclamation in the Parsley Bay area occurred between 1955-1965.

Due to the lack of information, including historical aerial photographs, regarding the Mooney Mooney Creek catchment it is not possible to report extensively on the history of development and land use change in this area. The growth of Kariong and much of the development of the Somersby light industrial area has occurred in the past 15 years. Population statistics from the Gosford City Council website show a nearly two-fold increase in the population of Kariong between 1991 and 1996 (3122 and 5859, respectively) and a decline in the population of Somersby (864 in 1991 and 691 in 1996), reflecting an increase in light industrial land. Orthophoto maps published by the Land Information Centre from aerial photography taken in 1998 show Kariong to be a high density residential settlement, while Somersby is a sprawling area of farm blocks with industrial estates in the south. A large portion of the Piles Creek catchment has been zoned for further industrial development in Somersby (DLWC, 2001).

3.4 Catchment Runoff

This section identifies sources of pollutants through runoff from both point and diffuse sources. Possible pollutant sources include:

- Urban and rural runoff
- Roads and railways
- Licenced point sources
- Septic tank seepage and on-site sewage treatment (see section 3.6)
- Vessel discharges (see section 3.6)
- Groundwater (see section 3.7)
- Upstream Hawkesbury River (see section 3.9)

3.4.1 Urban and Rural Runoff

Various substances are carried with flow generated from the catchment as a result of rainfall. Land use, along with rainfall, soil type and geology, strongly influences both the amount and composition of runoff. Urban runoff is typically a source of suspended solids, plant nutrients (nitrogen and phosphorus), oxygen reducing substances and micro-organisms. Additionally, urban runoff can contain litter, pesticides and herbicides from local gardens, trace metals and oils from roads and cars, and faecal coliforms from animal and human faeces. Rural runoff, especially in areas of intense agriculture and cultivation, often contain high levels of nutrients, suspended solids, pesticides and herbicides.

3.4.1.1 Nutrient Loadings

In most estuarine catchments the primary water quality concerns relate to nutrient levels. High levels of nitrogen and phosphorus can result in nuisance plant growth, excessive algal proliferation and increased levels of oxygen-consuming microbes causing low dissolved oxygen concentrations.

Diffuse source nutrient generation rates have been derived for the Hawkesbury-Nepean basin by CSIRO (Marston, 1993). These rates relate to various catchment land uses and when multiplied by the area of each land use provide catchment nutrient loadings (Table 3.7). The generation rates are derived from available literature for each land use and the error term spans the range of values covered by the various literature sources.

The calculated average nutrient loadings for the Brooklyn Estuary catchment are 47000 ± 2400 kg/yr for total nitrogen and 8200 ± 4600 kg/yr for total phosphorus. This estimate is based on the 1981 GIS land use data provided by DLWC (see Table 3.6).

Table 3.7
Diffuse source nutrient generation rates in the Hawkesbury-Nepean basin

Land use	**Phosphorus (kg/ha/yr)**	**Nitrogen (kg/ha/yr)**
Bushland	0.1 ± 0.10	1.50 ± 0.50
Established Sewered Urban	1.3 ± 0.40	5.00 ± 2.00
Recent Sewered Urban & Disturbed	20 ± 10	63 ± 40
Unsewered Peri-urban	0.60 ± 0.30	4.00 ± 3.00
Industrial and Commercial	1.80 ± 0.40	6.00 ± 2.00
Intensive Vegetable Growing	8.00 ± 4.00	8.00 ± 3.00
Orchards	0.30 ± 0.20	4.70 ± 3.00
Turf Farming	8.00 ± 4.00	8.00 ± 3.00
Fertilized Grazing	1.25 ± 0.50	8.00 ± 4.00
Unfertilized Grazing	0.25 ± 0.10	0.90 ± 0.50
Extensive Agriculture - Arable	2.50 ± 2.30	12.5 ± 12.50

Source: Marston (1993)

From the generation rates shown in Table 3.7 it is possible to estimate the effects that a change in land use may have in terms of nutrient inputs to the estuarine system. Established urban areas generate a relatively low amount of nutrients, however during the development phase when land is disturbed the rate can be at least ten times greater. Industrial and commercial land has higher generation rates than established residential land, presumably because of the large amount of impervious area involved. Some forms of agriculture have relatively low nutrient generation rates, such as unfertilized grazing, while those requiring the application of fertilizers and herbicides/pesticides, such as fertilized grazing and intensive vegetable growing, have much higher rates.

Land use change can clearly cause large variation to the amount of nutrients carried in catchment runoff and the degree of variation is highly dependent on the type of land use involved. In terms of urban land uses, the current restrictions on growth including natural factors such as topography and legislative factors such as land zoning make it unlikely that the existing urban centres will expand in the immediate future. Changes to the type and intensity of urban land use in existing areas may occur, zoning permitted, as is being experienced in Somersby.

3.4.1.2 HSPF Model Results

HSPF modelling undertaken by AWT provides flows and pollutant loadings for specific catchments. Results for the Brooklyn (primarily Sandbrook Inlet), Mooney Mooney Creek and Mullet Creek sub-catchments were available for the period 1985-1994.

Examination of the modelling results show that flow and pollutant loads for the total catchment of the study area are highly variable over the 10 year period and are highly dependent upon rainfall (Figure 3.7). Statistics describing the annual flow and loads are shown in Table 3.8.

Table 3.8
Statistics for Catchment Annual Flow and Pollutant Loads from HSPF Model Results

	Flow (ML)	**NOx + NH_3 (kg)**	**Phosphate (kg)**	**Suspended sediment (tonnes)**
Mean	4538.9	636.1	25.5	116.5
Median	4686.7	676.5	26.7	114.7
Minimum	382.7	50.2	3.6	2.15
Maximum	9256.7	1206.5	52.1	239.4

The three sub-catchments within the study area contribute different proportions to the total catchment inputs, related to land area and land use. Table 3.9 shows the percentage contributions of the Brooklyn, Mooney Mooney and Mullet sub-catchments.

Table 3.9
Percentage Contribution of Sub-Catchments to HSPF Model Results

	Sub-Catchment % Contribution		
	Brooklyn	**Mooney Mooney**	**Mullet**
Catchment Area	17.4	65.6	17.0
Flow	18.5	64.6	16.9
NOx + NH_3	14.8	69.5	15.7
Phosphate	19.0	71.1	9.9
Suspended sediment	15.3	66.8	17.9

Note that the three modelled sub-catchments cover a slightly different area to the study area and thus the % area of the sub-catchments is different to that stated in Section 3.1.

The HSPF modelling does not specifically take into account road and rail runoff and estimates of this component are provided in Section 3.4.2.

3.4.2 Road and Rail Runoff

Road and rail runoff is a complex mixture of litter, dust, heavy metals and organic matter washed from both the paved and unpaved surfaces of the road and rail corridors. Roadways in particular act as efficient carriageway for the transport of sediments and nutrients from surrounding land. Road runoff is typically directed into stormwater systems and then into receiving water without treatment, although stormwater is increasingly being managed to decrease the impact on receiving waters (see Section 3.7).

The Sydney-Newcastle Freeway and the Pacific Highway form the major road network within the catchment and the Main Northern Railway runs through the south-eastern part of the catchment. The railway was the first of these constructed, with the original Hawkesbury rail bridge opened in 1889 and its replacement in 1946. The Peats Ferry bridge on which the Pacific Highway crosses the river was opened in 1945 and the Freeway bridge adjacent to it was opened in 1973. These three transport corridors form a vital link in the connection between Sydney and areas to the north of the Hawkesbury River.

Highway and railway construction is associated with land clearance in which vegetation and other naturally occurring soil stabilising material is removed from the construction site. It leaves surface areas and slopes created by excavation or embankments exposed to erosive forces of wind and rain until earthwork is completed and restored by grassy vegetation or artificially stabilised surfaces.

The effects of highway construction can be substantial even though it covers a small portion of the watershed. Various studies have examined the effects of highway construction, which include changes to sediment transport and deposition (e.g. Goldman *et al.*, 1986; Vice *et al.*, 1969), changes to surface and groundwater quality in relation to turbidity and suspended solids (e.g. Embler and Fletcher, 1983; Burton *et al.,* 1976; Garton, 1977), and the subsequent effects of siltation on aquatic macrobenthic and fish communities (e.g. Chisholm and Downs, 1978; Cline *et al.,* 1982; McLeese and Whiteside, 1977).

The following two estimates of nutrient and suspended solid runoff from the F3 Freeway, Pacific Highway and Main Northern Railway assume that there are no stormwater management or sediment control devices in place in the catchment. The estimates produce different results, emphasising the variation involved when using loading estimates from the literature and the importance of in-situ measurements to verify runoff loads.

Cattell and White (1989) reported the level of contaminants that are present in Sydney rainfall, assuming the mean annual rainfall for Sydney is approximately 1600 mm. These contaminants are then transported from the road surface by surface runoff into the stormwater system and receiving waterways. Table 3.10 presents these data.

Table 3.10
Recorded Runoff Contamination in Sydney

	TP Total Phosphorous (μg/L)	FRP Free Radical Phosphorous (μg/L)	NH_3 Ammonia (mg/L)	TKN Total Kjehdal Nitrogen (mg/L)	NOx Nitrate & Nitrite (mg/L)	SS Suspended Solids (mg/L)
Mean	51.4	19.5	0.2	1.3	0.1	8.6
Median	27	5	0.2	0.6	0.1	8
Std. Dev	58.3	35.3	0.1	1.9	0.1	5.8
Geo. Mean	29	9	0.1	0.5	0.1	7.2

Source: Cattell and White (1989)

The annual load of contaminants from rainfall has been calculated using the geometric mean from the above table. Rainfall nutrient loadings from the Sydney-Newcastle Freeway, Pacific Highway and Main Northern Railway were then calculated, assuming a road/rail width of 10 metres and length of each carriageway of 30 km, 39 km and 21 km, respectively. The results of this analysis are presented in Table 3.11.

Table 3.11
Runoff Nutrient Loads from Major Road and Rail Lines in the Brooklyn Estuary Catchment

	Loading from rainfall (kg/ha/yr)	**Sydney-Newcastle Freeway (kg/yr)**	**Pacific Highway (kg/yr)**	**Main Northern Railway (kg/yr)**
TP	0.5	15	19.5	10.5
FRP	0.14	4.32	5.6	3.0
NH_3	1.6	48	62.4	33.6
TKN	8.0	240	312	168
NOx	1.6	48	62.4	33.6
TN (TKN+NOx)	9.6	288	375	202
SS	115.2	3456	4492.8	2419.2

Note: Derived from values in Table 3.10 from Cattell and White (1989).

The above loading values give an annual nitrogen loading from the three major transport networks of 864 kg. For total phosphorus the annual loading is 45 kg and for suspended solids the annual loading is 10,368 kg.

A similar result of 882 kg/year for total nitrogen was obtained when using estimates of highway runoff composition compiled by Barrett *et al*.(1995). However for total phosphorus, the Barrett *et al.* (1995) review provides a range of loading values obtained from various literature sources of 0.6 – 8.23 kg/ha/yr. From these estimates it follows that the maximum total phosphorus loading for the Sydney-Newcastle

Freeway is 246 kg/yr, the Pacific Highway is 320 kg/yr, and the Main Northern Railway is 172 kg/yr. This gives a *maximum* annual phosphorus loading from the major networks of 738 kg.

From these results it is apparent that the highway and railway system within the Brooklyn Estuary catchment is potentially contributing a small but significant amount of nutrients and suspended solids to the total catchment load. These values would have been greatly increased, especially for suspended solids, during the construction phases when land was stripped of vegetation and road and rail cuttings and tunnels were created.

3.4.3 Point Sources of Pollution

The NSW EPA's Online Register of EPA Licences (EPA, 2002) was searched to find details of premises within the study area that are licenced under the Protection of the Environment Operations Act (1997) to discharge to waters or otherwise impact on the Brooklyn Estuary environment. The following premises were found:

- Fenwicks Marina (Brooklyn Road, Hornsby LGA)
  Licence type: marinas and boat repair facilities
  Extracts from licence:
  - "All activities at the premises must be carried out in a manner that will prevent waste from polluting waters" and stormwater, sewage and greywater must be "managed in a manner that will prevent pollution of waters".
  - No odour or offensive noise to be emitted beyond premise boundary.
  - Pollution reduction programs to be established, e.g. fuel spill containment on refuelling pontoon.

- Hawkesbury River Marina (Dangar Road, Hornsby LGA)
  Licence type: dredging, 0-30,000 m^3 obtained or moved
  Extracts from licence:
  - Floating boom to be installed around dredge area.
  - Dredging activity must not increase turbidity of water outside or must not increase migration of fine silt or organic matter from inside boom.

- Anglers' Rest Hotel (Brooklyn Road, Hornsby LGA)
  Licence type: miscellaneous licence to discharge to waters (sewage treatment plant 0-20 ML discharged)
  Extracts from licence:
  - Discharge from chlorination tank at maximum rate of 12 KL/day.
  - Pollutants discharged must not exceed the following: BOD 20 mg/L, TSS 30 mg/L, Cl (free reactive) 0.5 mg/L.

- Hornsby Shire Council (Crown Land – McKell Park, Hornsby LGA)
  Licence type: dredging, > 30,000-50,000 m^3 obtained or moved
  Extracts from licence:
  - Floating boom to be installed around dredge area.
  - < 50 mg/L TSS to pass through curtains of boom.

- Pioneer, Central Coast Sands (Reservoir Road, Somersby, Gosford LGA)

Licence type: extractive industries, land-based extraction >500,000-2,000,000 T obtained
Extracts from licence:
- stormwater overflow permitted to discharge to waters
- must monitor oil and grease, pH, TSS
- dust emissions minimised or prevented

Three other small extraction industries in the Gosford LGA also have licences with provisions regarding noise and dust emissions.

These premises do not appear to introduce significant aqueous pollutants to the Brooklyn Estuary. The Hornsby Shire Council has recorded several odour complaints regarding the Anglers Rest Hotel, which have been referred to the NSW EPA. Moreover, the upstream Hawkesbury River, as discussed in Section 3.9, is a greater source of contaminants with a number of sewage treatment plants discharging to the river and extensive urban and agricultural development in the catchment.

3.5 Fluvial Sedimentation

3.5.1 Sources of Fluvial Sedimentation

The sediment yield from a catchment area is related to the soil characteristics, the topography, the land use and vegetation cover, and the rainfall intensity and runoff. The Brooklyn Estuary catchment has steep topography and primarily undisturbed bushland vegetation cover. However, areas on the waterfront and near the ridge tops have been developed for agricultural and urban land use, which has altered the sediment load over time.

Sediment delivery to the Brooklyn Estuary is likely to have altered greatly over the history of development in the catchment. Specific development events, such as the construction of roads and bridges, will have temporarily caused very high sediment loads, while longer-term changes in land use and cover will have caused more subtle but perpetuating alterations to sedimentation rates. Sediment delivery from the upstream Hawkesbury-Nepean catchment will also have increased dramatically since the early 1800’s when agricultural and urban development began.

As discussed in Section 3.3, changes in land use area estimated from Census data indicate that bushland in the Brooklyn Estuary catchment decreased by approximately 15 % between 1954 and 1996. This represents a significant reduction in the amount of vegetation cover, allowing a greater proportion of rainfall to directly impact and erode the soil surface. The ultimate land use following clearance and development further determines the sediment yield and trends over time. For example, while urban development is in its construction stage sedimentation levels are very high but once buildings and paved areas are completed and planted areas are established sediment yields are much reduced. Clearance of land for farming has a lesser initial impact on sediment yields but the resultant loads are persistent over time as tilling of soils and grazing animals continually maintain a low level of protective cover for the soil. The large area of National Park in the Brooklyn

Estuary catchment as well as the steep topography have ensured that agricultural and urban developments have remained small-scale and, apart from the initial stages of urbanisation, sediment yields related to land use are expected to be relatively low.

Specific events that will have generated large sediment yields are the construction of the roads and railway and their respective bridges spanning the Hawkesbury River. As indicated in the development timeline presented in Section 6.3.1 the railway causeway that blocked off the eastern end of Sandbrook Inlet was constructed in the mid 1880's, presumably from material dug from the railway tunnels on the southern shore and through Long Island. The method of construction of the causeway is not known from the available literature and while large rock material would have been primarily used sedimentation during the period is likely to have been high due to land disturbance. The causeway has since caused an increase in the amount of sediment deposited in Sandbrook Inlet due to reduced tidal flushing.

The rail link from Sydney reached Brooklyn in 1887 and the first rail bridge was opened in 1889 and its replacement in 1946. The tunnelling required as well as land clearance would have generated a large sediment load around these times. The first road bridge at Peats Ferry opened in 1945, and now carries the Pacific Highway, and the Sydney-Newcastle Freeway Bridge opened in 1973. Aerial photos from 1965 and 1977 show how the land was affected by construction of the most recent bridge and provides an indication of the impacts likely from all of the construction events (Figures 3.5 and 3.6, see further discussion in Section 3.3). When comparing the two photos, in 1977 areas on either side of the bridge were cleared of vegetation and cuttings have been made into the hillside to accommodate the road. Sediment loads from these activities would have been extremely high. Land on the northern side has been reclaimed, presumably using road cutting material, which again would have caused a short-term influx of sediment to the estuary. It is interesting to note that by 1992 vegetation has recovered and there is no bare soil visible, and thus, sediment yields from erosion are likely to have returned to low levels (Figure 3.6).

The Pacific Highway, Sydney-Newcastle Freeway and the Main Northern Railway cross the study area for distances of 39 km, 30 km, and 21 km, respectively. Their construction required the clearance of vegetation for these distances and to a width of at least 10 metres, which equates to a total area cleared of at least 90 hectares. A large amount of bedrock cutting was required as well as tunnelling for the railway, which further increased sediment loads at the time of construction.

3.5.2 Sedimentation Rates

Sediment transport in the Brooklyn Estuary study area is a result of the action of tidal currents, fluvial inflows and wind waves on the generally coarse sediments (sands) of the river floor. The composition and grain size of the bed sediments also has an impact on the rates of erosion and accretion in the area.

A sedimentological analysis of sand from the Lower Hawkesbury River found that the main river channel is predominantly coarse sediments (sands) whereas sediments in the tributaries into the Lower Hawkesbury River are muds and sandy muds. Sediments in Sandbrook Inlet are a mixture of silts and sands. Fluvial sands in the main channel of the estuary extend to Patonga. Sedimentation within the main navigational channels is further discussed in Section 4.5.

Sedimentation rates across the study area were determined by comparison of three hydrographic surveys taken over the past century (1872, 1952, 1980). Therefore, the bathymetric changes over three different time periods (1872-1952, 1872-1980, 1952-1980) could be determined.

Sedimentation rates for Sandbrook Inlet and Brooklyn Boat Harbour were not determined due to a lack of data in the surveys used. However, the dredging history of the Brooklyn Boat Harbour suggests that there has been significant sedimentation in the area as over the last thirty years, 25,000 cubic metres of material has been dredged. Previous analysis of Sandbrook Inlet has calculated the accretion rate in Sandbrook Inlet to be about 10 to 20 millimetres per year.

When interpreting the results of this analysis it is important to realise a few limitations to the accuracy of this method. Firstly, the methods used to obtain data for the three different surveys used in the analysis (1872, 1952 and 1980) were varied and may have had different levels of accuracy. Furthermore, as the maps were all surveyed in different projections and datums, transformation of all the surveys to a common datum may have resulted in some distortion of the eastings and northings. The frequency of data measured was also quite dissimilar for the three surveys and the detail of the analysis was limited by the survey that had the least frequent data (the 1984 survey). However, as the analysis took place on a large scale, these impacts can be overlooked to an extent. The methods of analysis for this study are found in Appendix F.

<u>1872-1952</u>

The analysis of the changes in the bathymetry of the study area during this period is probably the most indicative of the three time periods, due to the extent of the coverage of the hydrographic surveys used for the analysis. As can be seen in Figure 3.8, there appears to be a sedimentation rate of 0-5m for the majority of the study area over the eighty year period, with several localised points of accretion and erosion. An area of rapid erosion appears to be between Long Island and Dangar Island, which would correspond to the high velocities and consequently high bedshears that are experienced in the area of the study site. It is possible that the currents direct some of this eroded material into the Brooklyn Boat Harbour, where reduced velocities and increased sedimentation rates are experienced. Another area of rapid erosion appears to be the eastern side of the river along the Little Wobby Beach foreshore from The Tanks to Croppy Point, however, the differences in elevation in this area may be a result of the matching of the boundaries. It is possible that erosion does occur in this area as the deepest channel is around the eastern side of Dangar Island.

<u>1952-1980</u>

The analyses with the most current dataset (1980) are less reliable due to the frequency of spotheight data in the dataset. The distribution of data of the 1980 dataset must be taken into consideration when interpreting the results. Therefore, the large areas of erosion which can be observed between Long Island and Spectacle Island in Figure 3.9, are probably not realistic. The sedimentation rates in the channel in close proximity to where the data points are more likely to be symbolic of the real situation. Therefore, if these sedimentation rates are observed, it would appear that in the main channel between Long Island and Spectacle Island a small amount of erosion has occurred in the thirty-eight year period. There appears to be larger areas of erosion around Dangar Island. The area of accretion between Long Island and Dangar Island should be discounted as the velocity patterns in this area suggest that accretion is not likely to occur. There also appears to be a large increase in sedimentation around the southern side of Spectacle Island and on the eastern side of the channel

<u>1872-1980</u>
The differences in bathymetry between 1872 and 1980 (Figure 3.10) look similar to those between 1952 and 1980 and this is probably due to the relatively small changes in bathymetry in the study site between 1872 and 1952. The pronounced areas of accretion and erosion remain the same and as mentioned previously, these should be interpreted with caution. Over the entire area, there appears to be more accretion when compared with the changes that took place from 1952-1980 which is to be expected.

3.6 Sewage Disposal

3.6.1 Brooklyn and Dangar Island

Brooklyn and Dangar Island are not serviced by the Sydney Water reticulated sewerage system and currently households individually manage their sewage. The following types of on-site systems are in use:

- septic tanks with effluent disposal on-site via soil absorption trenches;
- septic tanks with effluent removed by tanker and discharged to the Sydney Water depot in Leighton Place; and
- aerated waste water treatment systems (AWTSs with effluent disposed by soil absorption) (SMEC, 2000).

A Council pump-out service is available in Brooklyn only and its use is advised due to small lot sizes, close proximity of dwellings, steep land and inappropriate soil types for absorption (HSC, 1996). Table 3.12 shows the proportion of developed lots that use each of the sewage management systems in Brooklyn and Dangar Island.

Table 3.12
Existing Sewage Management Systems in Brooklyn and Dangar Island

System	Brooklyn	Dangar Island	Total
Septic tank pump-out system	35.5 %	-	22.2 %
Septic tank system with absorption trenches	55.6 %	88.5 %	68.0 %
AWTS	8.9 %	11.5 %	9.9 %

Source: AWT (1999a)

Septic tanks are designed to discharge domestic wastewater into the subsurface soil above the watertable following anaerobic biological action and the retention of solids and floatable scum. Septic tanks and absorption trenches have finite lives and have a history of failure due to inappropriate siting and poor maintenance. Aerated wastewater treatment systems are self-contained units that consist of a series of treatment processes and require power, regular maintenance and large lot sizes for discharge via garden irrigation (SMEC, 2000).

Hornsby Council's 1999 audit of properties identified that more than 50% of inspected properties had problems with their on-site systems including leaking septic tanks, odours, nuisance insects and weed problems. The audit concluded that 16% of the systems in Brooklyn and 36% on Dangar Island were having an impact on water quality, 22% of systems in Brooklyn and 66% on Dangar Island were affecting community amenity, and 40% of systems in Brooklyn and 74% on Dangar Island were posing a serious threat to public health (SMEC, 2000). As is discussed in Section 5.1.1, water quality monitoring undertaken as part of the Environmental Impact Assessment for the Brooklyn and Dangar Island Sewerage Scheme indicated that existing on-site systems are responsible for high pollutant loadings in surface water and groundwater in the area (AWT, 1999a).

A sewage management scheme has been proposed incorporating a sewerage system for each town and a local centralised sewage treatment plant (SMEC, 2000). Water quality modelling carried out for the EIS options assessment has suggested that nutrient loads from the Brooklyn catchment area will be greatly reduced by this facility (AWT, 1999b). Table 3.13 shows modelling results comparing nitrogen, phosphorus and faecal coliform loads from unsewered and sewered land during dry and wet weather.

Table 3.13
Comparison of Nutrient Loads Derived from Model Results for Sewered and Unsewered Land in Brooklyn and Dangar Island

	Total Phosphorus (kg/yr)		Total Nitrogen (kg/yr)		Faecal Coliforms (x 10^9cfu/yr)	
	Unsewered	**Sewered**	**Unsewered**	**Sewered**	**Unsewered**	**Sewered**
Brooklyn (dry weather)	207	13	551	15	12,478	1,382
Brooklyn (wet weather)	318	74	690	111	102,408	11,567
Dangar Island	28	4	90	29	14,500	3,300
Total	**554**	**90**	**1,330**	**156**	**129,386**	**16,249**

Source: AWT (1999b)

The wet weather loads are clearly much higher than during dry weather, however hydrodynamic modelling of particle movements (discussed in Section 4.4.5) suggests that under wet weather flows particles such as contaminants move out of Sandbrook Inlet at a much more rapid rate than under baseflow conditions. Based on the results in Table 3.13 the proposed scheme for a reticulated sewerage system will have a marked effect on water quality in the estuary with an approximate 80 % reduction in nutrient and faecal coliform loads related to sewage inputs.

The Brooklyn and Dangar Island Sewerage Scheme EIS (SMEC, 2000) states that a new sewage treatment plant (STP) at Brooklyn will add to the quantity of nitrogen and phosphorus currently discharged from STPs into the lower Hawkesbury. Compared to the loads of nitrogen and phosphorus from the existing sewage system (as shown above in Table 3.13), however, the scheme is predicted to result in a net reduction in the total load of nutrients discharged into the lower Hawkesbury River (SMEC, 2000).

The EIS considered a number of options for the sewerage scheme and a final preferred option was still under consideration at the time of preparation of this report.

3.6.2 Mooney Mooney, Cheero Point and Little Wobby

Within the Mooney Mooney Creek catchment the urban area of Kariong is sewered while Somersby in the north and Mooney Mooney in the south are unsewered (DLWC, 2001). The on-site sewage systems discussed above, including septic tanks and aerated wastewater treatment systems (AWTSs), are used in the unsewered areas. While detailed water quality information is not available on the impacts of these systems in these areas, nutrient and faecal coliform loads are expected to be similar to those presented above for Brooklyn and Dangar Island albeit at a smaller scale related to population size.

Gosford City Council is implementing an On-site Sewage Management Program involving inspections and assessments of all on-site sewage systems. Systems will be issued with approval to operate for one, three or five years depending on their assessed performance and risk classification with regards to environmental and public health protection criteria. A comprehensive inspection will be undertaken for those septic tanks with on-site disposal including sampling and testing of the final effluent (GCC, 1999).

As part of the NSW Government's Small Towns Sewerage program the urban areas of Mooney Mooney, Cheero Point and Little Wobby have been given priority for improved sewerage services (Ellis Karm & Associates, 2002). These towns currently contain approximately 260 developed lots with existing services primarily consisting of septic tank systems with transpiration trenches, some with a pump-out service in Mooney Mooney only, and a small number of AWTSs. These on-site systems are perceived to cause problems including public health risks, persistently wet and boggy ground conditions, effluent runoff during wet periods, odours, and contamination of groundwater and surface waters (Ellis Karm & Associates, 2002). In addition to these systems the Department of Community Services (DOCS) owns and operates a small STP on Peat Island, which services development south of the Mooney Mooney urban area including DOCS facilities (hospital, laundry, depot), the public school, a licenced club, an oyster depuration depot and approximately 30 residences owned by DOCS. The existing effluent discharged from the Peat Island STP is considered to be unsatisfactory (Ellis Karm & Associates, 2002).

An options report has been prepared and released investigating the various options for improved sewage disposal for Mooney Mooney, Cheero Point and Little Wobby (Ellis, Karm & Associates, 2002). The expected environmental benefits of a sewerage scheme include: (1) a reduction in pollution of surface and groundwaters, (2) a significant reduction in the quantity and concentrations of pathogens, and nutrients entering the waterways, (3) reduced public health risks due to inappropriate and/or poorly maintained on-site systems and illegal discharges, and (4) improved public amenity from the removal of on-site effluent disposal, including the removal of odours, boggy ground and mosquito infestations (Ellis, Karm & Associates, 2002).

3.6.3 Vessel Discharges

As discussed further in Section 6.2 the Brooklyn study area is a popular area for boating and other waterway activities. The discharge of sewage waste from vessels can potentially be a significant cause of water pollution. The vessels considered most likely to pose the greatest threat of polluting waters with sewage are those on which people can spend extended periods including overnight. These include:

- Class 4 commercial vessels (more than 6 metres in length that are likely to be hired for an extended period of time, e.g. houseboats); and
- Class 1 commercial vessels (e.g. charter vessels) (Waterways Authority, 2000).

The Waterways Authority currently estimates that there are approximately 400 vessels in the Brooklyn area of a size that could have a toilet fitted. Of these approximately 75 are commercial houseboats operating from Sandbrook Inlet (MHL, 2000).

Existing legislation in NSW that provides for the management of sewage from vessels includes the *Protection of the Environment Operations Act 1997*, which commenced on 1st July 1999, and the *Management of Waters and Waterside Lands Regulations – NSW*. A recent Waterways Authority discussion document (Waterways Authority, 2000) found that these existing regulations are not sufficient for the effective management of sewage pollution from vessels and proposed a number of regulatory actions, including the prohibition of untreated sewage from vessels in all NSW waters. For the discharge of treated sewage a risk management approach has been proposed assessing individual waterway risks, consequences and prevention of pollution (Waterways Authority, 2000).

The Waterways Authority had developed a Voluntary Code of Practice within Brooklyn which has since been withdrawn as successful implementation was not achieved. This defined "no discharge" zones and includes marinas, clubs, established mooring areas and regularly crowded anchorages, inlets or bays with minimal tidal flushing, all 4 knot, 8 knot and *No Wash* zones, and within 100 m of the shore.

Pump-out facilities at Kangaroo Point at the entrance to Sandbrook Inlet and at Holidays Afloat Houseboats at Brooklyn, provide a large number of recreational and commercial vessels with an easily accessible means of legal and environmentally safe waste disposal (MHL, 2000). These facilities were made operational during the 2002/03 summer boating season (Dylan Cameron, DLWC, personal communication).

3.7 Stormwater Management

In urban areas "poor stormwater quality presents the greatest threat to the conservation of aquatic ecosystems" (HSC, 2002). While the level of urbanisation in the Brooklyn Estuary catchment is relatively low (see Table 3.6), the discharge of stormwater from existing urban centres, highways and the railway presents a potentially significant threat to water quality if poorly managed. Section 3.4 discusses catchment runoff from all sources, whereas this section refers to specifically stormwater management. As mentioned in Section 3.4.1 urban runoff can be a source of suspended solids, nutrients, oxygen reducing substances, litter, pesticides and herbicides, trace metals and oils, and faecal coliforms.

Hornsby Shire Council has developed a Catchments Remediation Program (CRP) which includes a large number of capital works, such as the installation of gross pollutant devices, and non-capital activities, such as street sweeping and education/reporting programs (HSC, 2001). During the 2001/02 financial year the gross pollutant devices throughout the Hornsby LGA served to remove approximately 289 cubic metres of sediment, litter and organic matter from waterways (HSC, 2002). Within the Brooklyn Estuary study area there is a Humeceptor device at Parsley Bay that has been installed to capture polluted water originating from boat washing and flushing and fish cleaning waste. This device has been successful in reducing the concentration of nutrients, BOD, hydrocarbons, turbidity and suspended solids in the discharge to the estuary (HSC, 2001). In addition, there is a gross pollutant device proposed to be installed in Dangar Road, Brooklyn, and a sand filter and trash screen in Brooklyn Road that has been installed by developers as a condition of development consent. During 2000/2001 a sediment basin in Brooklyn Road prevented 1.5 tonnes of sediment from entering the estuary (HSC, 2001).

Gosford City Council has proposed an integrated Stormwater Development Control Plan which aims to include erosion and sediment control issues, nutrient control, water sensitive urban design and stormwater control issues (GCC, 2002a). Council is in the process of implementing its Stormwater Management Plan and projects to date are reported to have been very successful, with gross pollutant traps throughout the Gosford LGA having prevented over 23,000 kg of gross pollutants from entering waterways (GCC, 2002a). Information on stormwater projects implemented specifically in the Brooklyn Estuary catchment is not available at this time. Table 3.9 provides a breakdown of percentages of contribution from sub-catchments, however it is recommended that a list of specific legislative or private bodies having responsibility over potentially polluting catchments be assembled.

3.8 Groundwater

A search for groundwater discharge estimates has been made but no literature has been found detailing Brooklyn groundwater discharges. However, DLWC bores in the area of the Berowra STPs indicate that low to moderate yields (0.4 to 0.5 L/s) of fresh to saline groundwater have previously been produced from the fractured Hawkesbury Sandstone aquifer (MHL, 1998).

The Gosford City Council State of the Environment Report (1999) states that there is insufficient information currently available to determine trends in the quality of the groundwater resources within the region and that this is an issue which will need to be addressed in the coming years (GCC, 1999). The Hawkesbury-Nepean Catchment Management Trust also states that within the catchment available groundwater information is scarce (HNCMT, 1996).

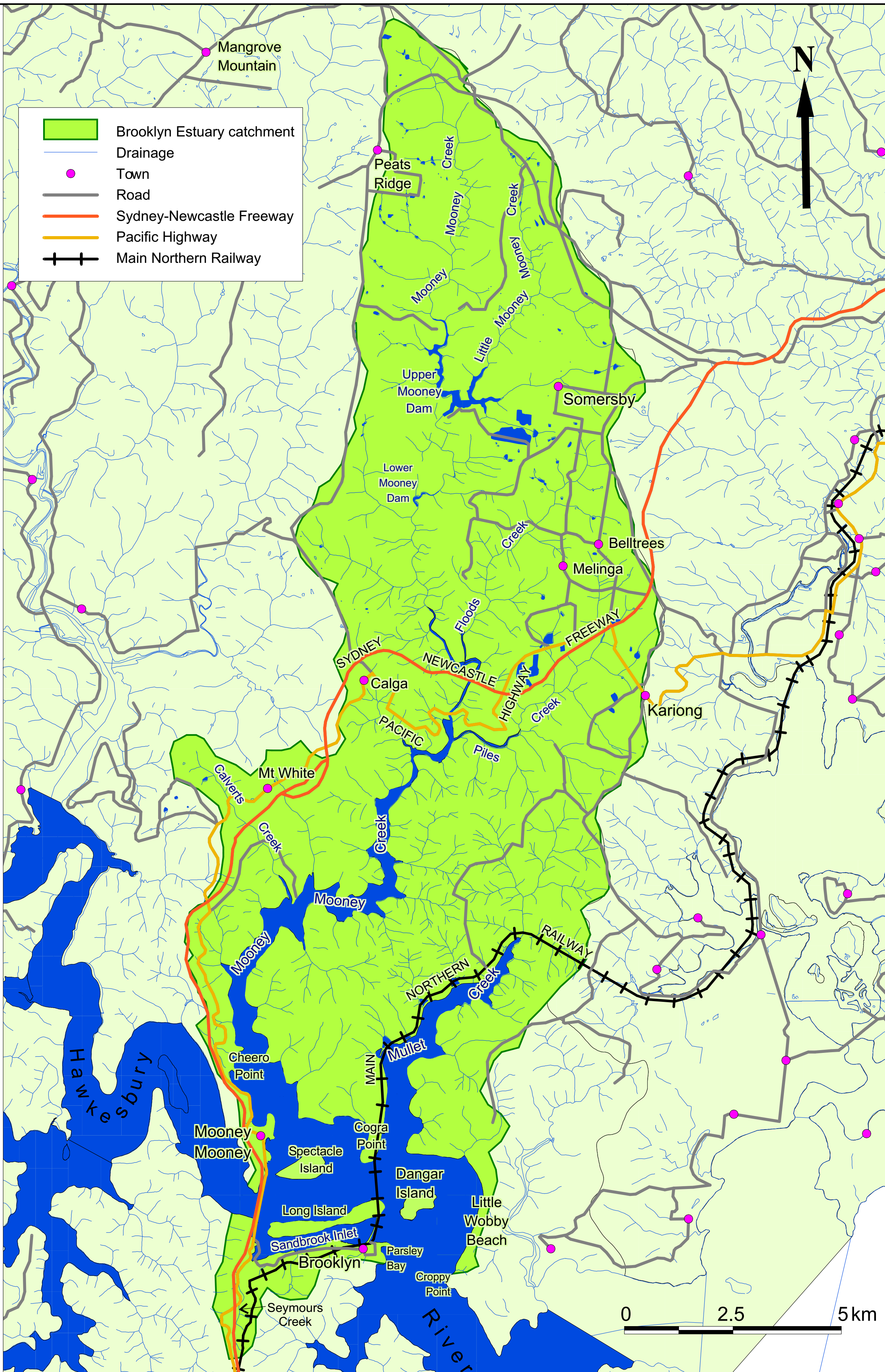
3.9 Hawkesbury-Nepean River

Due to its location in the lower Hawkesbury River the Brooklyn Estuary study area is strongly influenced by upstream processes and activities in the Hawkesbury-Nepean catchment. The Hawkesbury-Nepean River and its tributaries drain a catchment of almost 22,000 square kilometres, of which 68 % of the land is forested, 25 % is agricultural and less than 7 % is urbanised (HRC, 1998). In general terms, the health of the river is affected by:

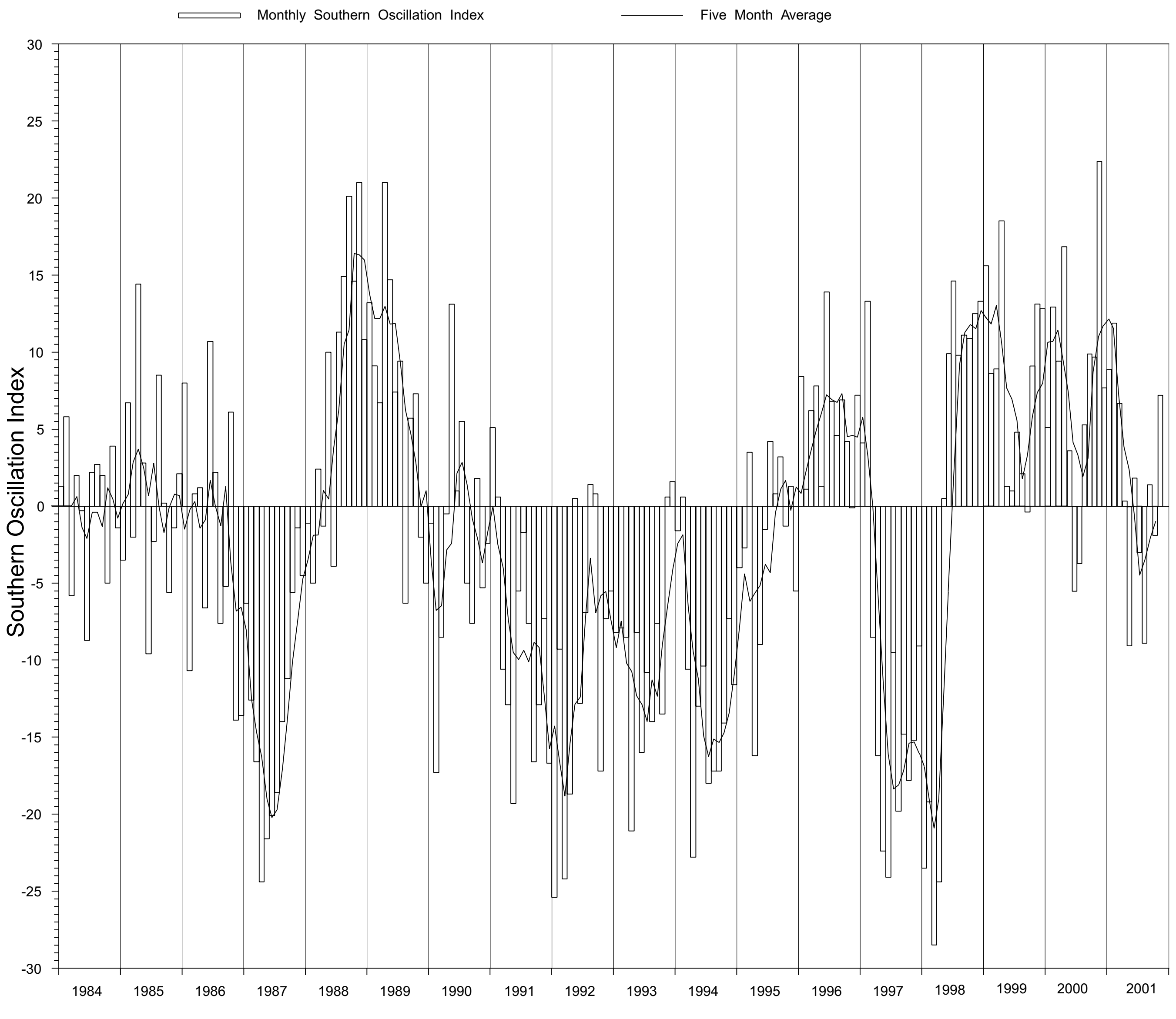
- removal of riverside vegetation (associated with both agricultural activities and urban development);
- dams and weirs which reduce downstream flows and inhibit fish passage;
- water abstraction for irrigation, town water supply, stock and domestic use;
- effluent disposal from sewage treatment plants (STPs), on-site disposal systems and boats;
- extractive industries both past and present; and
- an array of recreational pursuits (HRC, 1998).

The Hawkesbury-Nepean Catchment Management Trust (HNCMT) was formed in 1993 to oversee coordinated and cooperative management of the river system and its catchment. The HNCMT was disbanded in 2001 and is currently replaced by the Hawkesbury-Nepean Catchment Management Board. In an overview of water quality issues it found that water quality in the catchment is generally good, although measurements of total nitrogen, total phosphorus and faecal coliforms fail to meet standards consistently (HNCMT, 1996). These high nutrient and faecal coliform levels in the river system will influence the levels found in the Brooklyn Estuary study area.

Calculations presented in Section 5.1.1 suggest that the total nitrogen load to the study area from the upstream Hawkesbury River is 189.4 kg/day and the total phosphorus load is 7.4 kg/day.

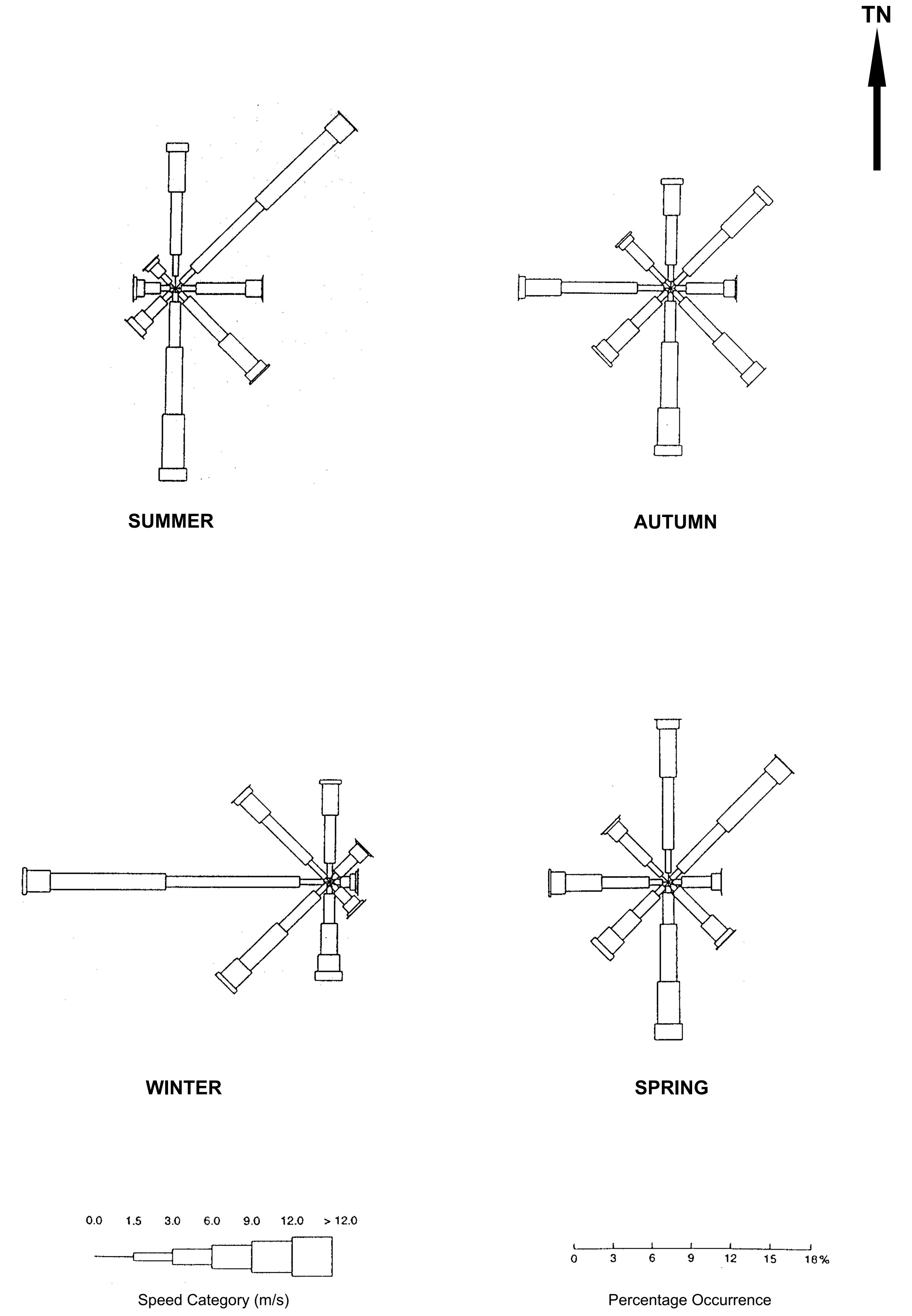


WRL Report No. 2002/20	BROOKLYN ESTUARY CATCHMENT	Figure 3.1 00758-03-01.cdr

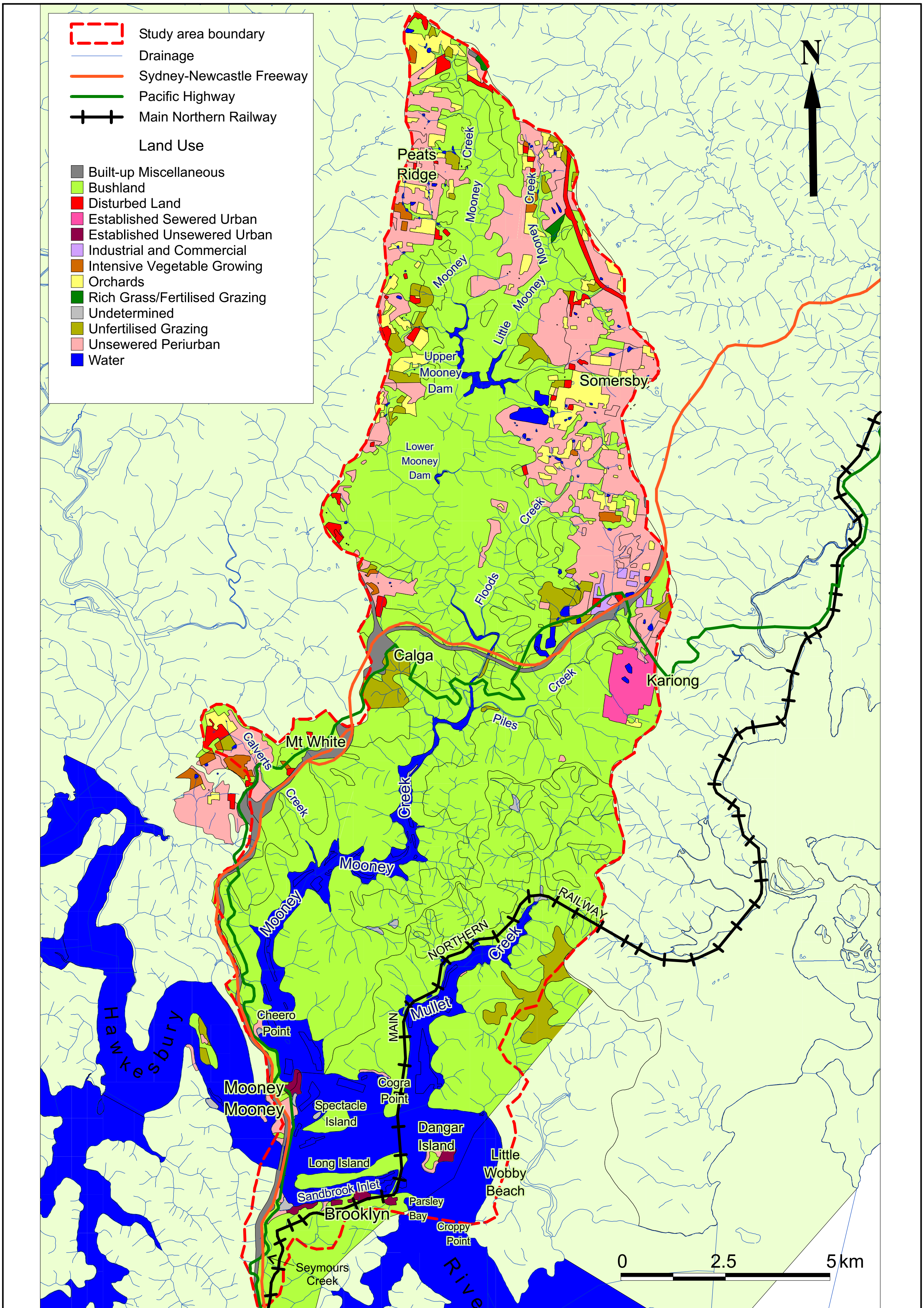


Source: Bureau of Meteorology

WRL Report No. 2002/20	SOUTHERN OSCILLATION INDEX 1984 - 2001	Figure 3.2 00758-03-02.cdr



WRL Report No. 2002/20	SEASONAL WIND ROSES FROM THE OCEAN REFERENCE STATION	Figure 3.3 00758-03-03.cdr



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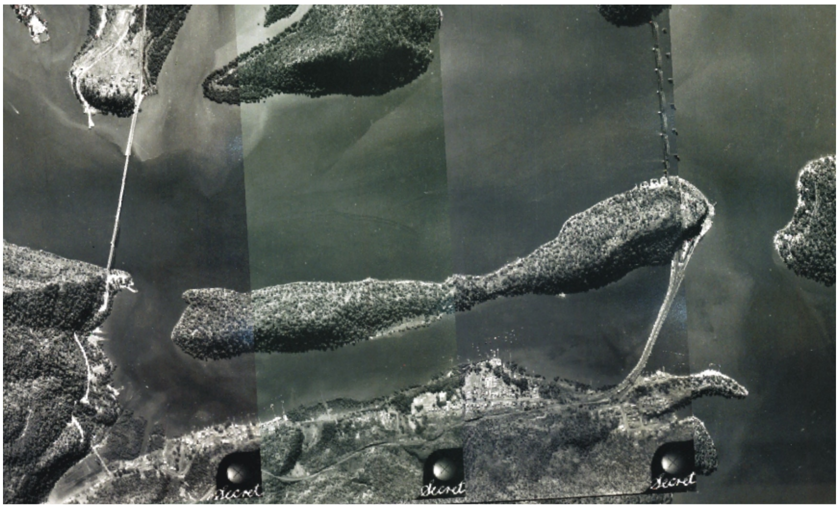
CATCHMENT LAND USE

Figure 3.4

00758-03-04.cdr



1955

1965

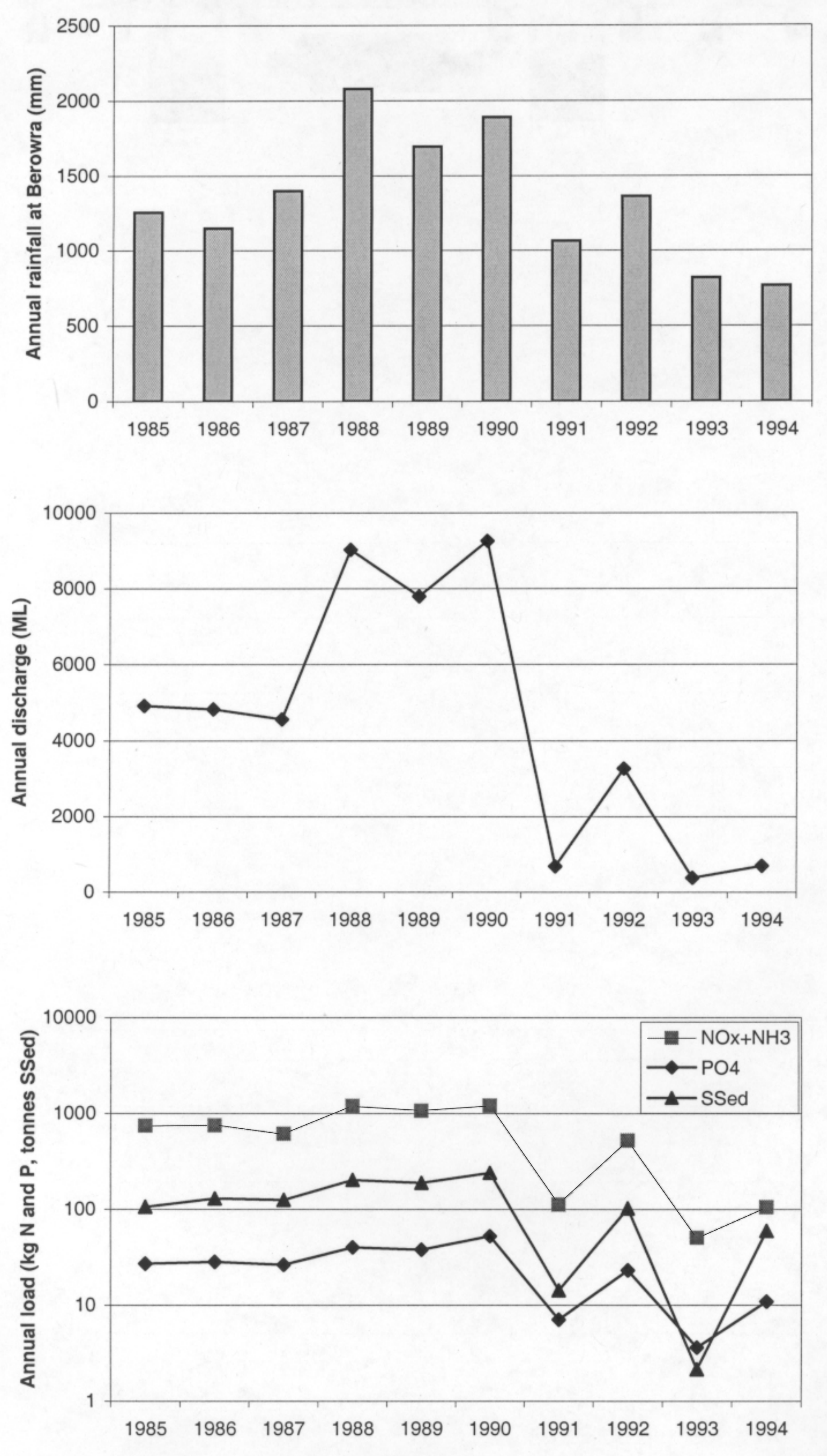
1977

WRL Report No. 2002/20	AERIAL PHOTOS OF SANDBROOK INLET 1955, 1965, 1977	Figure 3.5 00758-03-05.cdr

1992

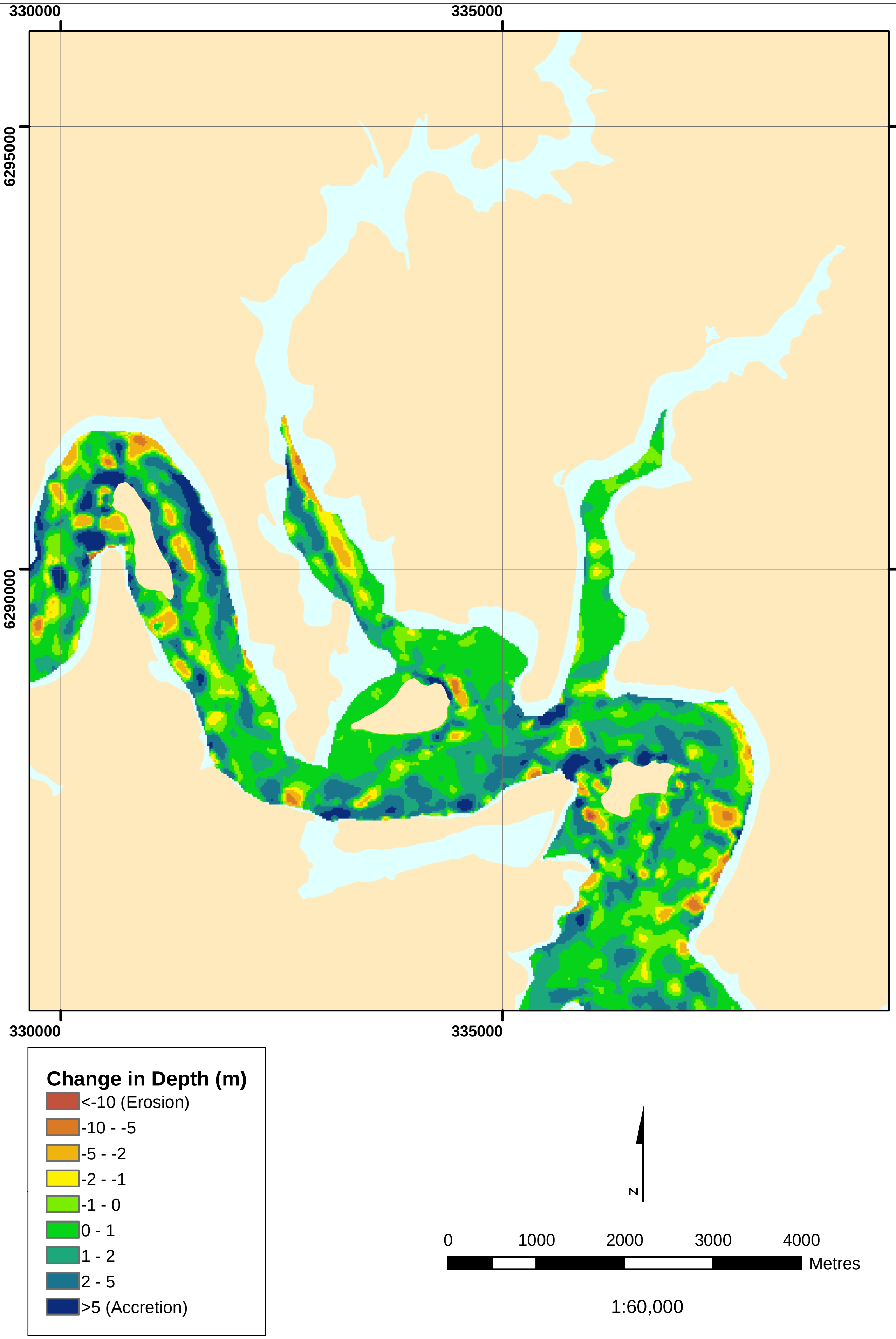
1997

WRL Report No. 2002/20	AERIAL PHOTOS OF SANDBROOK INLET 1992, 1997	Figure 3.6 00758-03-06.cdr



Source: AWT

WRL Report No. 2002/20	ANNUAL CATCHMENT LOADS AND RAINFALL FROM HSPF MODELLING	Figure 3.7 00758-03-07.cdr



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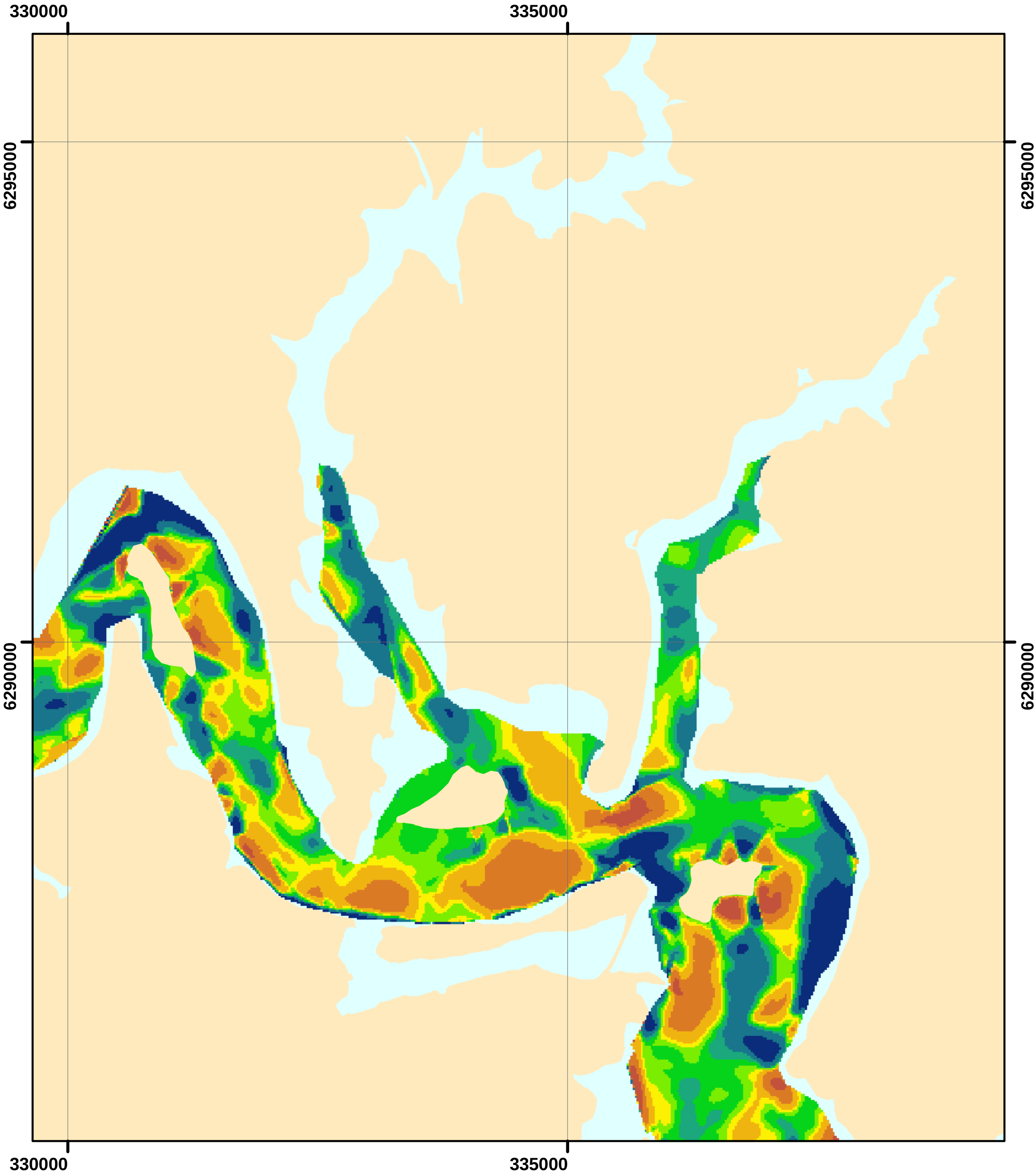
Report No. 2002/20

BATHYMETRIC CHANGES FROM 1872-1952

Figure
3.8

fig3_8.mxd



Change in Depth (m)
- <-10 (Erosion)
- -10 - -5
- -5 - -2
- -2 - -1
- -1 - 0
- 0 - 1
- 1 - 2
- 2 -5
- > 5 (Accretion)

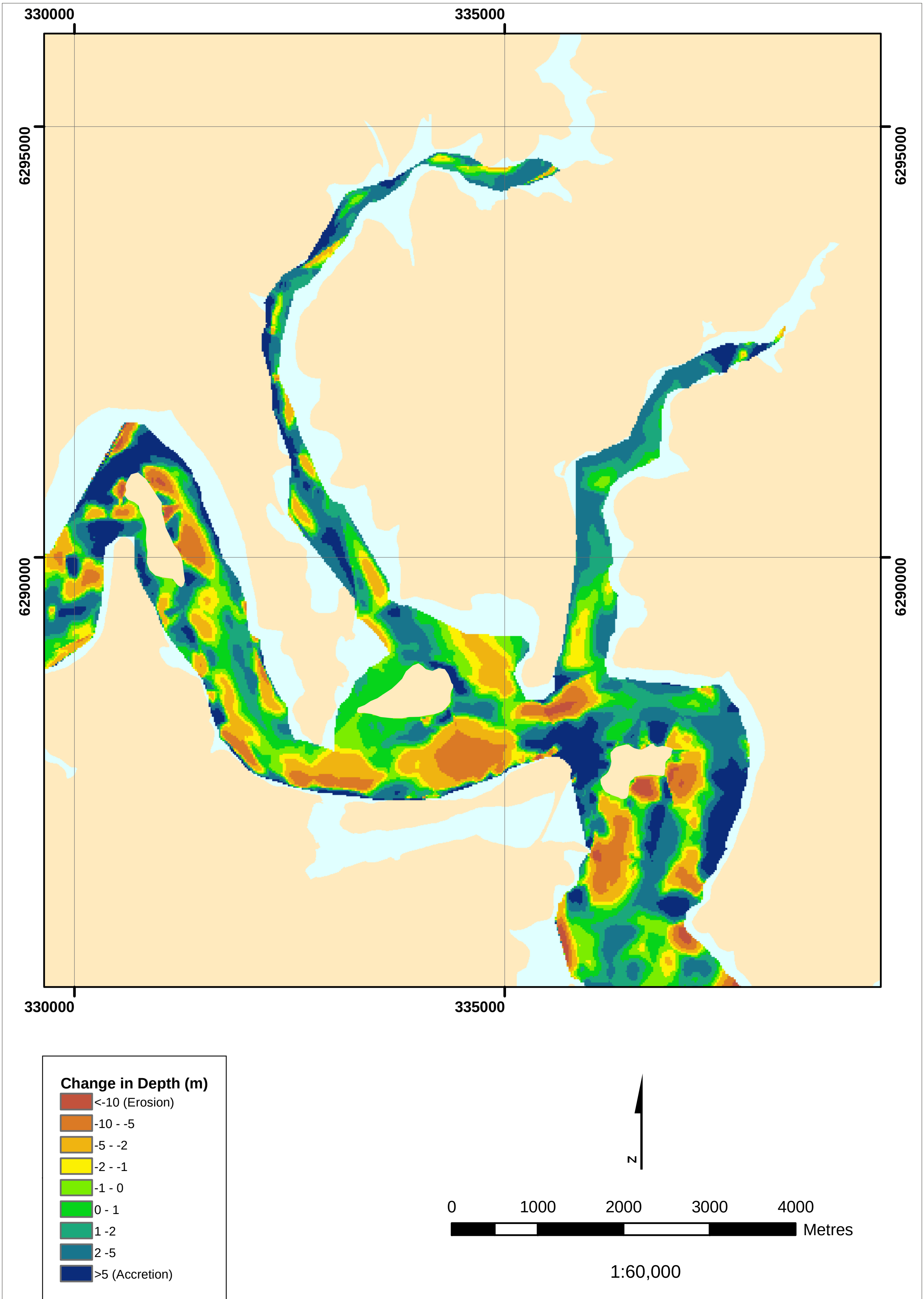
N

0 1000 2000 3000 4000 Metres

1:60,000

WRL Report No. 2002/20	BATHYMETRIC CHANGES FROM 1952-1980	Figure 3.9

fig3_9.mxd



WRL
Report No. 2002/20

BATHYMETRIC CHANGES FROM 1872-1980

Figure 3.10

fig3_10.mxd

4. Hydrodynamics and Flushing

The hydrodynamics of the study site as detailed in previous literature, analytical calculations, numerical analyses and on-site field experiments are described within this chapter. First, background literature pertaining to water movements within the study site are examined and analysed. Second, due to the limited amount of existing information field data was collected and a numerical model constructed. These tools were then employed to determine the water level variability and water exchange and flushing characteristics of the Brooklyn estuary. The chapter concludes with findings relating to sedimentation within navigation channels.

4.1 Review of Literature

The hydrodynamics of an estuary pertain to the water movements caused by different forcing phenomena. The most obvious forcing is the gravitational attractions of the moon and sun that result in the tides but other less regular factors include wind, rainfall, runoff and oceanic variability associated with coastal trapped waves, El Nino events and global warming. The Department of Public Works and Services have been involved in ongoing tidal monitoring of the study area as part of the Hawkesbury River Tidal Monitoring Program. Data measured as part of this program include; water levels, discharges, velocities, ebb and flow tidal gradients and salinity levels. A number of studies have investigated the hydrodynamic behaviour in the Hawkesbury Nepean region, some of which are particularly relevant to the Brooklyn Estuary Processes Study.

The Brooklyn Waterway Planning Study (PWD, 1988) summarises the results of a program that collected tidal data in the main river channel between Long Island and Spectacle Island. The study also refers to data collected by the Public Works Department (PWD), which determined that the greatest tidal current in the main river channel occurred during the ebb cycle and was located around Long Island. It was found that the maximum depth averaged ebb tidal velocity of 1.0 m/s occurred at this location for a mean spring tidal range of 1.3 m. The report estimated that a depth averaged maximum flood velocity of 0.6 m/s could be expected across the full river section under the same conditions (PWD, 1988).

The same study found that tidal information specifically about Sandbrook Inlet is limited, but that the tidal range within the Sandbrook Inlet would be approximately 90% of that measured in the Brooklyn Boat Harbour and the maximum flushing velocities at the entrance to Sandbrook Inlet are estimated to be 0.25 m/s.

Tidal currents have been measured across the mouth of Sandbrook Inlet as part of the Hydrodynamic Impact Assessment for the proposed Moire Resort, Brooklyn (Nielsen 1999). Currents were measured during a spring tide of range 1.1 m, along 11 transects from a high tide of 1.5 m to a low tide of 0.4 m. The investigation found that maximum current speed in the main channel of the river reached 1 m/s and that the currents experienced in the mouth of the inlet were seldom greater that 0.2 m/s. These results concur with the Brooklyn Waterway Planning Study (PWD, 1988), which considered the maximum current velocity within the inlet to be 0.2 m/s.

Tidal data has been collected by the Manly Hydraulics Laboratory branch of the Public Works Department (now Department of Public Works and Services) at a number of locations along the Hawkesbury River since 1971 (Figure 4.1) . Data before this time is limited, but enough data has been collected to determine the tidal constituents relative to Fort Denison. Figure 4.2 shows the water levels about the study site relative to the water level at Fort Denison in Sydney Harbour. The tides in the study area lag the tides at Sydney Harbour by about 20-30 minutes. Historical tidal records at Fort Denison can be readily obtained and transposed to the Hawkesbury estuary. The Environmental Impact Statement for the Brooklyn and Dangar Island Priority Sewerage Program (SMEC, 2000) used tide data measured from Little Patonga for its analyses as this was the closest gauging station to the study site.

Some tidal data has been recorded for Mooney Mooney Creek and adjacent to Peat Island (PWD, 1988). The data was measured to correspond to a predicted high-low-high ocean tidal cycle. Data measured included water level and discharge data and average velocities at a range of metering points. This data collection study found that during this period there was an influx of approximately 230,000 m^3 into Mooney Mooney Creek. Tidal data has also been gauged for Milson Island (Baldock and Wyllie, 1987) which lies just north of the upstream study area boundary. The tidal gradient for the Brooklyn study area (PWD, 1988) shows that there is a slight amplification of tides upstream from the ocean entrance (Figure 4.3).

Since the early 1900s a number of different agencies have shared the task of recording water level data along the Hawkesbury River and its tributaries, including the Public Works Department, Department of Water Resources, Sydney Water and the Bureau of Meteorology (AWACS, 1997). In regard to the Brooklyn Estuary study area, there are several reports that contain important information for hydrological modelling such as bathymetry (Nexus Environmental Planning, 2000; JBA Urban Planning Consultants, 2000) and groundwater information (Sinclair Knight Merz, 2000). Manly Hydraulics Laboratory (MHL) has produced hydrographic surveys of the region.

No wind data is locally available for the study site, however, other studies conducted around Brooklyn have used wind data from offshore Sydney (PWD, 1988, and see Section 3.2.3). While there would be some local topographic influences and differences due to the 45km separation between sites, it is expected that the local wind conditions are similar to the offshore site.

The Brooklyn Waterway Planning Study (PWD, 1988) reported that the topography in the region lends itself to the creation of wind shields and funnelling. Brooklyn is protected from the southerly to south-easterly winds and Parsley Bay is directly exposed to the south east. The study found that wind wave action in the study area is limited by the minimal occurrence of long stretches of uninterrupted water surfaces, with the exception of the approximately 3 km stretch from Bradley’s Beach on the eastern side of Dangar Island to Gunyah Point.

The Brooklyn Waterway Planning Study (PWD, 1988) estimated, using empirical calculations, that the lower limit of the flushing time for Sandbrook Inlet would be 1.5 days. This relatively short length of time is attributed to the combined effects of strong tidal currents in the main river channel and wind action that impact on the mixing time.

The 1997 Lower Hawkesbury River Flood Study (AWACS, 1997) used most of the flood data available for the Lower Hawkesbury. The study used a two dimensional finite element model to determine the extent of flooding in the lower Hawkesbury region (Figure 4.4). Flood hydrographs were used as inputs into the modelling at the locations shown in Figure 4.4. The flood hydrograph for a 20% AEP event can be seen in Figure 4.5. The results of this study are important in determining the fresh water flushing for the Brooklyn Estuary study area.

Flood events in the study area may be derived from local heavy rainfall that affects the upper reaches of the study area or from widespread rainfall in the upper Hawkesbury catchment (hundreds of kilometres from the study area) that affects the Hawkesbury River. During wider flood events flow in the Hawkesbury River increases, while at Brooklyn the water levels remain tidal with a general increase (PWD, 1988) (Figure 4.6). The Brooklyn Waterway Planning Study briefly looked at flooding in the study region based on the March 1978 flood event of the Hawkesbury River and suggested an inundation level of 2.0m AHD for the Brooklyn waterway.

4.2 Methods of Hydrodynamic Assessment

4.2.1 Tidal Gauging Exercise October 2001

An intensive tidal data collection exercise was carried out in October 2001 by the DLWC Estuaries Branch and Manly Hydraulics Laboratory (MHL, 2002). The aim of the exercise was to provide information on the tidal flows and salinity variability during a typical tidal cycle (16 and 17 October, 2001) and to collect time series data at a number of locations over a 5 week period to resolve the tidal characteristics within the study area. The results of the various surveys and presentations of the data set are described in the report MHL1158 (MHL, 2002) and a brief summary and interpretation of the data is provided here.

The data collected during the tidal spatial surveys provide a ‘snapshot’ of the conditions at the time while the time series collected at several locations for 5 weeks provide a measure of the temporal variability over the spring-neap cycle and recovery after fresh water inflow events (if such occurs during the deployment period). The main interest in the data set is an interpretation of:

- water level variability and the factors contributing to this variability at different time and space scales
- tidal velocity and discharge that lead to mixing and transport of water borne contaminants and sediments
- salinity variability and its use as a measure of flushing
- chlorophyll-a for use as a measure of the algal biomass at the time of the survey.

4.2.2 RMA Modelling

RMA-2 is a two-dimensional finite element hydrodynamic model for depth averaged flow (King, 1998). The shallow water forms of the Navier-Stokes equations are solved in two dimensions to obtain velocities and water surface elevations at each node on the finite element mesh. The model can either be operated in steady-state or dynamic modes.

A two-dimensional finite element model was developed for the Brooklyn Estuary study area to gain an understanding into the current hydrodynamics of the area and also to assess the impact on the hydrodynamics of the system from model simulation of the removal of the railway causeway from Brooklyn to Long Island. Two flow regimes were examined. These were base flows and the peak flows that would be expected for a 20% AEP flood in the Hawkesbury River.

Hydrodynamic modelling that has previously been carried out on the Hawkesbury River includes a calibrated hydrodynamic RMA2 model (Hawkesbury Model) that was designed to examine flood behaviour on the Lower Hawkesbury River from Sackville to Broken Bay (AWACS, 1997). For hydrodynamic modelling of the present study area a model domain was established with open boundaries at the upstream and downstream boundaries on the Hawkesbury River. Boundary conditions for the upstream and downstream boundaries were extracted from the flood model. Therefore, the hydrographic and tidal inputs of the flood model used for the Lower Hawkesbury River Flood Study were altered to simulate the flow conditions required for this study.

Details of the hydrodynamic modelling are included in Appendix A.

Calibration of the Brooklyn hydrodynamic model was undertaken using ADCP data collected by MHL on 16 October 2001 at four locations within the study area. The Lower Hawkesbury Flood Model was also calibrated and verified for the Hawkesbury River (AWACS, 1997).

4.3 Water Level Variability

Changes in water levels within the estuary are influenced by a range of phenomena that operate at different time scales, from a few minutes to millennia, including:

- astronomical tides
- wind setup
- fresh water inputs and floods
- ocean storm surges
- oceanic coastal trapped waves, and
- sea level rise associated with climate change.

Each of these factors and their relative contributions to the water level variability is discussed in the following sections. Water level data is collected at a number of permanent monitoring sites within the Hawkesbury River (Patonga, Spencer and Castlereagh) and the adjacent ocean (Sydney) while the short term deployments at selected sites within the study area (Brooklyn, Sandbrook Inlet, Kangaroo Point, Upper Mullet Creek, Mooney Mooney, Green Point and Mooney Mooney Bridge) are used to provide more detail (Figure 4.1).

4.3.1 Astronomic Tides

Astronomic tides are the ocean's response to the gravitational attraction of the planets (sun and moon). Each of the planetary and lunar orbits and the earth's rotation occur at set frequencies that force oscillations of the oceans - the tides - at similar frequencies. The major tidal components along the NSW coast occur in response to the lunar and solar attractions interacting with the rotating earth. The tides in the region are dominated by the semi-diurnal (twice per day) constituents with a strong spring-neap cycle as shown in the water levels recorded at Brooklyn and Sydney Harbour (Figure 4.2).

The tidal planes for the sites at the ocean and near the extremities of the waterways within the study area are listed in Table 4.1.

Table 4.1
Tidal Planes in the Ocean and in the Study Area

Tidal Plane	Ocean (2) Sydney Harbour Site 0	Brooklyn (1) Site 2	Mullet Creek (1) Site 10	Sandbrook Inlet (1) Site 3	Mooney Mooney Bridge (1) Site 14
HHW(SS)	1.059	1.101	1.134	1.125	1.278
MHWS	0.712	0.761	0.789	0.785	0.921
MHW	0.583	0.630	0.654	0.652	0.776
MHWN	0.454	0.499	0.518	0.518	0.631
MTL	0.069	0.098	0.110	0.109	0.193
MLWN	-0.316	-0.303	-0.298	-0.299	-0.245
MLW	-0.445	-0.434	-0.434	-0.433	-0.390
MLWS	-0.575	-0.565	-0.569	-0.566	-0.535
ISLW	-0.823	-0.808	-0.815	-0.809	-0.790
Tidal Ranges:					
HHW(SS) to ISLW	1.882	1.908	1.949	1.935	2.068
MSR	1.287	1.326	1.358	1.352	1.456
MTR	1.028	1.064	1.088	1.084	1.166
MNR	0.770	0.802	0.817	0.817	0.876

HHW(SS) - Higher High Water (Spring Solstices)
MHWS - Mean High Water Springs
MHW - Mean High Water
MHWN - Mean High Water Neaps
MTL - Mean Tide Level
MLWN - Mean Low Water Neaps
MLW - Mean Low Water
MLWS - Mean Low Water Springs
ISLW - Indian Spring Low Water
MSR - Mean Spring Range
MTR - Mean Tidal Range
MNR - Mean Neap Range

The tidal range in the study area is very similar to the ocean tidal range with a slight amplification of the tides towards to upper reaches of Mullet and Mooney Mooney Creeks. The ratio of the mean spring tidal ranges in the study area sites to the mean spring tidal range at the ocean varies from 1.030 at Brooklyn to 1.131 near the Mooney Mooney Bridge some 16 km from the Hawkesbury River up Mooney Mooney Creek. A similar trend occurs in both Mullet Creek and Sandbrook Inlet but to a lesser degree as these tributaries are shorter than Mooney Mooney Creek.

This ratio depends on the conveyance characteristics of the estuary channel that in turn are a function of the channel morphology.

The hourly water level data may be analysed using an harmonic analysis given the known planetary frequencies that cause the tides (solar, lunar and other planetary orbits). This analysis produces the so-called tidal constants that may then be used to predict the tides at any time. The difference between the observed water levels and the tidal predictions is referred to as the tidal residual. In essence the residual signal provides a measure of the non-tidal water level oscillations such as floods and the other phenomena referred to above. The tidal residuals for Brooklyn and Sydney Harbour are shown in Figure 4.7. While the residuals show smaller variations (around ± 0.2 m) than the tidal range (around 1.8 m) the long term nature of these changes, particularly near the tidal limit and within the low lying tidal flats and wetlands, may have an important influence on exchange and biota.

4.3.2 Low Frequency Sea Level Oscillations

Low frequency sea level oscillations include phenomena with periods greater than about four days such as the coastal trapped waves that propagate up the NSW coast causing ocean water level changes of around 0.1 to 0.5 m. These oceanic changes are transferred to the estuary and result in significant changes in the water volume within the estuary. To illustrate the effect of these signals the tidal residuals have been low pass filtered (smoothing of the tidal oscillations) to remove the high frequency "noise". The resultant longer period oscillations for the period 15 October, 2001 to 21 November, 2001 are shown in Figure 4.7.

The Castlereagh site is located in the upper Hawkesbury River upstream of the tidal limit and provides an indication of the freshwater inputs to the Hawkesbury River during the gauging exercise. The rainfall event of 7 November and its associated runoff caused an increase in the water level at Castlereagh on 9 November, 2 days after the rainfall event which is a typical response time for large catchments. The residuals at all the other sites in the study area show a good correlation with the ocean residuals (as illustrated by the Sydney Harbour site) indicating the non-tidal water level oscillations are associated with oceanic phenomena including coastal trapped waves and storm surges. Longer period oceanic oscillations associated with El Niño and climate change may also be important for the water level variability in the system.

4.3.3 Wind Setup

Wind blowing across a water surface moves the surface waters in the direction of the wind. As this water approaches a shore it is forced to build up against the shore and this change in water level is known as the wind setup. In an estuary the wind setup essentially causes a water surface slope with lower water level at the upwind shoreline and higher levels near the downwind shoreline. After the wind ceases the surface slope will return to the level position and generally overshoots resulting in oscillations at the scale of the basin. These motions, referred to as the surface seiche, are heavily damped and generally return to the still water position within a few cycles following cessation of strong winds. Given that the fetch lengths are relatively short, wind setup is likely to be negligible in the Mooney Mooney and

Mullet Creeks, but may influence the circulation within the shallow areas of Sandbrook Inlet.

4.3.4 Fresh Water Inputs

The freshwater inputs to the study area during the tidal gauging exercise have been derived for each of the creek's catchments from the rainfall data at Narara and the HSPF model discharge outputs provided by AWT. The freshwater inflow is required for estimating flushing characteristics. The flushing time may be derived from longitudinal salinity data and freshwater inflow averaged over an antecedent period equivalent to the flushing time, generally estimated to be about one week. The freshwater discharge entering the creeks for the week prior to the salinity measurements taken on 16 October, 2001 is listed in Table 4.2. Also listed in the table are the estimates of dry weather flows that are also important for flushing during extended dry periods.

Table 4.2
Estimates of freshwater discharge entering from the catchments prior to salinity measurements on 16 October 2001, and dry weather flows

Catchment	Discharge ML/day	Dry weather discharge
Sandbrook Inlet	25	<0.01
Mullet Creek	14	0.01
Mooney Mooney Creek	43	<0.01

Source: AWT HSPF model results

4.3.5 Tidal Prism

A summary of the velocity measurement results collected on 16 October, 2001 is provided in Table 4.3 and locations of the 4 gauging lines are shown in Figure 4.1.

Table 4.3
Summary of Tidal Gauging Data

	Hawkesbury River at Brooklyn Bridge	Sandbrook Inlet	Mullet Creek	Mooney Mooney Creek
Tidal Range (m)				
Ebb	1.52	1.52	1.51	1.53
Flood	1.66	1.65	1.63	1.68
Maximum Velocity (ms^{-1})				
Ebb	0.96	0.30	0.58	0.78
Flood	0.95	0.26	0.56	0.70
Maximum Discharge ($m^3.s^{-1}$)				
Ebb	4750	150	400	700
Flood	5050	125	400	725
Tidal Prism (m^3x10^6)				
Ebb	70.36	1.42	4.28	9.33
Flood	75.66	2.05	4.41	10.19
Cross-section Area (m^2)	5670	870	1334	1715
Average Depth (m)	9.0	2.8	2.3	3.5
Maximum Depth (m)	20.0	3.8	3.7	5.5
Surface Width (m)	630	310	580	490

Source: MHL (2002)

The tidal range for the particular sampling event is similar at each site. Maximum velocities were recorded in the Hawkesbury River at the Brooklyn Bridge section.

The tidal prism for each flood and ebb sampled indicates the relative distribution of tidal flow from the Hawkesbury River to the three arms, Mooney Mooney Creek, Mullet Creek and the Sandbrook Inlet. Note that the tidal prism entering the study area at the downstream boundary would be the sum of volumes of the four sections (Table 4.3) plus the tidal volume in the main channel of the Hawkesbury River between the Freeway bridge and downstream boundary (12 x 10^6 m^3), giving a total of about 103 million m^3. Hence about 75% of the tidal prism that enters the study area passes straight through to move further up the Hawkesbury River while only about 10%, 4% and 1.5% enter the Mooney Mooney, Mullet and Sandbrook Inlet areas, respectively. The remaining 12% stays within the main channel of the Hawkesbury River between the upstream and downstream boundaries of the study area.

4.3.6 Current Velocities

Current velocity measurements taken during the tidal gauging exercise are shown in Table 4.3 above.

Hydrodynamic modelling of the Brooklyn Estuary predicted that under baseflow conditions the maximum velocities in the Brooklyn Estuary study area were around 1.2 m/s. These maximum velocities occurred in the section of the river between Long Island and Dangar Island. The location of maximum velocities was found to be the same under all flow regimes and with and without the causeway present. The velocities in Sandbrook Inlet ranged from 0.1 m/s at the western end of the inlet and decreased a few orders of magnitude to essentially zero at the eastern end of the inlet (see Table 4.4).

Under 20% AEP peak flow rate conditions the velocities increased, as would be expected and the maximum velocities that occurred under this flow regime were around 2.0 to 2.2 m/s between Long and Dangar Islands. Velocities in Sandbrook Inlet ranged from 0.3 m/s at the western end to zero velocity at the eastern end, similar to the base flow scenario (Table 4.4).

For the majority of the study area, removal of the causeway did not affect the hydrodynamic model results. However, it appeared that the maximum velocities (occurring between Long Island and Dangar Island) were slightly reduced and that the velocities at the eastern end of Sandbrook Inlet were approximately three times greater (0.3 m/s) than those estimated when the causeway was present (Table 4.5). Under flood conditions, the velocities predictably increased over the entire study site and in Sandbrook Inlet without the causeway the flood conditions produced maximum velocities at the eastern end of the inlet of around 0.8 m/s.

Table 4.4
Velocities observed in study area with Base Flows and 20% AEP Peak Flood Flows with railway causeway

Location	Max Velocity (ms^{-1})	
	Base Flow	20% AEP Peak Flood Flow
Between Long and Dangar Islands	1.2	2.2
Sandbrook Inlet (east-west)	<0.1-0.14	<0.1-0.3

Table 4.5
Velocities observed in study area with Base flows and 20% AEP Peak Flood Flows without railway causeway

Location	Max Velocity (ms^{-1})	
	Base Flow	20% AEP Peak Flood Flow
Between Long and Dangar Islands	1.1	2.2
Sandbrook Inlet (east-west)	0.3-0.1	0.55-0.8

4.4 Water Exchange and Flushing

Water exchange or mixing of waters between two locations plays an important role in determining water quality. While currents and general circulation actually lead to mixing and exchange the rate of change of a particular constituent (e.g. salinity or total phosphorus) at a particular location depends on the local sources and sinks as well as physical mixing characteristics.

The concept of flushing time pertains to the rate of physical mixing between two adjacent water bodies and hence will vary in accordance with the volumes of water considered. Flushing times may be derived by a number of techniques that may apply to local or regional scales. In the following discussion flushing times are derived from the numerical model, from salinity measurements and from empirical relationships regarding tidal prisms.

4.4.1 Circulation

Circulation in the study area is affected by the tidal currents, wind-driven flows that also induce turbulent mixing in the surface layers, stratification induced by freshwater inflows and heating/cooling of the water surface and the modification of the flows by topographic effects. The net effect of these influences combined with small scale turbulent mixing is termed ‘flushing’ that results in water exchange between the estuary and the ocean or in this case between the creeks and the Hawkesbury River. The flushing and mixing characteristics may be inferred from the available salinity and freshwater input data.

The temporal variability in salinity during the tidal gauging exercise is presented in Figure 4.8 along with the other physico-chemical variables collected by the instruments located at Kangaroo Point near the entrance to Sandbrook Inlet and in

Mooney Mooney Creek near the Freeway Bridge approximately 13km upstream from the Hawkesbury River.

The 5 week period covers roughly two spring-neap cycles and includes some rainfall events on 7 and 18-20 November, 2001. The salinity at Kangaroo Point shows a typical tidal variability associated with the longitudinal salinity gradient being swept back and forth past the instrument by the tide. Salinity varies between 30 ppt and 35 ppt which is close to ocean water concentrations of 35.3 ppt. Upstream in Mooney Mooney Creek the water is more brackish, between 25 and 30 ppt and shows the influence of longer period variability associated with the spring-neap cycle and fresh water input events.

4.4.2 Model Estimates of Flushing Times

The transport and mixing of a passive tracer was modelled to determine the time required to flush the tracer from particular areas of the system. On average, it took approximately three to five days for the pollutant to be reduced by approximately 95% of the original pollutant concentration from most areas of the model under baseflow conditions. When flood flows were modelled, the flushing time in the main channel dropped accordingly to about 2 days (Table 4.6).

Table 4.6
Model Flushing Times in study area with Baseflows and 20% AEP Peak Flood Flows - with railway causeway

Location	Flushing Time (days)	
	Base Flow	20% AEP Peak Flood Flow
Main Channel	3-5	2-3
Sandbrook Inlet	9	6
Mooney-Mooney Creek	14	14

Table 4.7
Model Flushing Times in study area with Baseflows and 20% AEP Peak Flood Flows - without railway causeway

Location	Flushing Time (days)	
	Base Flow	20% AEP Peak Flood Flow
Main Channel	3-5	2-3
Sandbrook Inlet	3-5	2-3
Mooney-Mooney Creek	14	14

Sandbrook Inlet took around nine days to flush with baseflows entering the system and about five days with flood flows. When the causeway was removed the flushing time in Sandbrook Inlet corresponded with that of the main channel of the estuary. These values for the flushing time of Sandbrook Inlet are significantly longer than the estimates determined empirically in the Brooklyn Waterway Planning Study (PWD, 1988), which calculated the flushing time to be 1.5 days. This earlier value was established using a simple analytical method that calculates the lower limit flushing time and does not consider the flushing efficiency of the water body (PWD, 1988). The results obtained for this study can therefore be considered more reliable due to the comprehensive modelling carried out.

Mooney-Mooney and Mullet Creek took significantly longer to flush pollutants, with Mooney-Mooney Creek taking up to two weeks to flush and Mullet Creek up to eight days. The Mooney Mooney Creek flushing calculations did not incorporate direct freshwater inflows.

Further analysis was conducted to determine the impact oyster leases in Sandbrook Inlet have on the time taken for the estuary to be flushed of pollutants. The modelling results showed that the oyster leases had minimal impact on the time taken to flush the inlet (see Appendix A). The most pronounced impact of the oyster leases on the flushing time was at the eastern end of the inlet, as may be expected, and even in this case there was only a slight increase in the time taken for a pollutant to be removed from that section of the inlet. These findings suggest that the tidal forcing in the inlet is the dominant factor in the mixing rate of the inlet. Contours indicative of flushing are shown as relative flushing in various parts of the estuary (Figures 4.9, 4.10 and 4.11)

Jetties and pontoons showed little effect on overall water movement and flushing. This is as expected because only a small portion of the water column is blocked to flow. Any structures that have blockage to the entire water column result in local reduction in flushing but not to the overall inlet.

4.4.3 Stratification

Stratification plays an important role in estuary mixing processes. Fresh water entering the inlet through the creeks and drains is generally lighter than the ambient estuary water and hence tends to float on the surface. Turbulence in the water column mixes the fresh water with the deeper saline estuary water to form a brackish plume that ultimately becomes indistinguishable from the ambient estuary water. Within the brackish plume, the layering of lighter fresh water over heavier salty water inhibits vertical mixing and hence vertical exchange of water-borne materials.

Stratification is controlled by density which in turn is a function of salinity, temperature and suspended material. In general, estuarine stratification is dominated by salinity, however temperature can play a role at times when rapid cooling or heating affects the waters, particularly during autumn and spring. The water quality profiles collected during the tidal gauging exercise indicate the presence of only weak vertical stratification in Mooney Mooney Creek (Figure 4.12). At fixed locations the vertical stratification appears to change rapidly through the tide and hence the rapid longitudinal mixing will generally preclude the formation of deep water stagnation.

4.4.4 Mixing Plot and Flushing in Mooney Mooney Creek

The mixing characteristics in the estuary are influenced by the topography, tidal flows and freshwater inflows. The freshwater inflows determine the level of density stratification and hence the importance of gravitational circulation. A simple analysis of the topographic variations and tidal flow in Mooney Mooney Creek provides useful insight into the potential mixing and flushing characteristics within the creek. This system is a typical drowned river valley and the depth and cross section area decrease with increasing distance upstream.

The water level data indicate the mean tidal range varies from 1.25 m near the mouth to 1.4 m at the Mooney Mooney bridge (15 km upstream) and decreases to zero at the tidal limit 19.2 km from the mouth. Applying conservation of volume admits an estimate of the depth- and width- averaged velocity at each cross section along the estuary. Multiplying the tidal velocity by the tidal duration (6 hours) provides an estimate of the tidal excursion (Figure 4.13).

Tidal exchange times for different reaches may be estimated by assuming that about $^1/_5$ of the tidal discharge is exchanged over the tidal period. The tidal exchange time may then be estimated as

$$T \sim \frac{\mathrm{V}}{0.2\,\mathrm{Q}}$$

where V is the volume of the reach and Q the tidal discharge. Using this approach the tidal flushing time for the reach between 10 and 15 km upstream is estimated to be about 5 days.

The spring neap cycle (Figure 4.2) also plays a role in the flushing characteristics. The tidal velocity estimates shown in Figure 4.13 assume a tidal range of 1.4 m which is typical of the estuary. Over the spring neap cycle the tidal range varies from around 0.8 m to 1.9 m. During neaps that occur once per fortnight, the flushing is minimal with minimal dispersion and dilution of inputs while during spring tides maximal dispersion and flushing will effectively mix water-borne constituents along the estuary.

The salinity gradient along Mooney Mooney Creek on 16 October, 2001 is shown in Figure 4.14.

The physico-chemical vertical profile data collected on 16 October along Mooney Mooney Creek were depth averaged and are presented as mixing plots in Figure 4.12. The salinity gradient at high (08:13) and low (14:15) water shows the salinity variability along the estuary. In the Hawkesbury River at the mouth of Mooney Mooney Creek the high water salinity was about 34 ppt and low water salinity 30.7 ppt. The decrease in salinity at 13 km upstream at low water indicates the fresh water input from the Piles Creek tributary.

The light attenuation is derived by fitting an exponential curve to the vertical PAR (photosynthetically active radiation) light profile. Low values of light attenuation indicate clear waters while higher values indicate more turbid and hence poor light transmission waters (Figure 4.12). Light attenuation is influenced by contributions of inorganic suspended material (fine clay and sediment) and organic particles such as microalgae. The light attenuation reflects contributions of the microalgae biomass as reflected by high chlorophyll-a and the turbid waters of the system.

The higher chlorophyll-a values upstream indicate the presence of an algal bloom upstream of the Piles Creek confluence (Figure 4.12). This type of response is similar to Berowra Creek where the nutrient input from the catchment lead to a bloom in the mid-upper estuary. The shift in the chlorophyll-a peak from the 24.5 ppt salinity to 26ppt between high (08:13) and low (14:15) water indicates the bloom growth between high and low water led to an increase in chlorophyll-a from 5 µg/L to 11 µg/L in this area.

The density signal is typical of mixing in estuaries that occurs along isopycnals. The small shift between 1017 and 1018 kg m^{-3} indicates the input of light (fresher) Piles Creek water during ebbing tide.

Using the runoff estimates derived from the rainfall and catchment characteristics and the salinity data for 16 October an estimate of the flushing times may be derived using the fresh water fraction method (Officer, 1976). The flushing times are sensitive to the freshwater discharge and two discharge values were used to demonstrate this variability. The flushing time derived using this method (Figure 4.15) varies between about 25 days at 18 km upstream down to about 15 days at 10 km upstream. These estimates are somewhat higher than the tidal estimates but are consistent with the presence of the algal bloom in the upper reaches where longer flushing times prevail.

4.4.5 Particle Tracking

A useful and simple way of determining the transport of waterborne contaminants in a waterway is by tracking the path of discrete particles introduced into the system. It is useful in determining how contaminants may be expected to disperse and in identifying key areas where contaminants can become trapped due to the geography and currents that exist in the area. A version of RMAPLT used the hydrodynamic model developed for the study area to plot the likely paths of pollutants placed in the study area at a number of critical sites. The potential paths of the contaminants were plotted under baseflow and flood conditions, and with and without the causeway.

<u>Freeway Bridge - Tides and Baseflows</u>

Most of the particles placed in the section of river under the Freeway Bridge and around Kangaroo Point were very strongly affected by the main channel tidal currents and therefore, moved with the flood and ebb tidal cycle along the main channel. Some particles placed around Kangaroo Point entered Sandbrook Inlet and tended to circulate on the western side of the inlet, however, if a particle moved further into the inlet it remained around the middle of the inlet and did not tend to move into the main channel. Once in the main channel, particles were observed to come very close to Dangar Island, and they seldom deviated from the main channel (i.e. did not enter the creeks or Sandbrook Inlet). Several particles were observed to enter Cowan Creek, however, this section of the river is outside of the study area so the significance of this has not been determined, but it should be noted.

With the causeway removed, particles that were placed under the freeway bridge and around Kangaroo Point would rapidly move away from the initial position where they were placed. Particles would move through the inlet and took a couple of days to be flushed from the inlet.

Freeway Bridge - Tides and Wet Weather Flows

When the upstream inflows were equivalent to peak flood flows the particles placed in this area were rapidly transported downstream via the main channel (i.e. no particles entered Sandbrook Inlet) and left the study area within a couple of days.

Mooney Mooney Creek - Tides and Baseflows

Particle tracking in Mooney Mooney Creek showed that a pollutant that enters the waterway will move steadily downstream towards the confluence with the Hawkesbury River, gradually moving further downstream on the ebb cycle. However, many particles had a tendency to circulate in the area around Big Bay and not enter the main channel. The incidence of this seems to depend on the distance upstream the contaminant was placed. If the contaminant was originally placed in the centre of the creek close to the confluence, it generally did not appear to get caught in the Big Bay area, however, those particles coming from further upstream tended to more frequently remain in that area. Also once a particle had moved away from that area its transport was dominated by the main channel tidal currents and it did not re-enter that cycle. Particles were also observed to circulate between Cogra Bay and Spectacle Island.

With the causeway removed, it was observed that fewer particles entered the main channel and particles were more likely to circulate around the area between Big Bay, Cogra Bay and the northern side of Spectacle Island. Also, if a particle did enter the main channel it was not initially transported by the tidal currents in the same way as when the causeway was present. Particles tended to remain nearer to the opening of Mooney Mooney and Mullet Creeks and sometimes re-entering Mooney Mooney Creek before becoming fully influenced by the main channel currents.

Mooney Mooney Creek - Tides and Wet Weather Flood Flows

Under flood conditions, particles placed in Mooney Mooney Creek rapidly moved downstream into the main channel and out of the study area. Particles did not remain around the Big Bay area. When the causeway was removed, particles tended to remain circulating around Cogra Bay more so than when the causeway was present before being carried downstream by the fluvial flows. Particles also appeared to get caught where the creek bent toward a north-easterly direction. In the scenario where the causeway was removed, some particles moved downstream via the inlet, however, movement of the particles through the inlet was very fast.

Sandbrook Inlet - Tides & Baseflows

Particles that were initially placed in Sandbrook Inlet tended to remain in the inlet and their movement was more restricted depending on where they were initially placed. Particles near the mouth of the inlet and on the northern side were the most mobile and generally moved out of the inlet within the tidal cycle. Particles on the southern side of the inlet tended to remain in a trajectory defined by the tidal currents but remained fairly stationary. Particles placed at the eastern end of the inlet did not move far from their original position. Once a particle left the inlet it followed a pattern observed under other scenarios and tended to not deviate from the main channel of the study area.

Removal of the causeway meant that the maximum time a particle remained in the inlet was approximately ten days. Once particles had left the inlet they did not tend to return to the inlet either through the northern or eastern entrance of the inlet.

Sandbrook Inlet - Tides & Wet Weather Flood Flows

With flood flows entering the system, particles placed within Sandbrook Inlet all left the inlet except for those placed at the very eastern end of the inlet which appeared to be unaffected by the variation in inflow. Particles tended to move beyond the inlet at a much more rapid rate than under baseflow conditions and moved downstream and out of the study area as witnessed in other scenarios. With removal of the causeway, particles all moved downstream and out of the inlet within a period of hours.

Dangar Island

As Dangar Island is situated in the middle of the main channel, particles initially placed at almost any site around the study area were observed to come into very close range with Dangar Island. Therefore pollutant sources observed at Dangar Island may have originated at many places in the study area as well as outside (either upstream or downstream) of the study area.

4.5 Sedimentation of Navigation Channels

The sedimentation of navigation channels is determined primarily by the available sediments in the water column and water velocities. Suspended sediments have a settling velocity being the rate of settling through the water column. Water velocities apply a shear on bed sediments and a turbulence that keep sediments in suspension. As such, the sedimentation rate of a navigation channel is determined by the water velocities through the channel, the sediment content in the water column and the source of sediments provided to the water column.

A conceptual sediment budget for the study region comprises:

External Sediment Sources
- Hawkesbury River sediment loads
- Local catchment runoff from creeks and land based runoff
- High rate of sediment delivery during flood events

Suspended Sediment Transport
- Advection with tidal currents
- Fall velocities of sediments
- Particles settling to the bed on slack water of the tide
- Larger sands have a faster fall velocity than fine mud

Sediment Mobility
- Particles being re-entrained by tidal velocities
- Wind wave mixing and stirring in shallow water
- Mobilisation through bottom stirring by vessels
- Flood waters increase velocities in main channels causing potential scour
- Larger sands require greater shear to resuspend than fine mud

During Dry Periods of Tidal Action Alone

The Hawkesbury River is a major source of fine sediments (mud) to the study area. Based upon an ebb tide discharge of 70×10^6 m^3 of water passing under the freeway bridge with a sediment content of only 1mg/L (conservative estimate), this equates to 70 tonnes of sediment passing through on each tide. The amount of sediment load from the Hawkesbury River has changed from natural conditions due to urbanisation as discussed in Section 3.9.

The majority of this suspended sediment travels through the study domain on each tidal cycle. However, when suspended sediment enters less flushed parts of the estuary on the flood tides, there is likely to be some depositing and trapping of sediments. This is supported by the coring of sediments that found a thin layer of fine mud overlaying coarser materials in these locations.

During Wet Weather Periods and Flood Flows

During wet weather, local water sources such as creeks and direct catchment runoff deliver a sediment load directly to the study area. If the flows are great enough, sediment will be transported into the main channels and out of the study domain. However, in areas where flows are low (and therefore bottom shear stress is low), this sediment is likely to accumulate and result in accretion.

Changes to catchment land use will result in greater sediment delivery and subsequently greater accretion. Table 3.8 lists the maximum annual suspended sediment load predicted from the combined Brooklyn, Mooney Mooney Creek and Mullet Creek sub-catchments as 240 tonnes. This is significantly less than the amount passing through the study domain annually, however the delivery location may have a greater impact on the sedimentation of navigation channels.

During wet weather events, the waters from the Hawkesbury River will increase the turbidity in all areas of the estuary including the less flushed regions. It is likely that some of the suspended sediment in these waters will settle onto the bed before these areas are fully flushed.

Variations in Sedimentation Rates

The sedimentation of an area cannot be considered linear with time. Years with above annual rainfall are likely to have greater sedimentation rates. After bushfires or large construction on a catchment, there will be a significant increase in the sediment delivered to the water body.

The hydrodynamics of an estuary or inlet will ensure that the sedimentation reaches some equilibrium. As the channel becomes shallower due to accretion, the shear velocities on the bed become greater resulting in lesser material remaining on the bed. If areas become very shallow, wind wave mixing will ensure that sediments are resuspended. In addition, channels used regularly for navigation will experience a degree of bed stirring due to propeller wash.

It is expected that a channel dredged to a deeper depth will (at first) accrete at a faster rate than a channel dredged to a more shallow depth.

Given the sediment loads to the system, it can be expected that dredging will be required into the future to maintain navigability.

Navigation Channels in the Study Domain

Specific navigation channels with sedimentation issues in the study domain include:
- The channel into Brooklyn Harbour
- The channel about Spectacle Island
- The channel into Sandbrook Inlet

In addition, dredging is often required about marinas to maintain depth for navigability. As marinas are located in naturally protected areas, they are also in locations more susceptible than the main channels for accretion.

Estimation of Sedimentation Rates

There have been no direct measurements of sedimentation rates and a precise history of dredging has been unable to be obtained.

A dredging history to 1986 was presented in the Brooklyn Waterways Planning Study (PWD, 1988). This concluded that sedimentation rates were in the order of 20mm/year in the main navigation channel of Sandbrook Inlet, with minimal accretion in the eastern end of the inlet. The minimal accretion in the eastern end is due to an equilibrium being reached. Accretion is likely in the direct vicinity of Seymours Creek and Salt Pan Creek due to direct sediment loading from the catchment. However, this is likely to fluctuate with varying discharge. It is likely that the loads from these creeks increased during the construction of the Sydney-Newcastle expressway but is also likely to have now reduced from that time.

The dredging history of Brooklyn Harbour would indicate that sedimentation rates are in the order of 30-130mm/year with an average of 80mm/year (PWD, 1988). Between 1968 and 1986, a total of 25000m^3 of bed material was removed from the Brooklyn Harbour area (PWD, 1988). This is comparable with the 80mm/year estimated.

No information on sedimentation of other channels was available. Sedimentation of the main estuary of the study area was provided in Section 3.5.2 but unfortunately these surveys did not extend into the areas concerned with dredging.

The sedimentation rates will vary significantly from the main channels to specific areas within the study domain. Siltation traps may be able to stop some sediment catchment loads, however they will not stop the sedimentation of these channels completely.

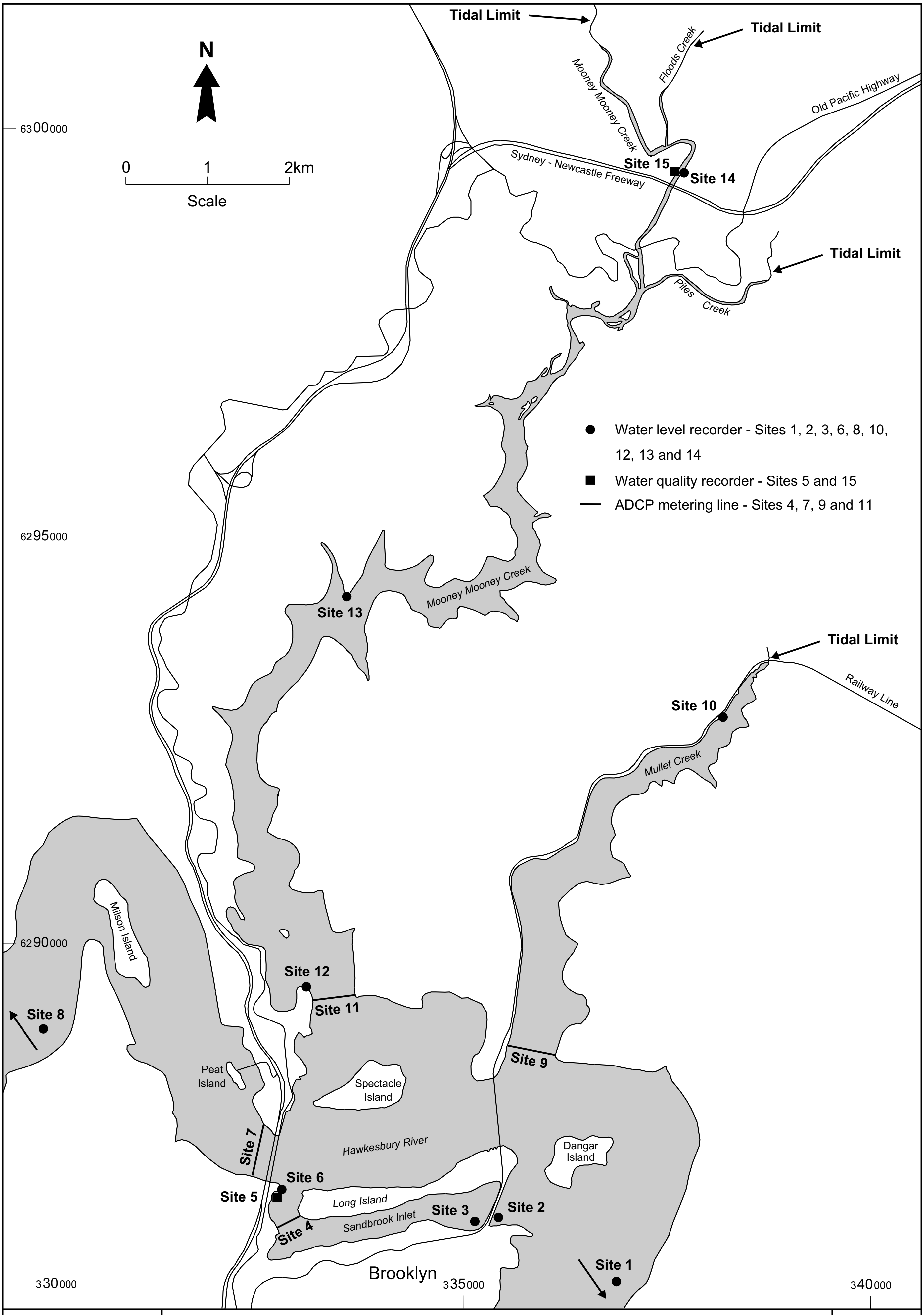
Sections 4.4 (flushing) and 6.7 (ecology) discuss the benefits of opening or partially opening the causeway. Special consideration must be made of the effects of the increased velocities through the eastern end of Sandbrook Inlet on the sediments in the area. It is likely that areas of the bed at the eastern end would be eroded as the current equilibrium between velocities and sediment settling would be changed. Further specific study would be required as to where that sediment mass may be deposited or whether it would be transported out of the inlet.

A recommendation of the Healthy Rivers Commission (1998) was that dredging should be undertaken to maintain access to existing navigation channels to existing channel depths, in order to maintain waterway use. Prior to any dredging works the potential for acid sulphate soils should be examined. Historically observed sedimentation rates are likely to remain unchanged unless changes occur to flow regimes or changes occur to influence catchment loads. Given the sediment loads to the system, it can be expected that dredging will be required into the future to maintain navigability.

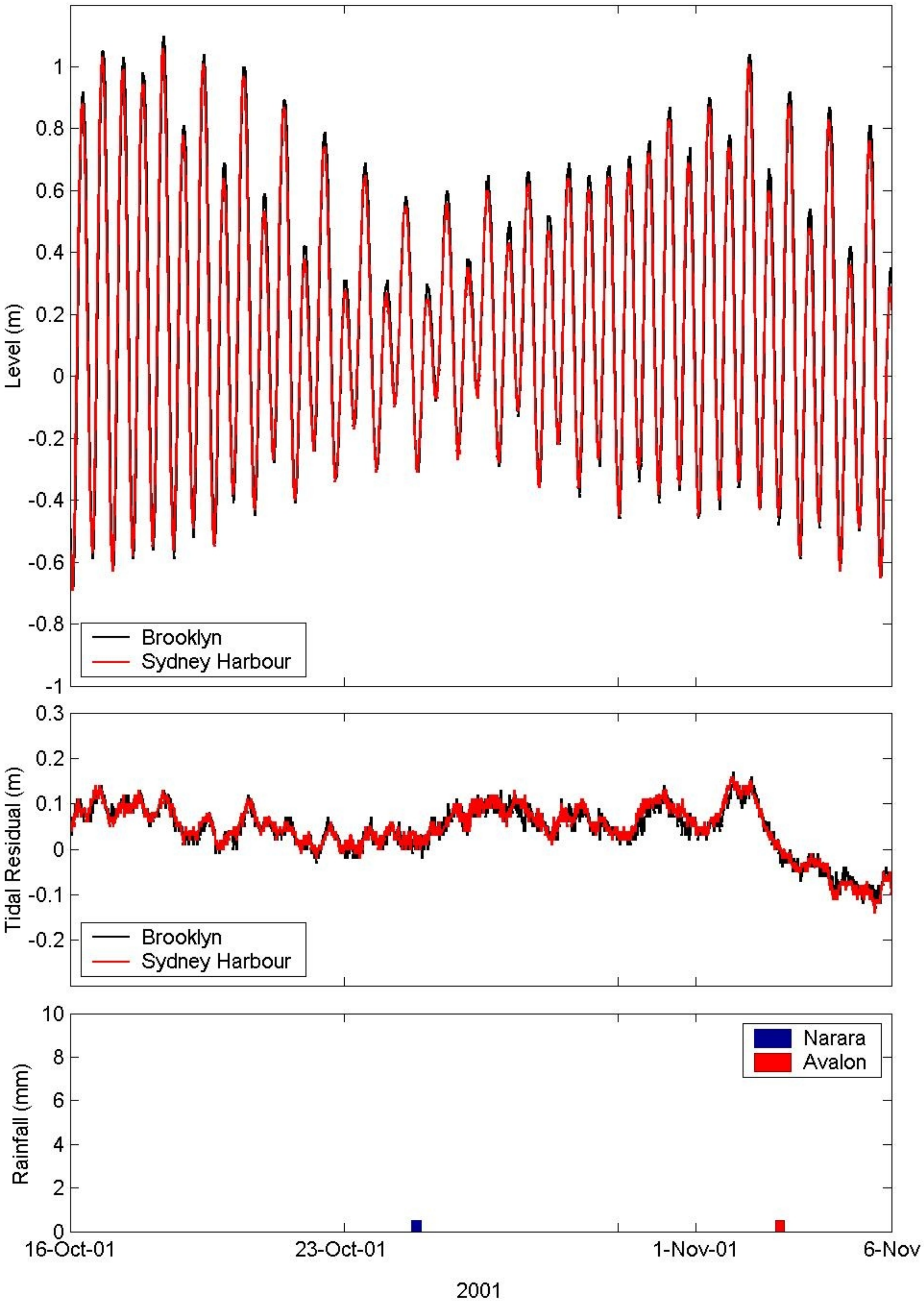
4.6 Summary

Water circulation within the study area is predominantly determined by the tides, sporadic flood events and more subtle density driven currents during periods following floods and low freshwater inflow. Existing data have been collected largely in the main channels and generally lead to the view of a well flushed system. The data collection and numerical hydrodynamic modelling carried out for this study indicate that while the main channels are well flushed, the upstream extremities of the waterway area are generally not well flushed and there are indications of water quality issues.

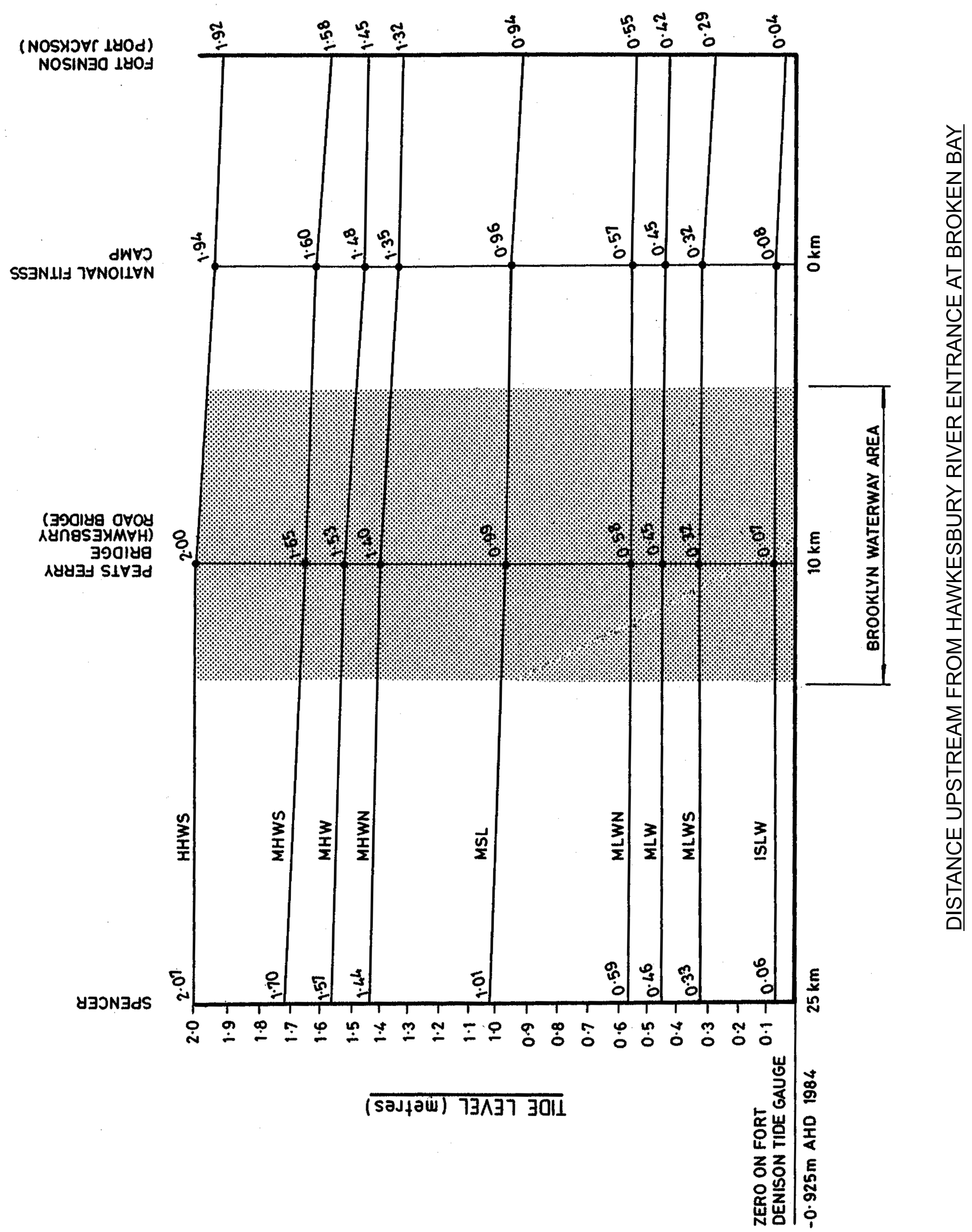
The major source of nutrients to the study area is via the Upper Hawkesbury River but local sources are not insignificant when they enter the upper reaches.



WRL Report No. 2002/20	WATER LEVEL AND TRANSECT LOCATIONS	Figure 4.1 00758-04-01.cdr



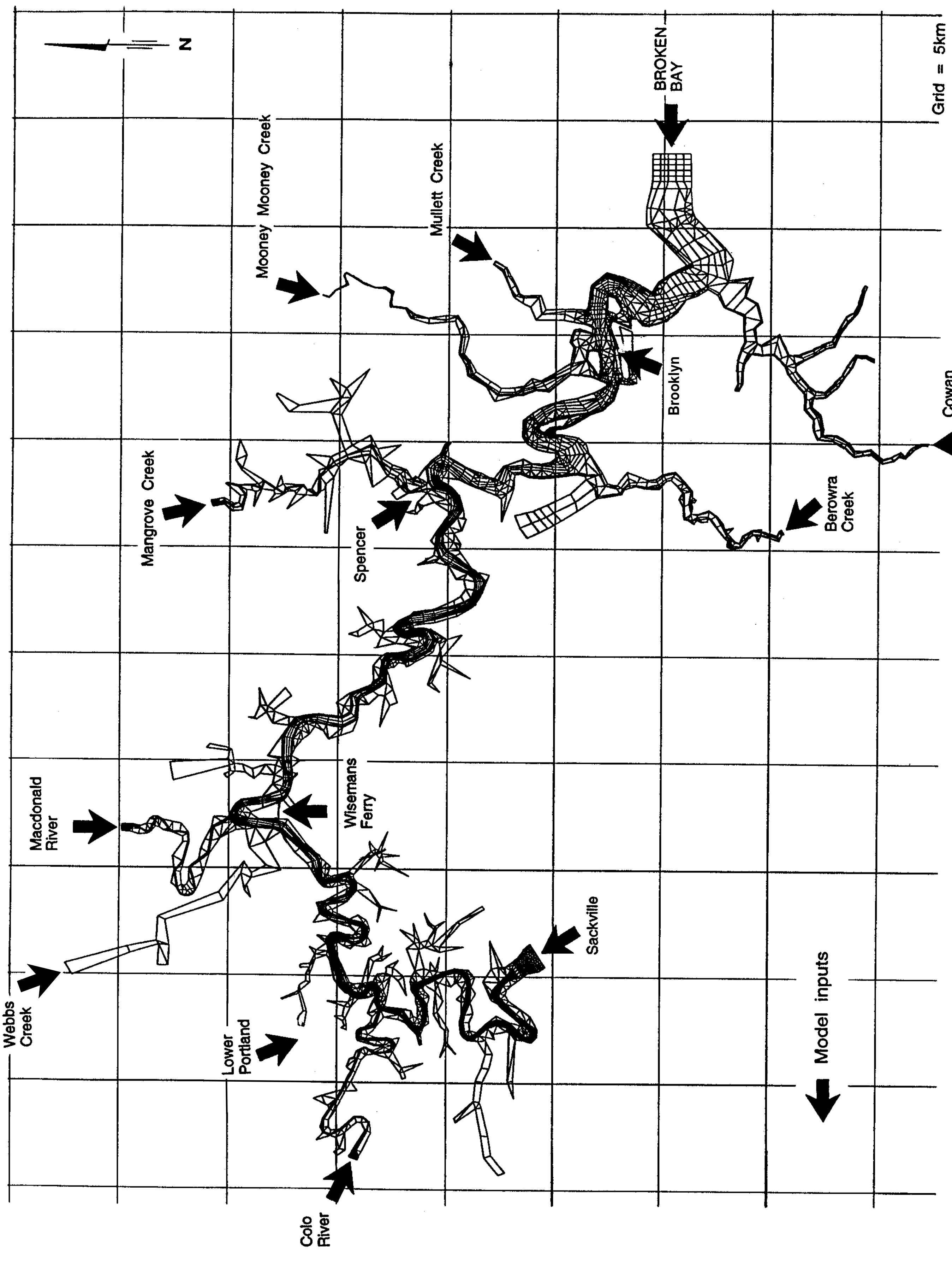
WRL Report No. 2002/20	WATER LEVELS AT BROOKLYN AND SYDNEY HARBOUR	Figure 4.2 00758-04-02.cdr



Source: PDW (1988)

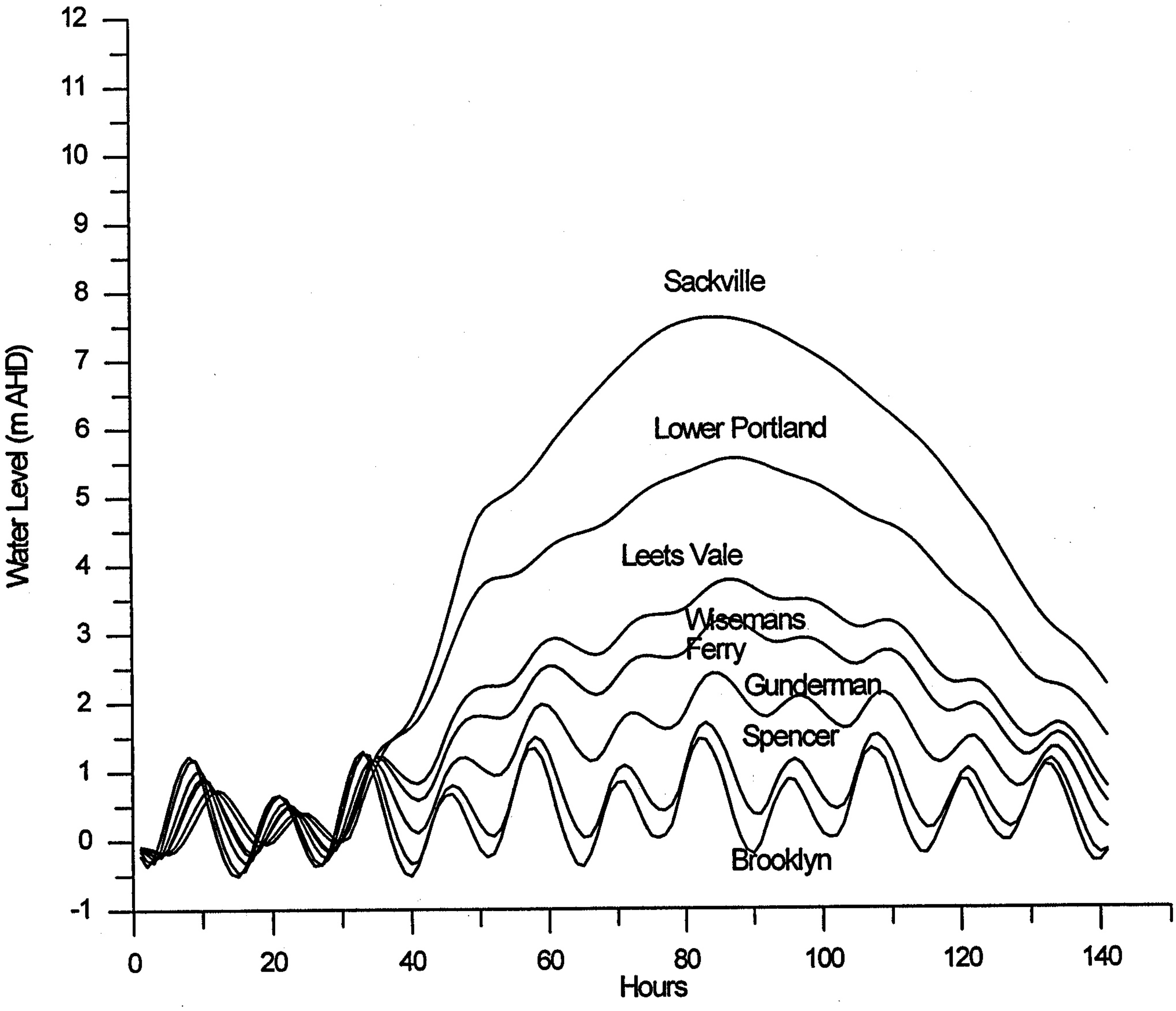
WRL Report No. 2002/20	BROOKLYN WATERWAY TIDAL GRADIENTS	Figure 4.3

00758-04-03.cdr



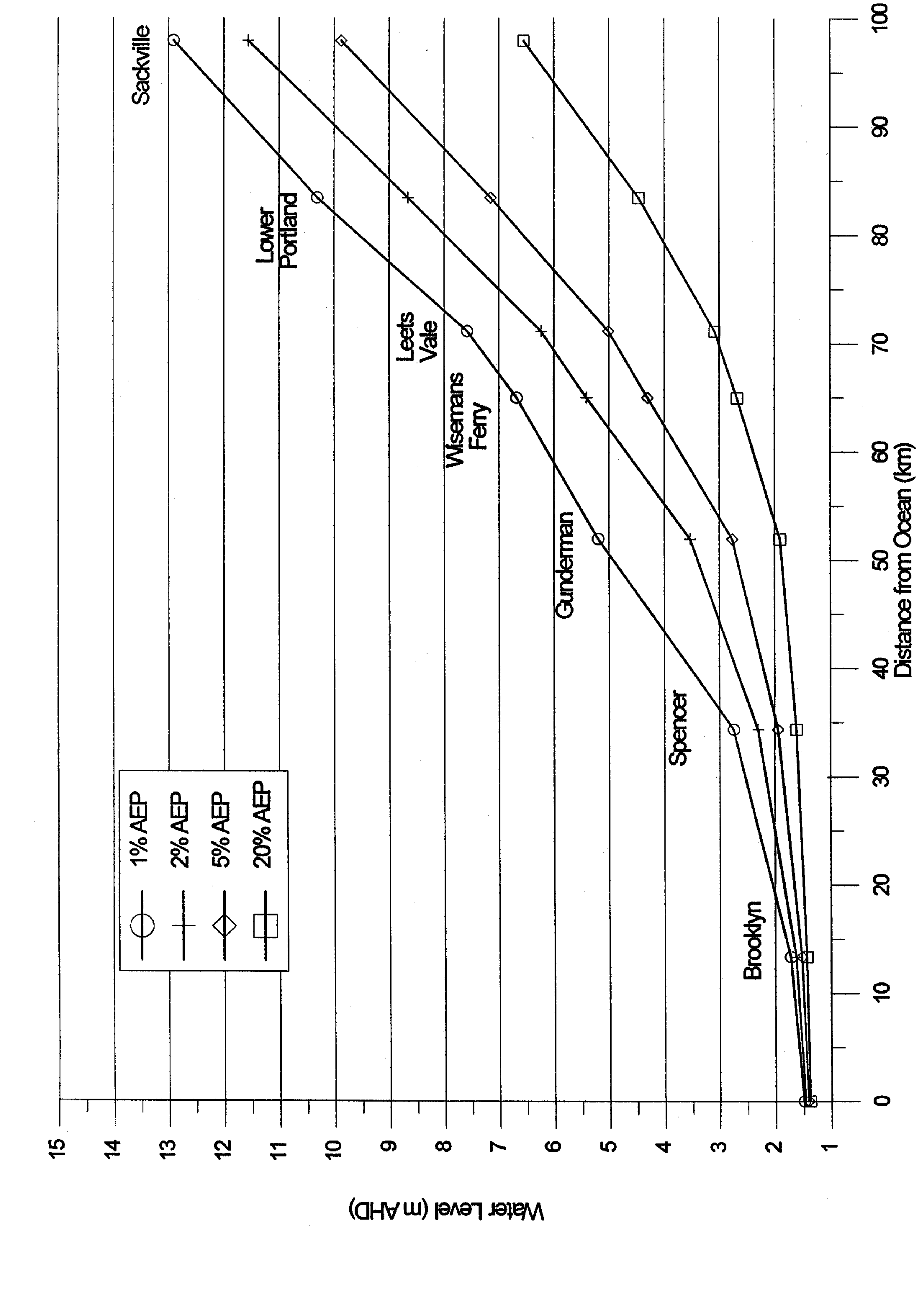
Source: AWACS (1997)

WRL Report No. 2002/20	LOWER HAWKESBURY RIVER FLOOD STUDY: HYDRAULIC MODEL SCHEMATISATION	Figure 4.4 00758-04-04.cdr



Source: AWACS (1997)

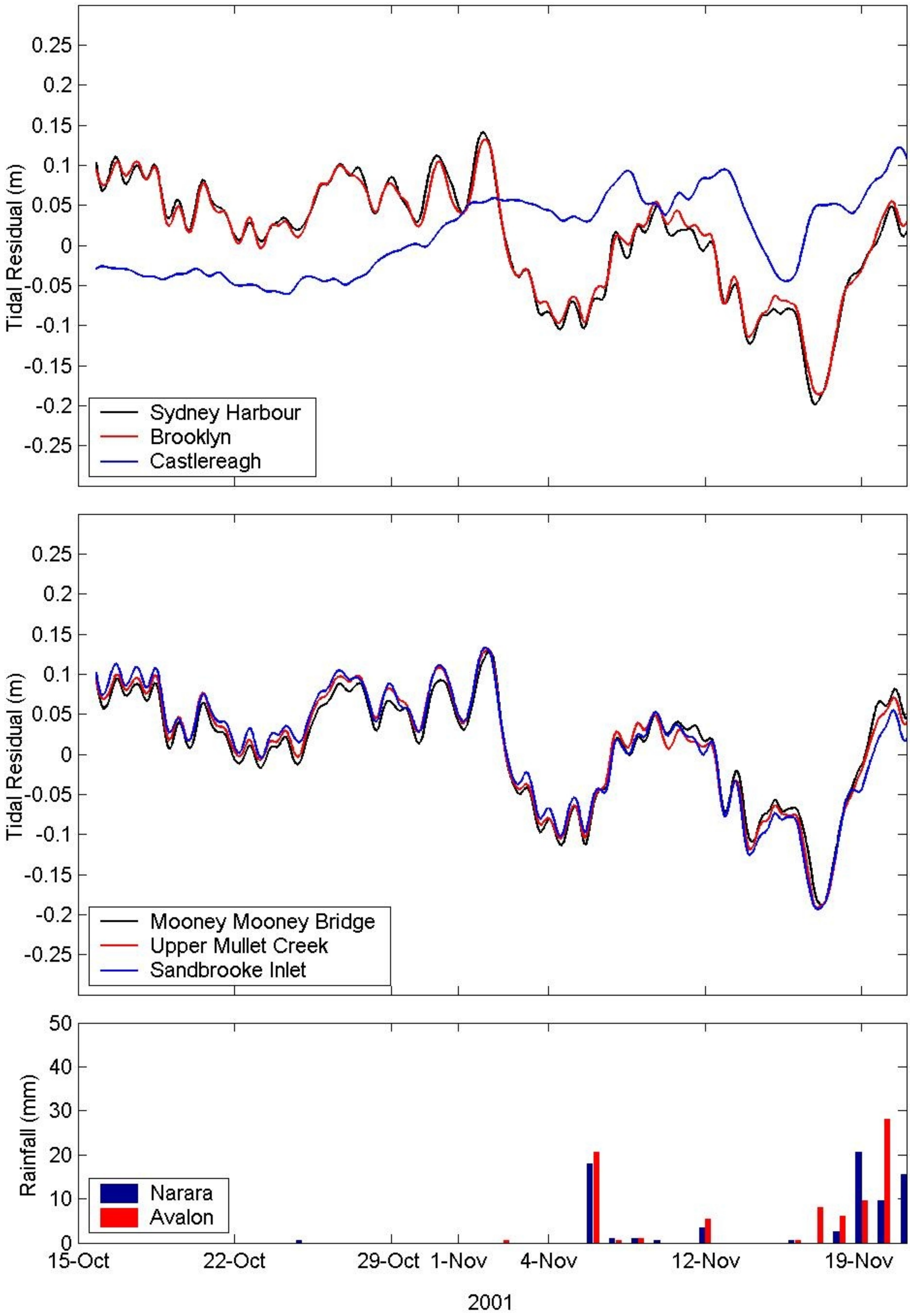
WRL Report No. 2002/20	20% AEP DESIGN STAGE HYDROGRAPH	Figure 4.5 00758-04-05.cdr



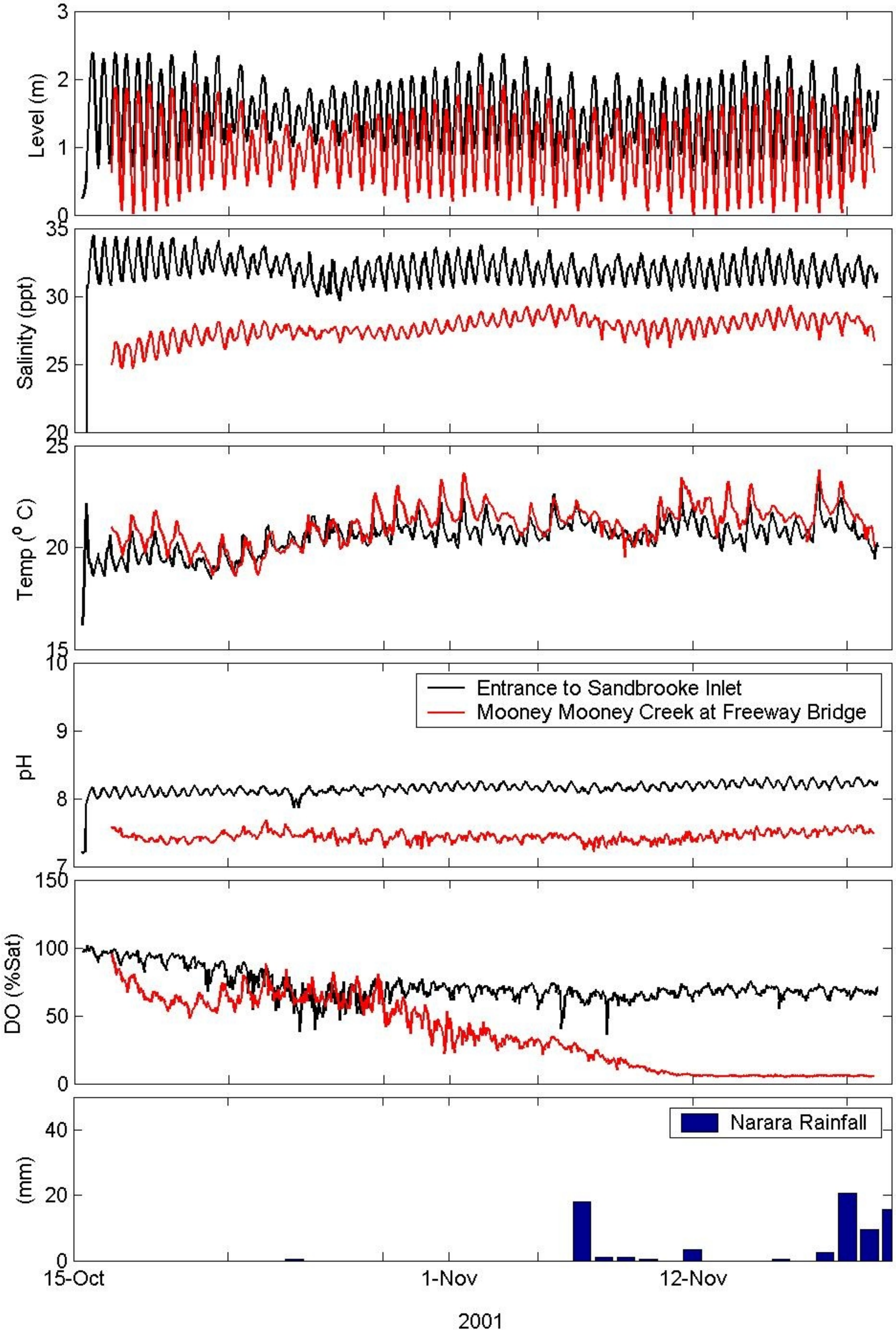
Source: AWACS (1997)

WRL Report No. 2002/20	DESIGN FLOOD PROFILES	Figure 4.6

00758-04-06.cdr



WRL Report No. 2002/20	TIDAL RESIDUALS AT OCEAN AND ESTUARY SITES AND RAINFALL AT NARARA AND AVALON	Figure 4.7 00758-04-07.cdr



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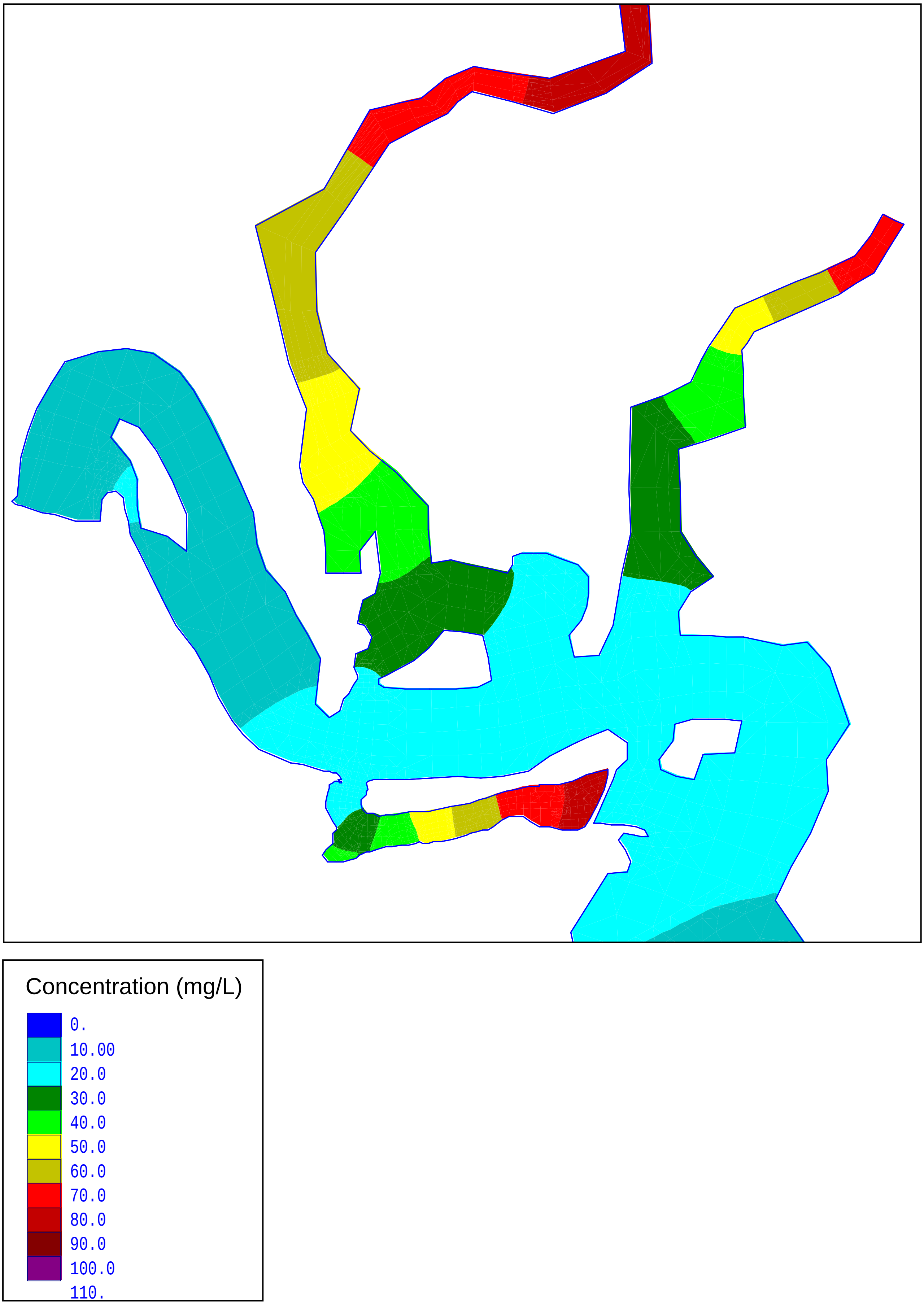
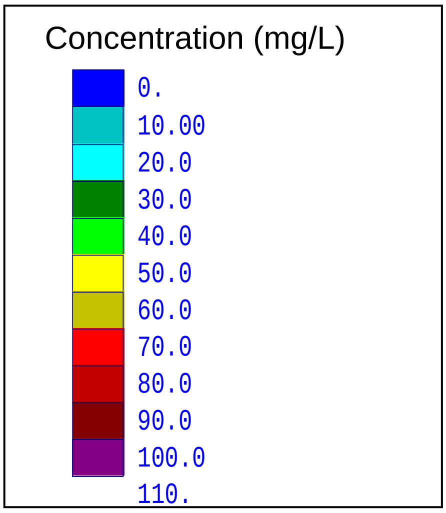
TEMPORAL VARIABILITY IN WATER QUALITY VARIABLES IN SANDBROOK INLET AND MOONEY MOONEY CREEK AND RAINFALL AT NARARA

Figure 4.8

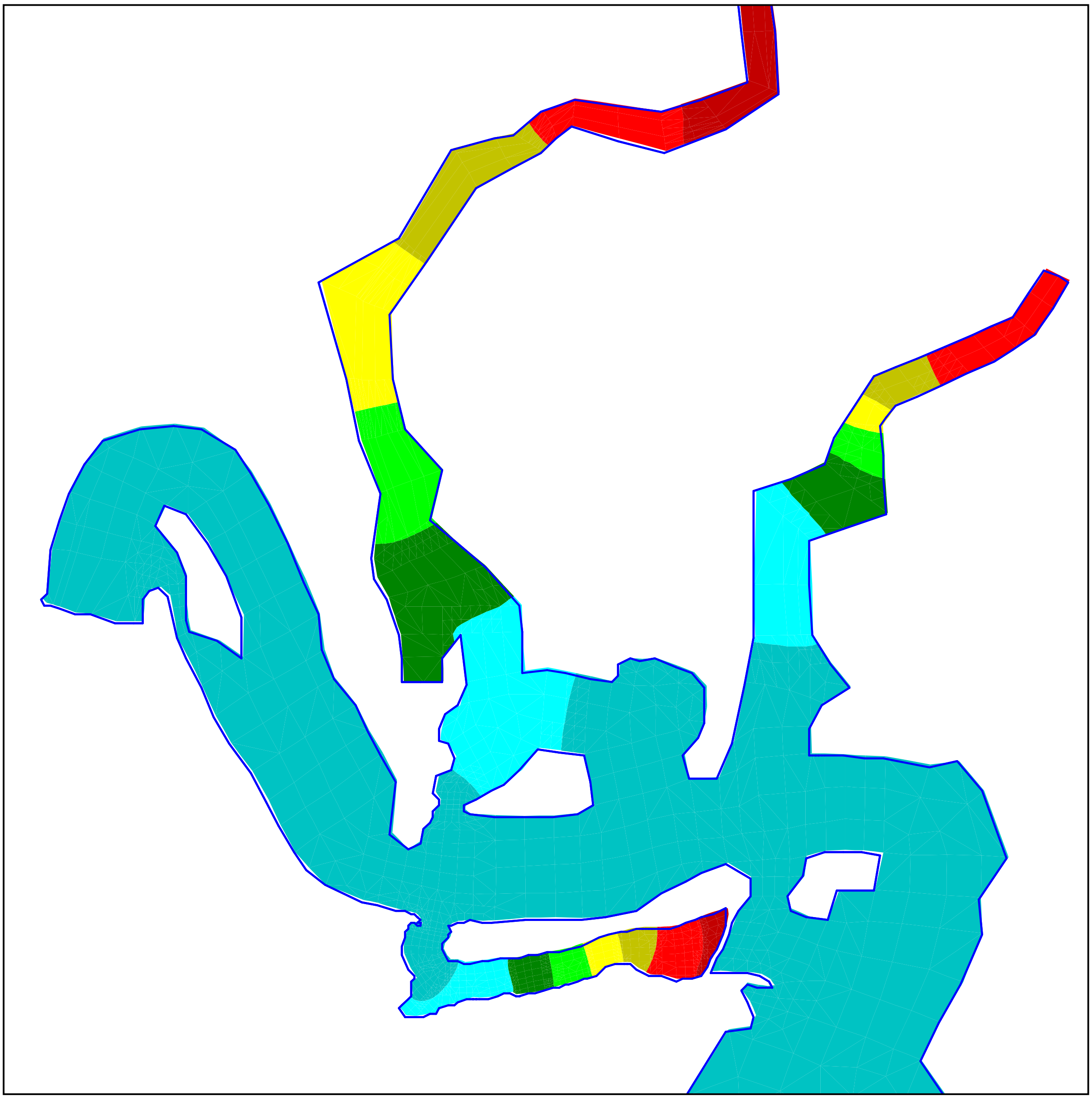
00758-04-08.cdr

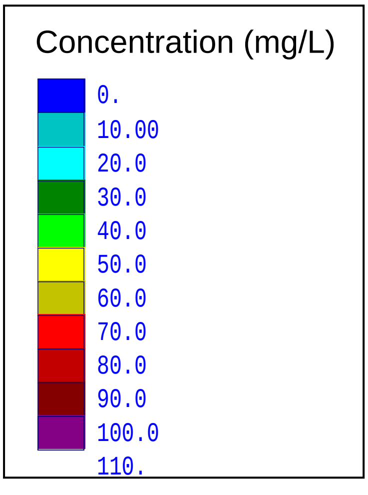


WRL Report No. 2002/20	CONTOURS INDICATIVE OF FLUSHING EXISTING CONDITIONS	Figure 4.9 f00758-04-09.doc



WRL Report No. 2002/20	CONTOURS INDICATIVE OF FLUSHING RAILWAY CAUSEWAY REMOVED	Figure 4.10
		00758-04-10.doc





WRL Report No. 2002/20	CONTOURS INDICATIVE OF FLUSHING WET WEATHER FLOWS	Figure 4.11
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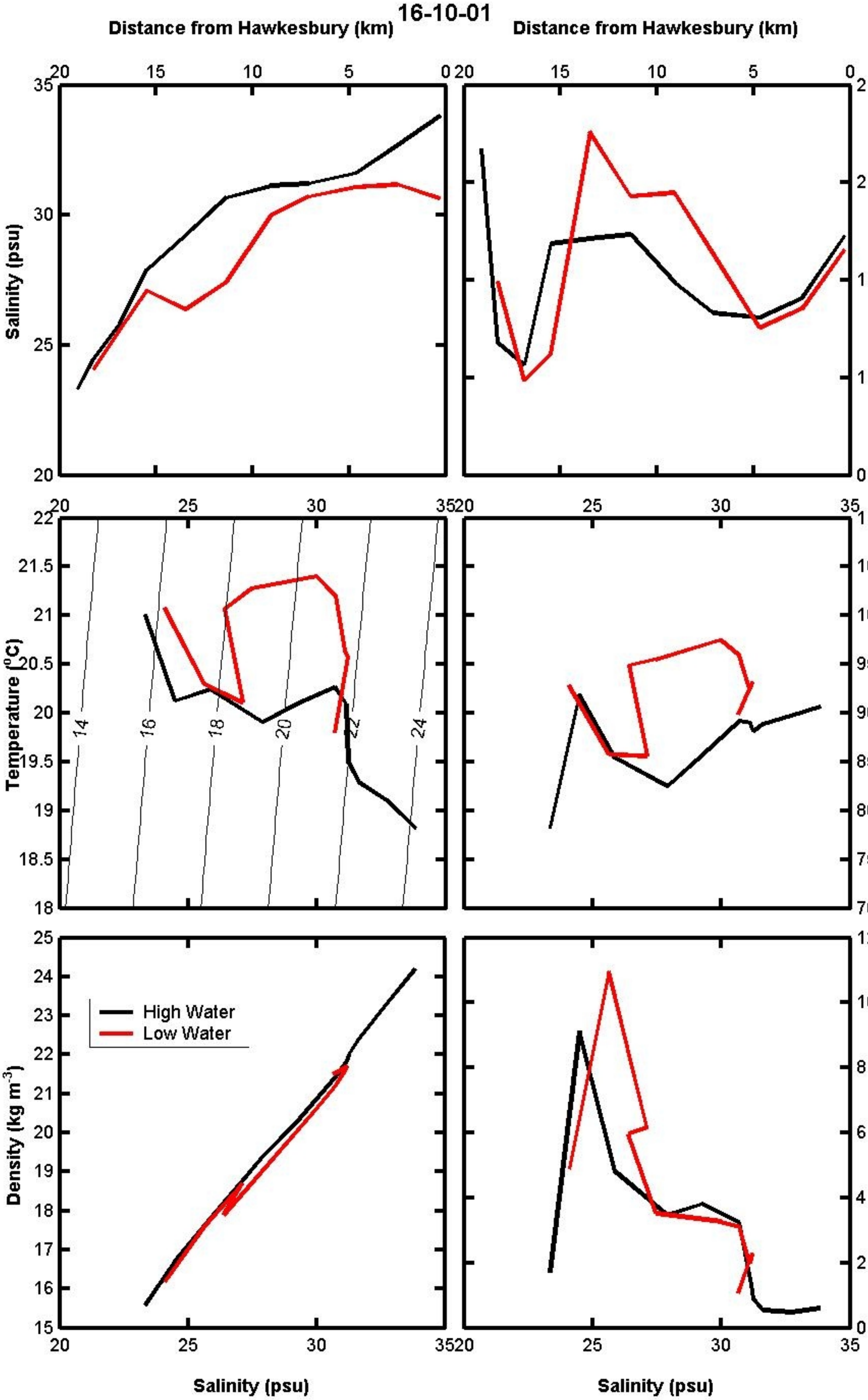
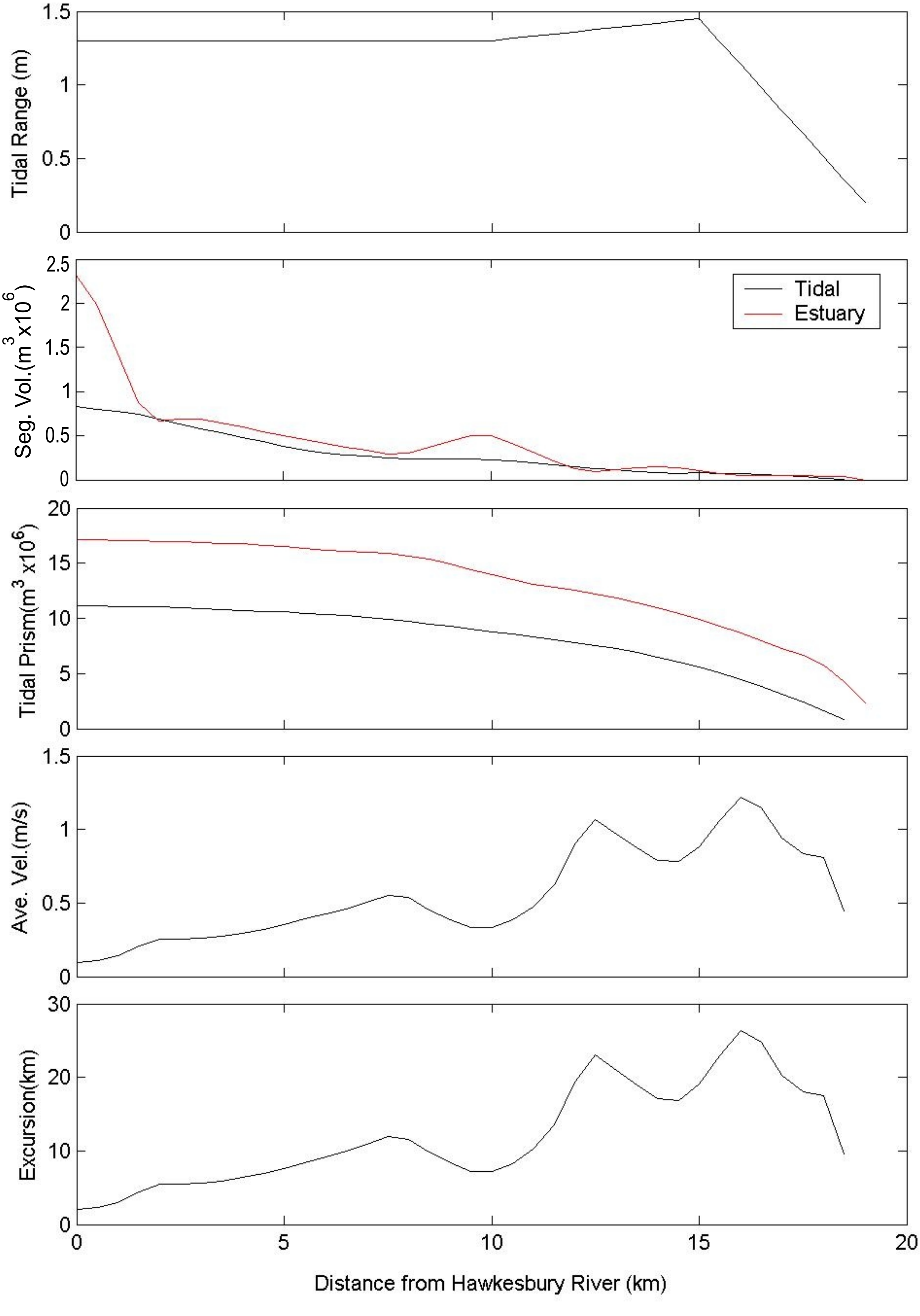
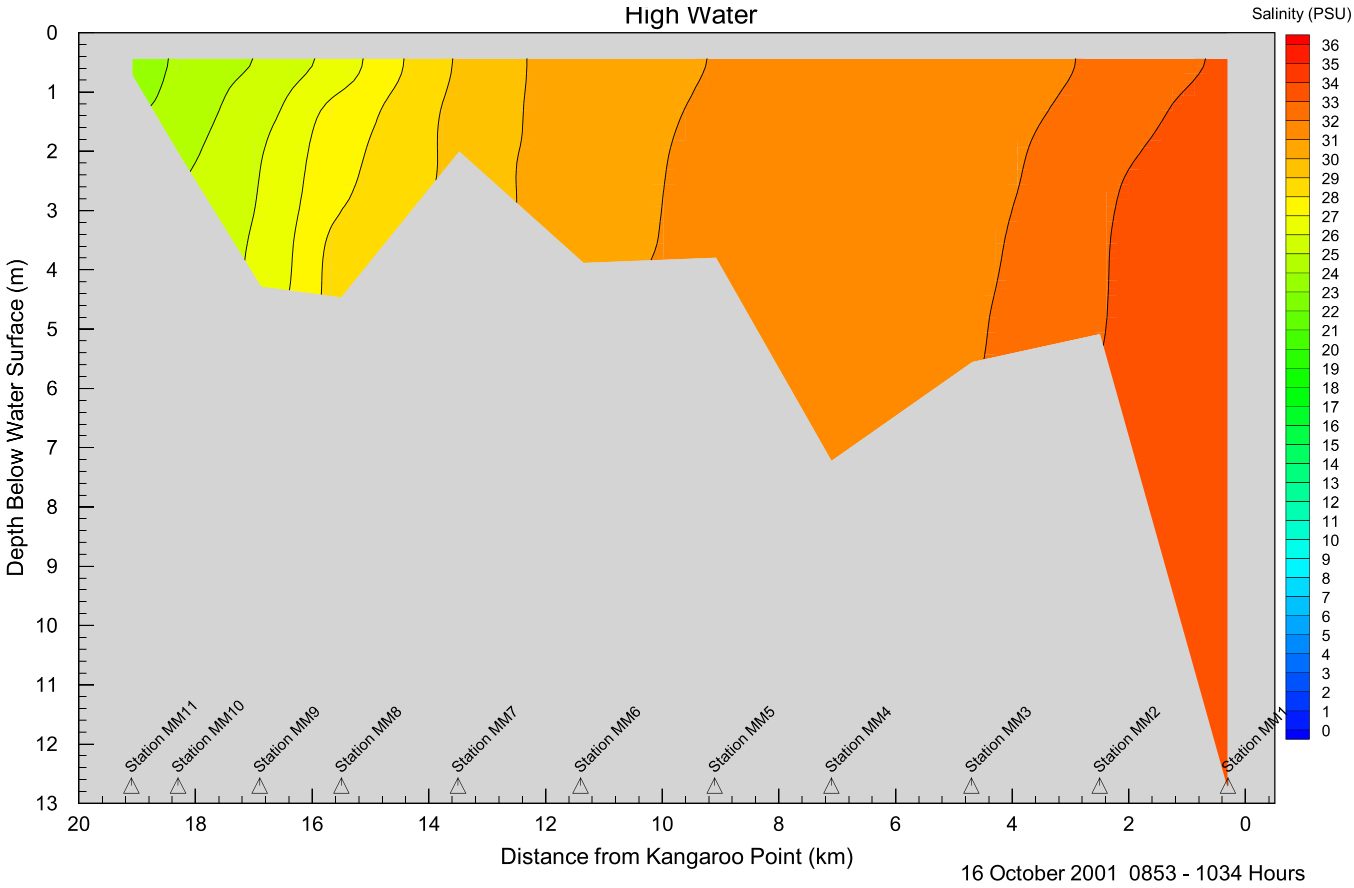


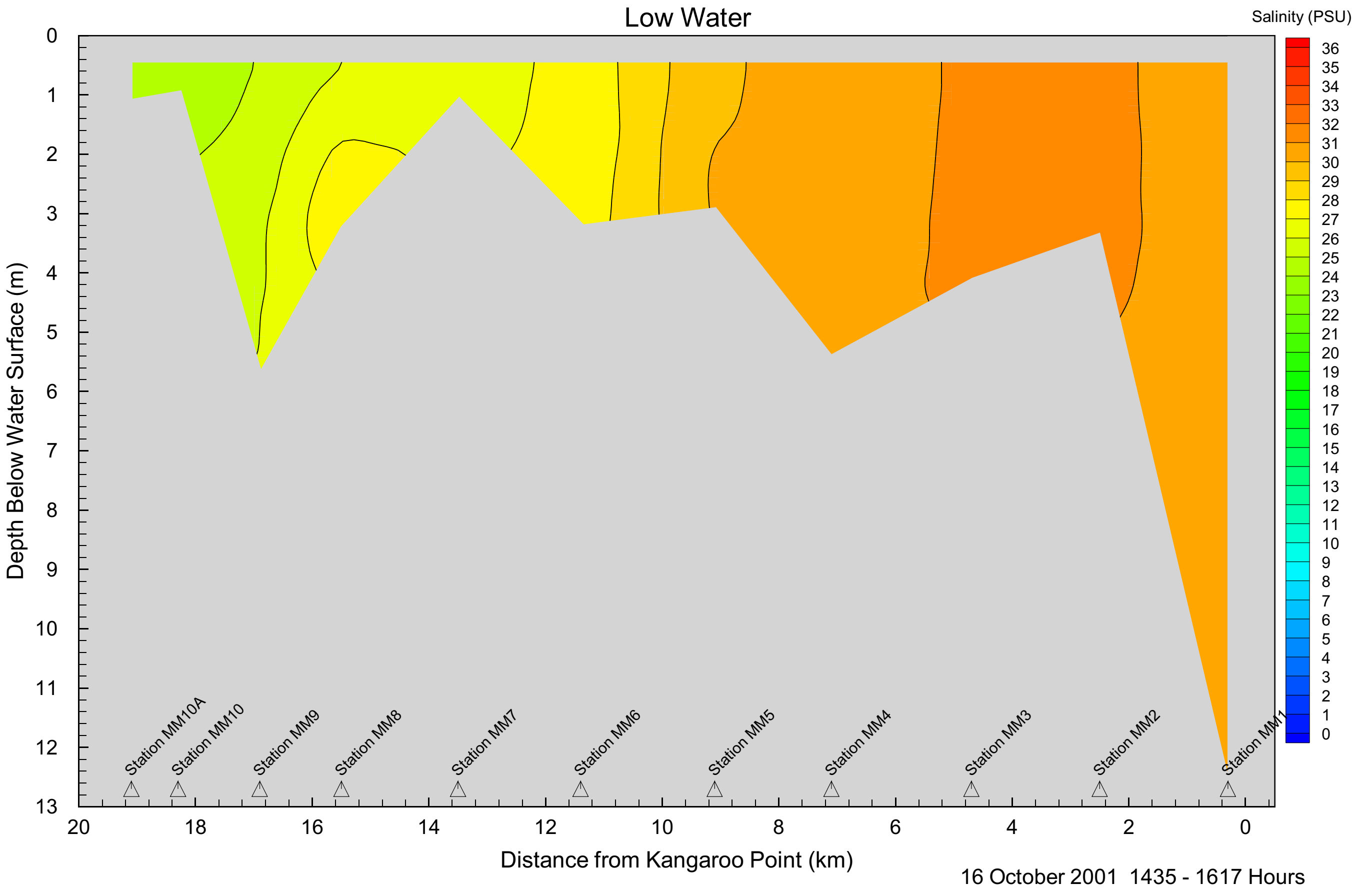
WRL Report No. 2002/20	VERTICAL PROFILES IN MOONEY MOONEY CREEK	Figure 4.12

00758-04-12.cdr



WRL Report No. 2002/20	SPATIAL VARIABILITY ALONG MOONEY MOONEY CREEK	Figure 4.13 00758-04-13.cdr

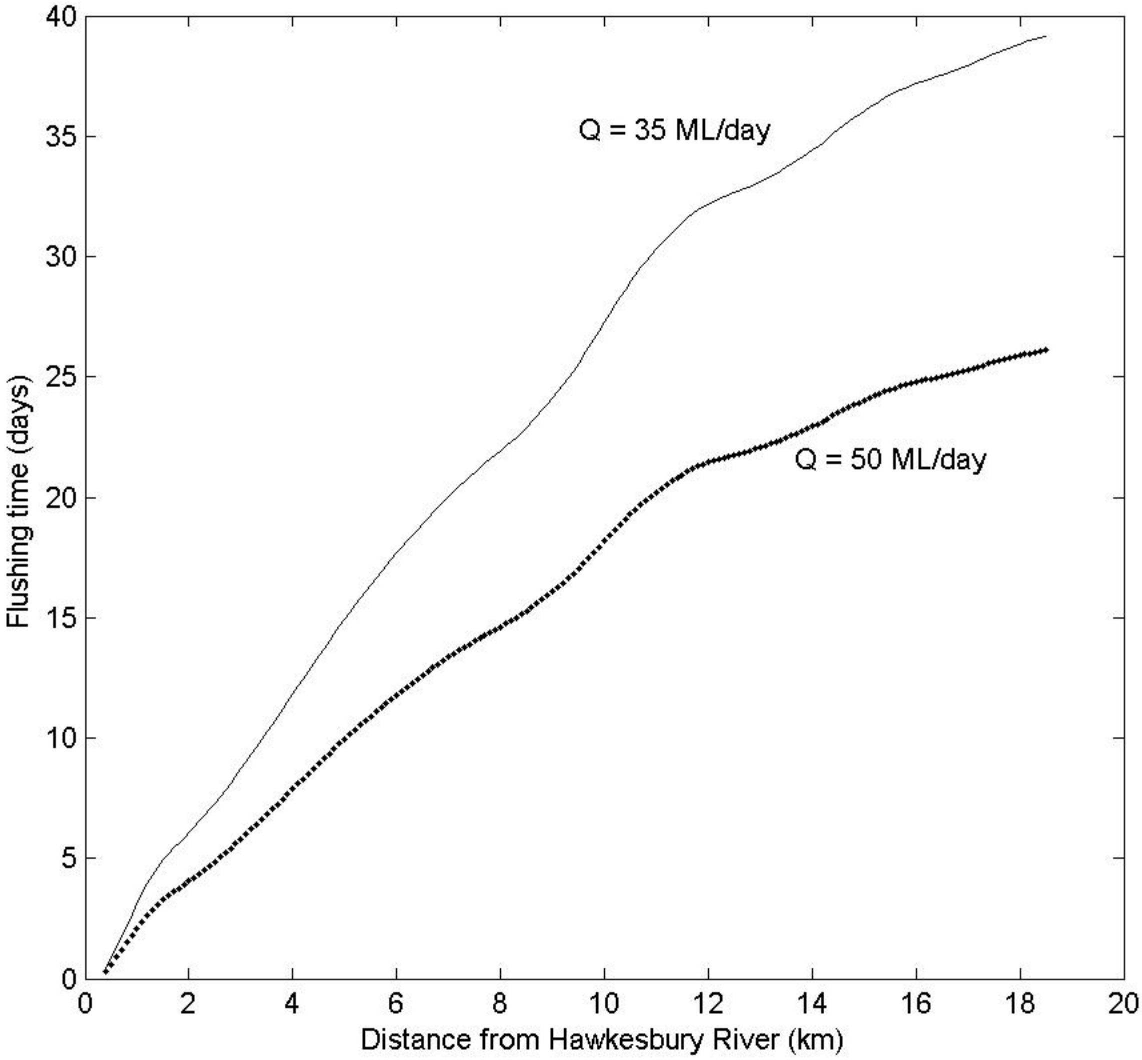




Source: MHL (2002)

WRL Report No. 2002/20	SALINITY GRADIENT ALONG MOONEY MOONEY CREEK	Figure 4.14

00758-04-14.cdr



WRL Report No. 2002/20	FLUSHING TIMES IN MOONEY MOONEY CREEK WITH VARYING FRESHWATER DISCHARGE (Q)	Figure 4.15 00758-04-15.cdr

5. Water and Sediment Quality

Water and sediment quality provides quantifiable criteria to determine the health of an estuary. Within this chapter water and sediment quality data from previous studies and collected as an additional component of this study are presented. This data is then compared with water and sediment quality guidelines. The chapter concludes with an investigation on the microbiological influences and other additional factors affecting water quality.

5.1 Water Quality Data

5.1.1 Review of Literature

The Brooklyn Estuary study area lies in the lower Hawkesbury River and its water quality is influenced by activities and processes occurring upstream in the Hawkesbury-Nepean as well as by oceanic influences. The influence of the Hawkesbury-Nepean catchment is particularly strong during wet weather as flood flows act as a large source of nutrients and sediment, while oceanic inputs are most important to the system during dry weather. Water supply dams in the upper reaches of the river and a number of sewage treatment plants (STPs) throughout the catchment have altered flows in the Hawkesbury-Nepean. The STPs represent a constant source of freshwater and nutrients and the West Hornsby and Hornsby Heights STPs that discharge into Berowra Creek immediately upstream of the study area (MHL, 1998) may affect downstream water quality and flows, especially during dry weather. There is a small STP on Peat Island immediately upstream of the road bridges that dates from the mid-1960s and existing effluent discharged is considered to be unsatisfactory (Ellis, Karm & Associates, 2002) (see Section 3.6.2).

The Environment Protection Authority (EPA) has published reports on water quality monitoring between 1990 and 1996 for the Hawkesbury-Nepean River System including sites within the present study area and immediately upstream (EPA, 1994; 1997). The data presented in these reports provides some information on the level of upstream river pollution that is contributing to the study area. Summarising results for the whole river system, it was found that phosphorus and nitrogen levels were high and exceeded ANZECC (1992) guidelines for the majority of the sites, while chlorophyll-a levels often exceeded guideline levels in the section of the river between Penrith and Wisemans Ferry. Surface and bottom measurements of temperature, pH and dissolved oxygen suggested that the water is well mixed at least to a depth of 10 metres. Faecal coliform levels exceeded guidelines for recreational use frequently at many sites in the mainstream and tributaries of the river. Despite these results it was concluded that a number of key water pollution trends in the river have been reversed since the introduction of the 1985 Hawkesbury-Nepean water quality management strategy (EPA, 1994).

The overall contribution of nutrients from the upstream Hawkesbury River can be estimated using data collected by the EPA (EPA, 1994). Mean freshwater discharge values from gauging stations at Yarramundi Bridge, South Creek, Eastern Creek and Cattai Creek have been summed to estimate a total low flow discharge into the study area of 296 ML/day. Median nutrient concentrations for sampling occasions at Bar Point, just upstream of study area, and Flat Rock Point (Figure 5.1), at the downstream end of the study area, have been multiplied by the calculated discharge to give nutrient load estimates. Table 5.1 provides the results from these calculations.

Table 5.1
Nutrient Loads from the Hawkesbury River

Sampling Site	Total Nitrogen		Total Phosphorus	
	Concentration (mg/L) *	Load (kg/day) #	Concentration (mg/L) *	Load (kg/day) #
Bar Point	0.64	189.4	0.025	7.4
Flat Rock Point	0.35	106.3	0.025	7.4

* from EPA, 1994
# assumes a low flow discharge of 296 ML/day (see text)

The significantly higher levels of total nitrogen at Bar Point compared to Flat Rock Point indicate that the study area may be acting in some way as a nitrogen sink while the phosphorus appears to be advected through the study area.

The Hawkesbury-Nepean Catchment Management Trust produced a series of environmental values for water in the Hawkesbury-Nepean River catchment following extensive community consultation (HNCMT, 1996). The river was divided into sub-catchments to determine issues of significance and assign desired environmental values. The Brooklyn Estuary study area falls into the Mangrove/Lower Hawkesbury subcatchment and has been further divided into zones including the Mooney Creek Dam zone and the Lower Mooney Creek/Mullet Creek zone. The Mooney Creek Dam zone was considered to be a discrete zone critical to the quality of water in Mooney Creek Dam and quality targets were based on values set for protection of healthy aquatic ecosystems, visual amenity, drinking water supply with disinfection only and groundwater without disinfection, and irrigation. The Lower Mooney Creek/Mullet Creek zone was assigned water quality targets for protection of healthy aquatic ecosystems, human consumption/aquaculture, water associated wildlife, visual amenity and drinking water supply of groundwater without disinfection.

The Hornsby Shire Council 1999/2000 Annual Water Quality Monitoring Program Report describes the water quality at a site in Sandbrook Inlet and compares results for this site, and others outside of the study area, to 1992 ANZECC guidelines (HSC, 2000). Sampling for the Sandbrook Inlet site began in October 1994 with measurements being taken monthly. The report states that in relation to other sites within Hornsby Shire, the physico-chemical indicators, which include pH, conductivity, turbidity, dissolved oxygen, temperature and salinity, were ranked as ‘poor’ and the chemical indicators, including oxidised nitrogen, ammonia, total nitrogen, total phosphorus, suspended solids and chlorophyll-a, were ranked as ‘very poor’. The report noted that elevated nitrogen and phosphorus concentrations, which are indicative of nutrient enrichment, may be due to several factors including sewage effluent leaching into the river, house boats or resuspension of bottom sediments. Algal blooms have not been reported in this area and low concentrations of chlorophyll-a in samples reflected this. Faecal coliform measurements did not exceed the primary recreation guidelines on any occasion during the 1999/2000 sampling period. Statistical ANOVA tests found that faecal coliforms were greater during wet weather, which was suggested to be due to surface runoff collecting pollutants from the land.

As part of an Environmental Impact Assessment that was carried out to assess the likely impact of options for the Brooklyn and Dangar Island Sewerage Scheme, a water quality monitoring exercise was undertaken from February to September 1998 (AWT, 1999a). Sites were located in Sandbrook Inlet, its tributary creeks and on Dangar Island. Samples at each site were analysed for faecal coliforms, enterococci, total nitrogen, total phosphorus, ammoniacal nitrogen and oxidised nitrogen. In the Brooklyn area, higher concentrations of faecal coliforms, enterococci, total nitrogen and total phosphorus were measured in stormwater drains downstream of residential areas and concentrations were accentuated during wet weather. Analysis suggested that the sources of contamination were leaks from septic systems. Discharges from vessel traffic are another potential source of faecal coliforms within the study area, but were not a source in this case as the measurements were taken in stormwater drains before reaching the main waterway. Sewage contamination was also identified on Dangar Island, both during dry weather in groundwater wells and during wet weather in surface water systems. Despite the high concentrations of pollutants measured on Dangar Island, the impact of nutrient loads on the Hawkesbury River was suggested to be negligible due to large tidal flushing volumes that wash past the island every day.

5.1.2 Available Water Quality Data

Water quality data have been provided by Hornsby Shire Council (HSC) and the Environment Protection Authority (EPA). The HSC data cover four sites within the study area, located at Mullet Creek, Mooney Mooney Creek, Spectacle Island and Sandbrook Inlet. The EPA data were collected at three sites located upstream of the study area at Bar Point and within the study area at Mullet Creek and Mooney Mooney Creek (Figure 5.1). Data were collected approximately monthly over different periods between 1992 and 2001.

Appendix B summarises the water quality variables for which data is available and the time periods and frequency of data availability. Also presented in Appendix B are the analytical techniques and protocols used by the EPA and HSC monitoring teams, which provide an indication of the reliability of the data. The data were analysed for spatial and temporal trends and the details of this analysis are provided in Appendix B with a summary of results presented below in Section 5.2.

5.1.3 Additional Data Collection

Water quality variables were measured as part of the DLWC and MHL tidal data collection exercise described in Section 4.2.1. In situ water quality measurements were taken at Kangaroo Point and the Mooney Mooney Freeway bridge (Sites 5 and 15, Figure 4.1) using Datasonde DS4 instruments that collect data on salinity, temperature, pH, dissolved oxygen and turbidity. The instruments were deployed for a period of 5 weeks from 15 October - 20 November (MHL, 2002). In addition, water quality profiles were collected at high and low water at twenty-one sites in Sandbrook Inlet, Mooney Mooney Creek and Mullet Creek using a Sea-Bird Seacat SBE25-03 instrument. The variables measured were density, temperature, salinity, dissolved oxygen, pH, backscatterance, and chlorophyll-a (MHL, 2002). These data were collected over a short time period and present only a snapshot of the conditions in the Brooklyn Estuary.

5.1.4 Data Limitations

The longer term EPA and HSC sampling sites provide limited spatial coverage and therefore, the variability that is likely to exist in the study area is not well represented. This is particularly the case in the upper reaches of Mooney Mooney and Mullet Creeks. While the additional data collected by DLWC and MHL cover a much larger range of sites up to the tidal limits of the creeks, these data cover a short time period and thus provide only a snapshot of the water quality conditions at the time of sampling.

The regular EPA and HSC water quality sampling programs at these sites began relatively recently and datasets cover only a maximum seven year temporal scale. It is therefore difficult to relate any temporal trends determined from a 7 year record with longer scale (> 10 years) catchment changes, such as the introduction of sewerage schemes and urban development.

A further limitation of the data is the varying detection limits for variables measured by different laboratories (see Appendix B), which restricts the level of interpretation possible at lower concentrations. In addition, there exists virtually no information on water concentrations of less common pollutants such as tributyl-tin, organic compounds and hydrocarbon compounds.

Nevertheless, the available data provides sufficient information for a general overview of the water quality status of the Brooklyn Estuary. Additional long-term sampling sites are recommended to enhance the level of knowledge of water quality in the study area, particularly with respect to specific activities and land uses, such as marina operations in Sandbrook Inlet and Brooklyn Harbour and the impacts of industrial activity in the Somersby area.

5.2 Analysis of Water Quality Data

The discussion below summarises the results of analysis of the EPA and HSC water quality data with the inclusion of selected data from the MHL (2002) tidal data collection report. Further details of the analysis are presented in Appendix B.

5.2.1 Comparison to Water Quality Guidelines

The current ANZECC (2000) and HRC (1998) guidelines for water quality are presented in Table 5.2. The guidelines provide an indication of the concentrations typically found in 'healthy' systems and comparison with the available data provides a broad assessment of the water quality status of the study system.

Table 5.2
ANZECC (2000) and HRC (1998) guidelines for water quality variables.

Water quality variable	ANZECC recreational guidelines	ANZECC aquatic ecosystem trigger values	ANZECC aquaculture protection guidelines #	HRC recommendation (for the Hawkesbury-Nepean River system)
Dissolved oxygen	> 80 % sat. > 6.5 mg/L	80 - 110 % sat.	< 100 % sat. > 5.0 mg/L	
Temperature	15 - 35 °C		< 2.0 °C change over 1 hr	
pH	5.0 - 9.0	7 - 8.5	6.0 - 9.0	
Salinity			33-37 g/L	
Suspended solids			< 10 mg/L	
Secchi depth	Horizontal sighting of 200mm black disc should be > 1.6 m			
Turbidity (noted as not a useful measure in estuarine and marine waters)		0.5 - 10 NTU		
Ammonia	10 µg/L (as N)		< 100 µg/L (un-ionised)	
NO_x (nitrate + nitrite)		15 µg N L^{-1}		
Total N		300 µg N L^{-1}	< 1000 µg/L (TAN)	400 µg N L^{-1}
FRP (Filterable reactive phosphorus)		5 µg P L^{-1}		
Total P		30 µg P L^{-1}	< 50 µg/L (Phosphates)	30 µg P L^{-1}
Chlorophyll-a		4 µg/L		7 µg/L
Enterococci * (organisms/100mL)	1° contact < 35 2° contact < 230			
Faecal coliforms * (organisms/100mL)	1° contact < 150 2° contact < 1000			

Guidelines for saltwater aquaculture production
* 1° implies primary contact recreation, 2° implies secondary contact recreation
Faecal coliform and enterococci guidelines apply to the median count where a minimum of five samples are taken at regular intervals not exceeding one month.

Due to the wide range of activities carried out within the study area, recreational aquatic ecosystem and aquaculture protection values are important to the health of the waterway and have been assessed. The variables measured by the EPA and HSC include basic physico-chemical descriptors, such as dissolved oxygen, temperature, pH and salinity; measures of particulate matter in the water column, such as suspended solids concentration, secchi depth and turbidity; nutrients, such as ammonia (NH_3), oxidised nitrogen (NO_x), total kjeldahl nitrogen (TKN), soluble phosphorus and total phosphorus; and biological measures, such as chlorophyll-a, faecal coliforms and enterococci.

Dissolved Oxygen

Dissolved oxygen (DO) is an important water quality constituent as it plays a role in many biological and chemical processes. High DO levels are vital for maintaining suitable conditions for aquatic life and for the efficient functioning of some estuarine processes, such as denitrification in bottom sediments. DO is strongly influenced by temperature, salinity and diurnal biotic activity, and therefore shows tidal, diurnal and seasonal fluctuations. Data from all sites within the study area generally show healthy DO levels, with all satisfying the aquaculture protection guideline of greater than 5 ppm and at least 75% of samples at all sites meeting the recreational criteria of greater than 6.5 ppm. In terms of percentage saturation, approximately 25% of measurements are supersaturated and thus exceed the aquaculture guideline of <100% saturation. However, most data is within the acceptable limits set by the ANZECC aquatic ecosystem (80-110%) and recreational (>80%) guidelines.

DO measurements observed at Kangaroo Point from 15 October - 20 November 2001 varied between 50 and 100% with a mean value around 80%. The data at Mooney Mooney site are not reliable after 29 October due to sensor failure. Prior to 29 October values were similar to the Kangaroo Point site. These levels indicate a relatively healthy system.

Temperature

Water temperatures throughout the study area range from around ~ 11°C in winter up to ~ 29°C in summer. Apart from the occasional low measurement in winter, these temperatures lie within the recreational guidelines and would only be of concern in terms of aquaculture protection if significant changes were experienced in a short period of time, potentially causing thermal shock to biota.

pH

The majority of pH data lie within the range 7.5 to 8.0 pH units, which is within the ANZECC recreational, aquatic ecosystem and aquaculture protection guidelines. Significant changes in pH can have adverse effects on biota and can cause changes in the toxicity of pollutants. Some areas along the NSW coast have problems with leachate from acid sulfate soils (ASS) lowering the pH of waterways to acidic and dangerous levels. The ASS risk map published by DLWC for this area indicates that there are areas around Brooklyn with ‘high probability of occurrence of acid sulfate soil materials within the soil profile’ (MHL, 2000; SMEC, 2000). Any proposals to disturb bottom sediments or the ground surface should therefore include careful examination and management of the potential ASS risk.

Measurements of pH observed at two sites from 15 October - 20 November are relatively constant at each site with the higher value of 8.1 pH at Kangaroo Point reflecting the pH of ocean water, while in Mooney Mooney Creek, the value of 7.5 pH is typical of brackish waters. The pH in freshwater inflows is generally between 6 and 7 for the catchments around Sydney, but may drop in ASS prone areas.

Salinity

Measured salinity values are highly variable, ranging from 12 - 41 ppt, reflecting the inter mixing of freshwater and oceanic inputs to the estuarine area. The majority (>75%) of values lie below the ANZECC saltwater aquaculture protection range of 33 - 37 ppt. These values, however, cannot be directly applied across the estuary because of freshwater flushing. Nonetheless, salinity data is useful in determining mixing and stratification characteristics in an estuary, as demonstrated in Section 4.4.

Suspended solids

Suspended solid concentrations are well below the aquaculture protection guideline at all sites with the exception of Sandbrook Inlet. At the Sandbrook Inlet site half of the measurements exceed the 10 mg/L guideline and the mean value is 14 mg/L. These relatively high values are most likely due to the tidal reworking of fine sediments over the shallow tidal flats. The inlet acts as a trap for fine particles delivered from the local catchment and the Hawkesbury River, as discussed in Section 4.4.5 in relation to particle tracking.

Secchi depth

Secchi depth measurements consider the distance at which a black and white disk can be seen vertically in the water column and thus provide a measure of visibility through the water. At the Mooney Mooney and Mullet Creek sites the majority of measurements are less than the recreational guideline value of at least 1.6 m depth, indicating potential problems with visibility for recreational use in these areas.

Turbidity

Turbidity is a measure of the optical scattering of suspended matter in the water column and when measured as neplelometric turbidity has a notoriously 'noisy' signal. There is thus a large amount of variability in the data with values ranging from 0.7 NTU to about 200 NTU. Except for the Bar Point site, located in the Hawkesbury River upstream of the study area, all sites have a median value higher than the 0.5-10 NTU range recommended by the ANZECC aquatic ecosystem guidelines. Turbidity has been noted by the ANZECC (2000) guidelines as not being a very useful measure in estuaries. High values may be related to inputs of turbid water from the catchment, high levels of primary productivity in the estuary during summer, or as a result of wind-induced resuspension or constant resuspension of fine sediments due to tidal movements.

Nitrogen

Nutrients, and in particular the measured forms of nitrogen, are generally high at all sites. Ammonia (NH_3) values are very high with almost all measurements above the recreational guideline of 10 µg/L. Data provided as NH_3 often also contains NH_4^+ and can overestimate this variable. From the information provided it is not clear as to which form of nitrogen was measured. Oxidised nitrogen (NO_x) measurements are also high, with the majority of data at all sites exceeding the ANZECC ecosystem trigger value of 15 µg/L. This trend is consistent with results from the majority of water quality sampling sites in the Hawkesbury-Nepean River (EPA, 1994). The third form of nitrogen measured at four of the sites is total kjeldahl nitrogen (TKN), which has values ranging from 100-1,200 µg/L across the sites.

Guidelines are not available for TKN, however, the sum of TKN and NO_x gives total nitrogen (TN) for which the aquatic ecosystem guideline is 300 µg/L and the HRC recommended limit is 400µg/L. The majority of TN values exceed these guidelines and a few are also in exceedance of the saltwater aquaculture protection guideline of 1,000 µg/L. Nitrogen inputs from the Brooklyn Estuary catchment may be causing these elevated levels, but the upstream Hawkesbury River catchment may be the primary source as it is a known source of nutrients with significant agricultural development and a number of STP discharges to the river.

Phosphorus

From the available data phosphorus values do not appear to be as significant a problem in the study area as nitrogen. In terms of total phosphorus the majority of data lies below the aquaculture protection guideline of 50 µg/L and at all sites at least 50% of the data is below the ANZECC aquatic ecosystem guideline and HRC recommendation of 30 µg/L. Soluble phosphorus measurements range from 3-50 µg/L and mean values at all sites are between 10 and 15 µg/L. Guidelines are not available for soluble phosphorus, but the ANZECC (1992) aquatic ecosystem guideline for filterable reactive phosphorus, which also measures bioavailable phosphorus, is 5 µg/L.

Nitrogen and phosphorus are the two most commonly measured nutrients and in high levels can result in nuisance plant growth, excessive algal proliferation and increased levels of oxygen-consuming microbes that lower DO concentrations. Algal blooms are a common occurrence in estuaries along the NSW coast, primarily due to the increasing input of nutrients from upstream catchments and poor flushing conditions in some estuaries, which cause nutrients to accumulate and create eutrophic conditions.

Chlorophyll-a

Chlorophyll-a is the most commonly measured indicator of phytoplankton or algae growth. The EPA and HSC data indicate that chlorophyll-a concentrations are not a significant concern at the sampled sites, with almost all of the data lying below the HRC recommended guideline of 7 µg/L. At Sandbrook Inlet approximately half of the measured values are above the ANZECC aquatic ecosystem guideline of 4 µg/L, however nuisance algal blooms have not been reported in Sandbrook Inlet (HSC, 2000). From the water quality profiling exercise undertaken in October 2001 (MHL, 2002), which had greater spatial coverage than the EPA and HSC sampling, higher chlorophyll-a measurements were observed in the upper reaches of Mooney Mooney and Mullet Creeks. In Mullet Creek the highest chlorophyll-a value was 12 µg/L and in Mooney Mooney Creek upstream values reached 16 µg/L at low water in the mid afternoon, indicating that algal blooms may be a problem given the right combination of conditions. Chlorophyll-a measurements in Sandbrook Inlet did not exceed 5 µg/L during the profiling exercise.

Faecal coliforms

Faecal coliforms are a group of bacteria used to indicate waste (faeces) contamination of a waterway by warm-blooded animals. The presence of faecal coliforms is also taken to indicate that other pathogens (such as viruses) may be present. Available faecal coliform data are variable across the sites but the median values are between 1 and 4 cfu/100mL at all sites. The majority of data, except for some unusually high outlying values at Spectacle Island and Mullet Creek, do not exceed the ANZECC primary recreational contact guideline of 150 organisms/100mL.

Limited data (12 sampling occasions at each site) were also available for the bacterial measures of enterococci and faecal streptococci but the small sample size precludes any discussion of general trends.

5.2.2 Spatial and Temporal Trends

The sites at Bar Point and Spectacle Island represent the main Hawkesbury River conditions. Mooney Mooney Creek, Mullet Creek and Sandbrook Inlet are key areas in this study and it should be noted that the use of single sites within each area to represent spatial variability provides only a very broad assessment. Examination of spatial trends in the data enables possible causal mechanisms and/or locations of pollution sources to be established.

Analysis of temporal trends was restricted to water quality variables with data spanning at least four years. Linear regression analysis was used to examine the direction and degree of change over the period of available data. Time series of daily rainfall and runoff were compared to the water quality variable plots to determine if there were relationships between these variables and atmospheric inputs. Rainfall and runoff information was supplied by the Bureau of Meteorology (BoM) Berowra gauging station and Australian Water Technologies (AWT) catchment model HSPF outputs. Correlation analysis amongst water quality variables further examined relationships between variables.

Overall, the seven sites within the Brooklyn Estuary study area have similar values for the majority of water quality variables. Sandbrook Inlet showed different trends for total phosphorus, TKN, ammonia and suspended solids compared to the Bar Point, Mooney Mooney Creek and Mullet Creek sites. This may be because Sandbrook Inlet is more sheltered with longer flushing times than the main channel (see Section 4.4.2) or may be related to inputs from the Brooklyn urban area and associated roads and railway. Another possible explanation for the varying trends may be differences in sampling procedures or analytical techniques, as Sandbrook Inlet data was provided from HSC water quality monitoring programmes, while for these variables the data came from EPA sampling for the other three sites.

There were no statistically reliable trends over time found for any of the water quality variables measured indicating the duration of record (4-7 years) was too short to pick up interannual trends.

Faecal coliform (FC) data shows a strong positive association with rainfall, with a correlation coefficient of 0.69 (n = 101). Peaks shown in the FC time series plots at Mooney Mooney Creek and Mullet Creek coincide with high runoff events, but interestingly not on all occasions. Periods of high rainfall and subsequent runoff are likely to deliver animal waste from farms and wild animals into surface waterways and also cause stresses on the septic tank systems in the catchment with overflows and leakage possible. These potential sources of faecal material are very localised and generally lead to very patchy concentrations in the water that are difficult to measure.

A number of nutrient variables, including TKN and ammonia, show a negative relationship with rainfall, indicating that periods of local rainfall correlate with decreases in nutrient concentrations rather than increases as would be expected if nutrient inputs from catchment runoff were high. This may be due to the high ambient concentrations of nutrients in the Hawkesbury River that may override any local catchment effects. Local rainfall and runoff events may effectively dilute nutrient concentrations at the sampling sites due to the catchment nutrient inputs being low compared to the Hawkesbury River inputs.

Chlorophyll-*a* values show seasonal variations with higher summer levels relating to warmer water temperatures and more available light. There is also a positive association between chlorophyll-*a* and total phosphorus indicating that this nutrient may be a limiting factor in chlorophyll-*a* production. In general algal production in estuaries is nitrogen limited but may switch between nitrogen and phosphorus limitation depending on the conditions. It appears that the nitrogen concentrations are reasonably high and hence do not limit growth.

Water levels and water quality in the Brooklyn Estuary study area are affected by tidal processes, mixing with the Hawkesbury River and inputs from the local catchment area. During dry periods tidal influences can be particularly significant in reaches higher up the waterways that are most affected by catchment inputs during rainfall events. Negative correlations between salinity and oxidised nitrogen, ammonia and chlorophyll-*a* indicate that tidal flow and flushing help to moderate the levels of these variables. This is because the lower concentrations of oxidised nitrogen, in particular, occur when salinity values are high and thus tidal influences are strong. While another possible explanation for the observed negative correlation between these variables and salinity is that freshwater inflows from rainfall and runoff cause high levels of catchment inputs, examination of rainfall and runoff data does not provide evidence to support this.

5.3 Sediment Quality

5.3.1. Overview

The study area includes a 7km long reach of the Hawkesbury River between the Sydney-Newcastle Freeway road bridge downstream to Croppy Point, the northern tributaries Mooney Mooney and Mullet Creeks as well as Sandbrook Inlet (Figure 5.2). Previous investigations have suggested elevated levels of contaminants, primarily metals and synthetic organic compounds, occur in the vicinity of Sandbrook Inlet and sections of the Hawkesbury River channel (Appendix C). These data were seen as having limited value in identifying contemporary and background levels of sediment contaminants due to variations in sampling and analytical methodologies. As a consequence, a reconnaissance program of sediment coring was proposed.

Selection of core sites was preceded by a surface sediment sampling program conducted in February 2002 (Appendix C). Nine potential core sites were identified, of which seven were sampled in April 2002 (Figure 5.2). Core sites were selected to assess sediment contamination levels in three main areas of the estuary: the Hawkesbury River channel, Sandbrook Inlet and tributaries Mooney Mooney and Mullet Creeks.

This section summarises the results of the sediment coring program and provides an interpretation of the chemical analyses of estuarine sediments in the study area.

5.3.2 Methods

The sediment coring was conducted by representatives of Hornsby Council and Coastal & Marine Geosciences on 5 April, 2002. Core samples were collected with a gravity corer deployed from a 10m motorised punt equipped with a davit and power-assisted capstan (Figure 5.3). Samples of the estuary bed were recovered to a maximum depth of 1.3m. The corer utilised 80mm (OD), 74mm (ID) polycarbonate tubing and was operated in water depths of 1 to 7m. Coring in shallow water (<1m) was completed by simply pushing the core barrel into the substrate. Core locations reported here approximate the locations of surface sediment samples shown in Figure 5.2 marked "Core Site".

A minimum of 4 cores were collected at each site, including three samples of the top 5cm of the estuary bed and one sample at the maximum depth of core penetration. Core samples were logged and processed immediately on recovery. Processing involved subsampling, placing samples in glass jars and storing the samples on ice. A total of twenty seven samples were collected and delivered the same day to the Australian Water Technology (AWT) analytical laboratories at Ryde by Hornsby Council staff. A summary of the core samples and their analyses is presented in Appendix C. These results were provided by AWT to Hornsby Council and subsequently forwarded to Coastal & Marine Geosciences for interpretation. All analytical results are for total sample.

The range of chemical analyses undertaken was determined in consultation with Hornsby Shire Council representatives and included determinations of %Gravel:Sand:Mud, Total Organic Content, nutrients (TKN, TP, TN) selected metals and polycyclic aromatic hydrocarbons. The analyses allow a reliable estimation of sediment contamination with due consideration of the effects of grainsize and total organic carbon.

Contaminants bind differently to different sediments and knowledge of sediment grainsize and organic carbon content is critical in interpretations of contaminant transport, load and availability. Fine sediment (muds) can be transported long distances in suspension plus contaminants tend to bind more effectively to fine grained particles than to coarser grained sediments such as sand. High organic carbon contents also promote stronger binding of contaminants, reducing their availability. Analytical results were compared to the ANZECC 2000 Recommended Sediment Quality Guidelines (ANZECC, 2000).

5.3.3 Core Locations

Samples were collected in the Hawkesbury River channel (Sites 5, 6, 7 - Depositional Environment: fluvial channel/estuarine mud basin), Sandbrook Inlet (Sites 8, 9 - Depositional Environment: estuarine mud basin) and tributaries Mooney Mooney and Mullet Creeks (Sites 1 and 2 respectively - Depositional Environment: estuarine mud basin) (Figure 5.2). The sites are considered representative of areas of fine sediment deposition in the lower Hawkesbury River estuary and, as such, can be expected to identify regional and local sources of anthropogenic-related sediment contamination. Samples from Mooney Mooney and Mullet Creeks are remote from the main Hawkesbury River channel and were selected to assess possible sediment contamination associated with their respective catchments.

5.3.4 Physical Sediment Properties

A comparison of the basic physicochemical parameters of the core samples is shown in Figure 5.4. Core samples are grouped by site along the x-axis; triplicate surface samples are indicated by values Site ID.1, Site ID.2 and Site ID.3, single samples at depth by Site ID.4. Samples were collected at depth at all sites except C7 as limited core penetration at this site (<0.1m) precluded further sampling.

Figure 5.4 shows a range of sediment textures were encountered with 18 of the 27 samples containing more than 50% mud (%<0.063mm). Coarse grained sediments, typically muddy sands (<50% mud), tend to occur in areas experiencing stronger tidal currents (eg Hawkesbury River Site 7, Sandbrook Inlet Site 8 and Mooney Mooney Creek Site 1). Finer grained sediments (>50% Mud) characterise lower energy parts of the estuary (eg. Mullet Creek Site 3, Hawkesbury River Sites 5 and 6, Sandbrook Inlet Site 9). A similar observation on the distribution of fine and coarse grained surface sediments in the lower Hawkesbury River estuary has previously been made by Birch *et al.* (1998; 1999).

There is considerable variability in sediment texture with depth; uniform (Sites 3 and 6), fining down (Site 1), fining up (Site 5, 8 and 9) and mixed (Site 7) sediment sequences are present. Of interest is a surficial layer of fine grained mud blanketing coarser sediments (muddy sand) in the Hawkesbury River channel near Spectacle Island and Sandbrook Inlet which suggest long term trapping of fine grained sediments in these areas.

While grain size variability clearly complicates assessments of intra- and inter-core comparisons, surface sediments (top 5cm of estuary bed) with sufficiently high proportions of mud (>50%) and similar %TOC (<4.3%) were recovered from Sandbrook Inlet, Hawkesbury River, Mullet and Mooney Mooney Creeks to assess sediment contamination within the study area. Overall, percentages of mud and TOC in surface samples ranged 31.3-99.7% and 1.36 to 4.12% respectively; percentages in the samples collected at depth ranged 14.6-99.7% and 0.51-4.86% respectively. ANZECC guidelines are normalised for 1% organic carbon, the relatively high proportion of organic carbon in the study area sediments will influence (reduce) the availability of contaminants.

5.3.5 Nutrients

There are no ANZECC guidelines for nutrients in sediments although water quality guidelines can be used when assessing algal bloom risk. Relationships between elevated nutrient levels, particularly phosphorus, are shown in the Appendix C. With due consideration of variations in sediment texture, TP and TN values are similar across most sites. Phosphorus levels tend to be highest in the Mullet Creek (max. 842 mg/kg) and Sandbrook Inlet (Site 9 - max. 821 mg/kg). While phosphorus levels in the sediment exceed recommended water quality guidelines (0.1 mg/kg), it is unlikely these sediment nutrient levels are the same as nutrient levels in the sediment pore water. Despite this, the values are sufficiently elevated in comparison to other sites of concern as there is the potential for the release of these nutrients to the water and subsequent triggering of algal blooms in the future.

5.3.6 Metals/Metalloids/Organometallics

Analyses of total arsenic, cadmium, chromium, copper, lead, nickel, selenium, tin and zinc are summarised in Figure 5.5. Exceedances of the "low probability of biological effects" (ISQG-Low) trigger value guidelines were noted for arsenic in surface sediments at Site 7 (Hawkesbury River - Dangar Island sample C7.3) and nickel in subsurface sediments at Site 3 (Mullet Creek sample C3.4). The remainder of sites returned analyses below the minimum trigger values. Exceedance of trigger values do not necessarily indicate a problem level but rather scope for further testing to determine safety issues or causes. The relatively high organic carbon content of the samples may also act to mitigate effects of the contaminants by lowering their bioavailability.

A slight elevation of copper, lead and zinc concentrations occurs in surface sediments in the eastern portion of Sandbrook Inlet (Site 9), near the railway causeway, which may indicate long term trapping of contaminants in this area. A similar pattern of elevated metal contaminant levels, some above ISQG-Low, have been reported previously for the eastern portion of Sandbrook Inlet (JBA Urban Planning Consultants, 1998).

Comparison of samples collected in the study area show elevated levels of tin (0.34-0.39 mg/kg) in surface sediments at Sites 1 (Mooney Mooney Ck), 7 (Hawkesbury River near Dangar Island) and 8 (Sandbrook Inlet), as well as in subsurface sediments (0.24-0.42mg/kg) at Sites 3 (Mullet Ck.), 5 (Hawkesbury River near Spectacle Is) and 6 (Hawkesbury River). Elevated levels of tin in surface sediments in Mooney Mooney Ck, Sandbrook Inlet and the Hawkesbury River near Dangar Island may indicate a recent source, possibly related to marinas.

5.3.7 Organics

Analyses focused on a range of 18 polycyclic aromatic hydrocarbon compounds (PAHs). PAHs are produced in the incomplete combustion of organic matter (natural and anthropogenic sources) and are a widespread contaminant in the environment with some PAHs known or suspected carcinogens. They are a good indicator of anthropogenic-related sources of contamination. Common input points for PAHs to an estuary would include deposition of airborne particles, surface runoff from roads and land surfaces and direct inputs from industrial and sewage effluents and fossil fuel products.

All individual PAH compounds were found to be below ISQG-Low guidelines. Total PAH's ranged from detection limit in sandy sediments (<10 ug/kg) up to a maximum of 2530 ug/kg in the muddy sediment at Site 9 (Sandbrook Inlet). Figure 5.5 is a plot of Total PAH, Heavy Molecular Weight PAH and Light Molecular Weight PAH for all samples. Heavy Molecular Weight PAHs tend to take longer to breakdown and their presence can indicate long term contaminant accumulation. The plot shows elevation of the PAH levels in Mooney Mooney Creek, with the highest levels encountered in Sandbrook Inlet (Sites 8 & 9). ISGQ-Low levels for high and low molecular weight PAHs (552ug/kg and 1700ug/kg respectively) and Total PAH (4000ug/kg) were not exceeded.

While ANZECC guidelines for PAHs were not exceeded, a clear difference can be observed between Site 9 (eastern portion of Sandbrook Inlet) and all other sites indicating that future issues of sediment contamination in this area need to be addressed. Elevated values in Mooney Mooney Creek also warrant further investigation.

5.3.8 Summary

Physical and chemical analyses of sediment cores collected for the Brooklyn Estuary Process Study reported here give an appreciation of the sediment contamination trends in the study area which are interpretable in terms of current estuarine processes and likely patterns of sediment dispersal and accumulation. Low energy sections of the estuary away from the influence of strong tidal currents are blanketed with fine grained muds, indicating areas of sediment accumulation and, in some areas, build up of metallic and organic contaminants.

Selected chemical analyses of sediments at a majority of sites were found to be within the ANZECC (2000) guidelines for nutrients, metals and PAHs with the following observations and qualifications:

- Core sample grainsize differences make interpretations of background values difficult and further sampling to a greater depth below the estuary bed would be required to reliably establish natural levels of sediment contaminants. Of all analytes tested, PAH values seem to show the most consistent decrease with depth. Metal values are far more variable.
- Levels of phosphorus are elevated with respect to other areas sampled in this study in Mullet Creek and Sandbrook Inlet. The levels of total phosphorus (>821mg/kg) in these areas may lead to an early triggering of algal blooms in the future.
- Exceedance of ISQG Low metal guidelines were noted for arsenic in surface sediments near Dangar Island and nickel in subsurface sediments Mullet Creek. Most metals selected have not exceeded guidelines indicating no environmental

concern at this time. An exceedance of a trigger level does not necessarily indicate a problem but rather support for further testing (eg. an assessment of metal bioavailability using acid volatile sulphides/simultaneously extracted metals).

- While within ANZECC guidelines, elevated levels of contaminants (metals and PAHs) in Mooney Mooney Creek and Sandbrook Inlet are a concern and point to the long term accumulation of fine grained sediments and their contaminant load. Bioavailability testing using toxicity tests may be warranted to assist management options.

The results of this study and previous work indicate long term accumulation of sediments and their contaminant load in Sandbrook Inlet is a management issue. Tidal flows within the inlet appear to low to remove fine grained sediments, leading to a build up of contaminants from local sources. In view of this, important considerations for estuary management must include enhanced tidal flushing to minimise the build up of fine sediments and their contaminant load in the inlet, and the identification and reduction of local sources of contaminants. Sampling elsewhere in the study area suggests contamination issues are not as pronounced as those within Sandbrook Inlet due to a combination of greater tidal flushing and/or remote location away from anthropogenic pollution sources.

5.4 Microbiological Influence on Water Quality

Microbiological pollution in waterbodies can have three pathways to primary direct influences on human health. These are direct injestion of contaminated waters (e.g. while swimming), inhalation of spray from contaminated waters (e.g. recreation) and consumption of shellfish virally contaminated by estuarine waters.

Hazards associated with direct contact from swimming are generally addressed by the testing for faecal coliform contamination in sea water. Faecal coliforms, while being only one of the many microbiological factors that may infect humans, are an easy test to undertake and are regularly used as indicators to the presence of viruses and others.

The two types of hazards potentially derived from the shellfish growing environment associated with microbiological pathogens are (Safefood, 2002) enteric bacterial pathogens (eg Salmonella spp., Shigella spp.) and enteric viral pathogens (eg Norwalk and Hepatitis A).

Faecal waste from either man or animal is ultimately disposed of into the environment. In the vast majority of cases viruses infectious to humans are contained only in human faecal waste. While faecal waste from other animals does contain viruses, these are generally not pathogenic to humans (Dorairaj, 2000). Humans are susceptible to infection following contact with animal waste, however the illness will have a microbial rather than viral etiology, such as bacterial infection.

Figure 5.6 shows the potential sources of virus-carrying discharges into estuarine environments. These sources are:

- Wastewater – from either primary, secondary or tertiary levels of treatment or from sewer overflows. The most common means of wastewater disposal is by discharge and dilution into streams, rivers, lakes, estuaries or oceans.
- Septic Tanks and Cesspools – where waste is allowed to accumulate and natural biodegradation processes undertaken before the effluent is released into the subsurface (in the case of no-pumpout).
- Leachate from refuse sites
- Land spreading of sludges
- Surface runoff
- Boats – in particular raw sewage discharged from boats into waterways.

Each of these sources contains a considerable variety of pathogens, representing the complete range of pathogenic microorganisms endemic in that community which produces the source. Viral particles are found in all of the above-mentioned sources at considerable concentrations.

There are over 140 human enteric viruses that can be present in wastewater. Table 5.3 lists the major groups of these pathogenic human viruses and the symptoms of infection.

Table 5.3
Human Enteric Viruses Found in Wastewater and the Symptoms of Illness

Organism	**Symptoms of Illness due to Infection**
Adenovirus	Respiratory Illness, conjunctivitis, vomiting, diarrhoea
Astrovirus	Vomiting, diarrhoea
Calcivirus	Vomiting, diarrhoea
Coronavirus	Vomiting, diarrhoea
Enterovirus – Poliovirus	Paralysis, meningitis, fever
Enterovirus – Coxsackie A	Meningitis, fever, herpangina, respiratory illness
Enterovirus –Coxsackie B	Myocarditis, congenital heart anomalies, rash fever meningitis, respiratory illness, pleurodynia
Enterovirus – Echovirus	Meningitis, encephalitis, respiratory illness, rash diarrhoea, fever
Enterovirus – Enterovirus 68-71	Meningitis, encephalitis, respiratory illness, acute haemorrhagic conjunctivitis, fever
Hepatitis A virus	Infectious hepatitis
Hepatitis E virus	Hepatitis
Norwalk virus	Epidemic vomiting or diarrhoea
Reovirus	Not clearly established
Rotavirus	Diarrhoea, vomiting
Small round viruses	Diarrhoea, vomiting

Source: Dorairaj and Miller (2001)

Oysters, unlike other shellfish, are generally consumed raw or with cooking time insufficient to inactivate any viruses it may contain. Therefore, preventing viral contamination of oysters is of particular importance with regards to the spread of waterborne disease.

Pathogenic viruses persisting in the estuarine environment provide only the potential for infection. Whether an individual becomes infected by a waterborne virus is dependent on a number of variables such as the degree of exposure, the infective dose, the pathogenicity of the organism, its virulence and the susceptibility of the host. For human infection by viruses from the consumption of oyster or shellfish to occur, a chain of events must take place. Viruses must first survive hostile environmental conditions including possible wastewater treatment processes. Once infection of a human has occurred, then multiplication and cytotoxic effects must follow the illness. When the numbers of pathogens ingested is insufficient to cause illness, the infected individuals may become carriers and subsequently contaminate other foods or people. Hence, secondary sources of spreading may result from the primary waterborne route.

Dorairaj (2000) presented a summary of the viral transport mechanisms for viruses in the estuarine environments. These include waterborne transport where viruses are transported with currents as neutrally buoyant particles, groundwater transport with eventual delivery to water bodies and sediment transport where viruses can remain persistent is estuarine sediments before resuspension by currents or waves.

5.5 Factors Affecting Water Quality

The water quality in the study area varies in both space and time but can be broadly described within the following regions:

- main arm of the Hawkesbury River including Dangar Island
- Sandbrook Inlet
- upper Mooney Mooney and Mullet Creeks
- lower Mooney Mooney and Mullet Creeks

Urban and agricultural development of the catchment and recreational and commercial use of the waterways over the past 200 years has introduced a range of particular water quality issues pertaining to particular regions. For example, the marinas and boating activity in Sandbrook Inlet led to an increase in TBT concentrations within the inlet that has subsequently reduced since the banning of TBT antifouling paints (JBA Consultants, 1998). Nutrient inputs to Mooney Mooney Creek, for example from agricultural activities in the catchment, appear to be responsible for algal blooms in the upper creek but nutrient inputs to Sandbrook Inlet do not appear to result in algal blooms. The data presented in the preceding sections provide information on the variability of water quality variables and some discussion of the causal relationships that are responsible for the observed variability. There are, however, a number of processes that are not resolved by the available data, and hence, the discussion of the factors affecting water quality is based upon the preceding discussion and knowledge of processes in similar systems.

Temporal variability of water quality is linked to a range of forcing factors, including rainfall events and land use patterns within the local and Hawkesbury-Nepean catchment areas, tidal flushing and spring/neap effects, ocean sea level oscillations, seasonal variations, wet/dry periods and climate change. In addition to the inputs of constituents from local catchment runoff and Hawkesbury River inputs, estuarine water quality is also affected by sources and sinks within the estuary (such as bio-geochemical nutrient cycling and natural mortality of organisms), as well as ocean concentrations that may be a source or sink for particular constituents (eg. salinity).

A summary of the water inputs, including tidal flows and freshwater inputs, nutrient and sediment loads from the local catchments, and flushing times within the study area is presented in Figure 5.7.

Catchment Runoff From Both Point And Diffuse Sources

Diffuse sources of nutrients to the system may be linked to the general catchment and to the road and rail infrastructure. These latter sources are significant for Sandbrook Inlet and upper Mooney Mooney and Mullet Creek areas. The loads to Sandbrook Inlet are larger than in pre-settlement times but there are no apparent effects of nutrient eutrophication and hence it is suggested that the Sandbrook Inlet area has the capacity to absorb the additional nutrient load, most probably due to increased turbidity. Loads to upper Mooney Mooney Creek, in combination with longer flushing times, appear to be causing algal blooms but it is not clear whether the Freeway and Pacific Highway loads are a major contributing factor or whether the sediment recycling is a major factor in the nutrient and algal bloom dynamics.

Faecal matter contamination of the waterways appears to occur near populations including Dangar Island and Brooklyn from warm-blooded animal waste in inflows. The faecal bacteria are generally short-lived (from a few hours to a few days) and are an issue next to the source, but viruses can live for extended periods and may become an issue in the future. Viral concerns are further discussed in Section 5.4.

Direct Precipitation/Evaporation Dry/Wet Periods

Atmospheric sources of nutrients and sediments indicate a significant portion of the nitrogen and phosphorous may be generated in the atmosphere and is transferred to the water by direct rainfall. Evaporation is not likely to be an issue in the main arm, Sandbrook Inlet or the lower creek areas. During extended dry periods evaporation could be an important factor in determining the salt flux upstream when the water evaporated from the surface is replaced by more saline water from downstream. The wet periods are important for flushing the system and transporting constituents.

Aquifer and Groundwater

Groundwater flows to the system are likely to be negligible (in comparison to the surface runoff) for most of the time except perhaps during dry periods in the low lying areas near the confluence of Piles and Mooney Mooney Creek. While there is no information to assess the actual subsurface flow and water quality, it is generally expected that the contribution of these inputs would be localised and have little impact on the overall quality of the water.

Horizontal And/Or Vertical Stratification Seasonal Effects

Stratification is important in estuarine systems. Horizontal gradients in water density result in gravitational flows while vertical gradients are important for inhibiting vertical mixing and transport of water borne constituents. The strength of gravitational flows depends on the density gradient. This type of flow is likely to become more important in the upper reaches away from the main arm where the flow is dominated by the tidal currents. In the upper reaches gravitational flow forms an important contribution to the exchange flows, particularly during drier periods. Vertical stratification is also likely to be important in determining the vertical mixing characteristics, particularly in the upper reaches. In the lower reaches and main arm the tidal currents are sufficient to induce intense turbulent mixing that tends to homogenise the water column. As the tidal currents diminish further upstream, the stratification inhibits vertical turbulent mixing and water layers become isolated. This has a number of consequences for algal production and nutrient distributions in the water column. Again the relative importance of these mechanisms is highly variable temporally and is likely to contribute to the water quality response only in the upper reaches.

Sediment Recycling

Recycling of nutrients and other contaminants locked in the sediments is often a major factor affecting water quality in estuaries. Organic matter produced locally (algal and plant mortality) or transported into the system from the catchment or Hawkesbury River generally settles to the bottom and begins to decay through microbial processes that may be mediated by a number of environmental factors. The decay processes consume oxygen from the water column and release nutrients from the sediments. In addition, denitrification leads to the release of nitrogen gas that transfers to the atmosphere and is lost to the water system. A number of constituents (eg. metals and organic compounds, etc.) adhere to the fine sediment material that may be resuspended into the water column during wind stirring or freshwater flow events or even by the tidal currents, where they may be taken up by filter feeding organisms (oysters and mussels) or aquatic plants. The relative importance of sediment recycling is again not clear from the limited information. Comparing the nitrogen inputs and exports to/from the system it would appear that denitrification is an important nitrogen sink process, particularly in Sandbrook Inlet, and most probably in the upper reaches of Mooney Mooney and Mullet Creeks.

Waterway Usage (Boating In Particular) And Marinas

The study area and in particular Sandbrook Inlet is a focal point for boating activities servicing the Sydney region and local communities. These activities affect water quality in a number of ways but their impact is often localised and short lived. Cumulative impacts from a number of boats may result in changes to the biota (eg. clearing of benthic plants by mooring and anchor systems) and inputs from boat effluent including faecal material and nutrients. Marinas intensify these activities and the associated infrastructure and works, such as dredging of navigation channels and construction of breakwaters, also affects the water quality. The area is generally well flushed, and hence, any inputs are quickly diluted and transported downstream. The influence of waterway usage is discussed in greater detail in Section 7.2.

Discharges From Septic Overflows and Vessels

Septic overflows and vessel pumpouts have the potential to deliver high concentrations of faecal material containing nutrients and pathogens to the water. As the flows are generally small their impact is often localised and rapidly dispersed into the receiving environment. Again accumulated impacts from a large number of overflow points and boats in one area have been shown to cause deterioration in water quality during intense boating periods such as the Easter and Christmas breaks.

Vessel Pump Out Facilities
The pump out facility at Kangaroo Point and the proposed one at Brooklyn will hopefully lead to a reduction in nutrient inputs to the system with a corresponding decrease in the frequency of occurrence of poor water quality. It is not clear to what extent the present vessel discharges may affect the study area and hence the relative improvement to water quality is unknown. Furthermore, there is limited information on the number of users of the pump out facilities or the overall compliance with pump out regulations.

Oyster Leases
The high concentration of oysters within oyster leases has the potential to influence water and sediment quality in the immediate vicinity of the lease. Timber preservatives on oyster racks such as tar have been phased out over the past decade. Oysters filter the fine sediment and organic material from the water passing the lease and excrete by-products that settle to the bottom. There is very little detailed information on the materials produced but given the long history of successful oyster production it is unlikely these issues are having any major impact. Oyster leases can also reduce the tidal velocity in the local area, encouraging the settling of sediments resulting in localised sedimentation in and around the leases. The influence of oyster leases on water and sediment quality is discussed in greater detail in Section 6.6

Oceanic Waters and Waters Sourced From Broken Bay And The Hawkesbury River
The study area is rapidly flushed by the waters of the Hawkesbury River and within the study area waters are a mixture of oceanic waters from downstream and brackish waters from upstream. During large floods the Hawkesbury River can be flushed by fresh water to Broken Bay while during drier periods the saline ocean waters propagate upstream beyond the study area. These waters are the largest influence on the overall water quality of the system.

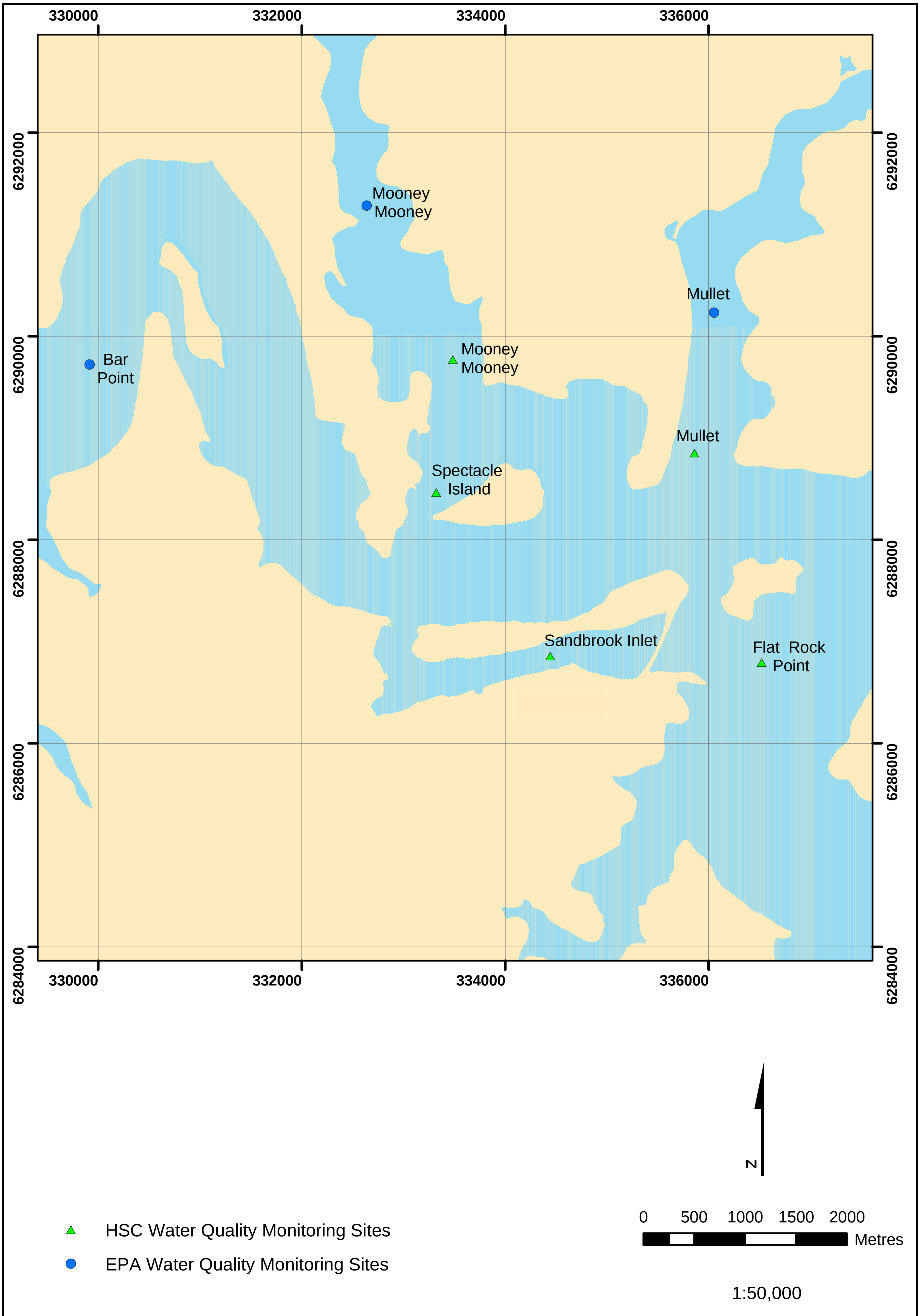
Wind Driven Currents
As the study area has limited fetch lengths, wind-driven surface setup and currents are likely to be negligible in comparison to the tidal currents. Wind induced surface waves and the energy transfer to turbulent motions may be a significant input to the mixing in the surface layer and stirring/re-suspension of fine bed material in shallow areas. These events are likely to be relatively important in the upper reaches where wind funnelling along the river valley will cause strong surface winds when the regional wind field is from certain directions.

Tidal Flushing
Tidal flushing forms a major determinant of the water quality in the system. Tidal flushing effectively disperses the material inputs along the system. For example the salt gradient is determined by a balance between fresh water input from the catchment causing downstream transport and tidal flushing resulting in mixing along the gradient and effective upstream transport of salt from the ocean. This mechanism affects all the water quality variables and the resultant gradient depends on the relative magnitudes of the upstream and downstream source concentrations. For example, nutrient concentrations are generally low downstream and high upstream resulting in a gradient from high to low concentrations moving downstream (the opposite to the salt gradient). Tidal flushing is also an important control on the concentration of algal blooms. The growth of algae within the estuary is an

effective internal source and the actual bloom concentration (as measured for example by chlorophyll-a) is determined by the algal growth rate that increases the concentration and the tidal flushing that effectively dilutes the bloom reducing the concentration. This mechanism is also important for the dispersion of faecal inputs. The tidal flushing intensity is strongest in the main arm of the Hawkesbury River and diminishes upstream in the tributaries.

Fluvial Currents

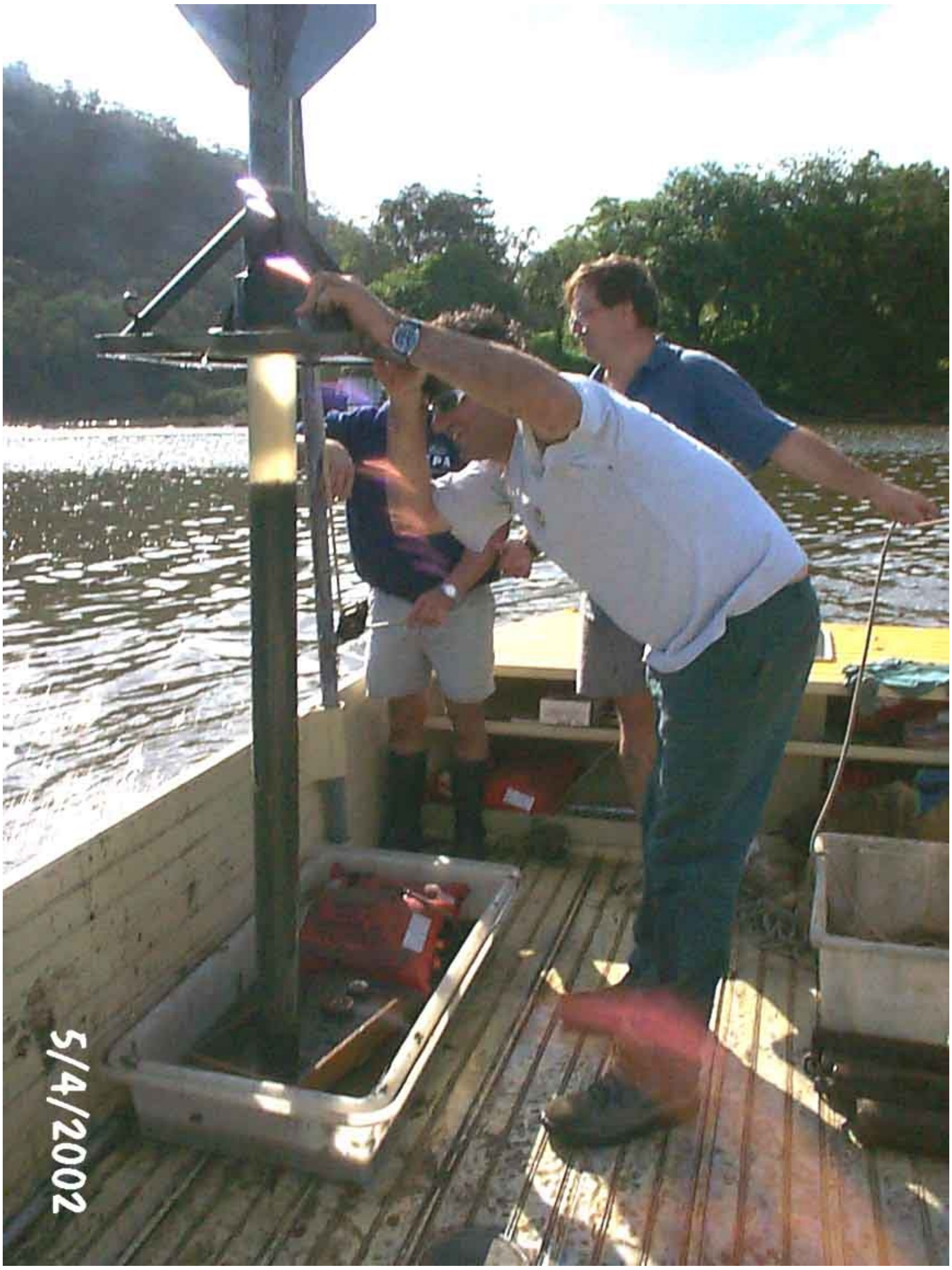
Fluvial inputs from the local catchment and the Hawkesbury River have an important role in delivery of contaminants and sediment to the system. The local inflows effectively flush the upper reaches from upstream while the Hawkesbury River floods and fresh events tend to transport fine sediment into the lower and middle reaches of the Creeks and Inlet.



WRL Report No. 2002/20	HSC AND EPA WATER QUALITY MONITORING SITES	Figure 5.1

fig5_1.mxd

WRL Report No. 2002/20	LOCATION OF SEDIMENT CORES	Figure 5.2 00758-05-02.cdr



WRL Report No. 2002/20	GRAVITY CORER	Figure 5.3 00758-05-03.cdr

WRL

Report No. 2002/20

BASIC PHYSIOCHEMICAL PARAMETERS OF CORE SAMPLES

Figure 5.4

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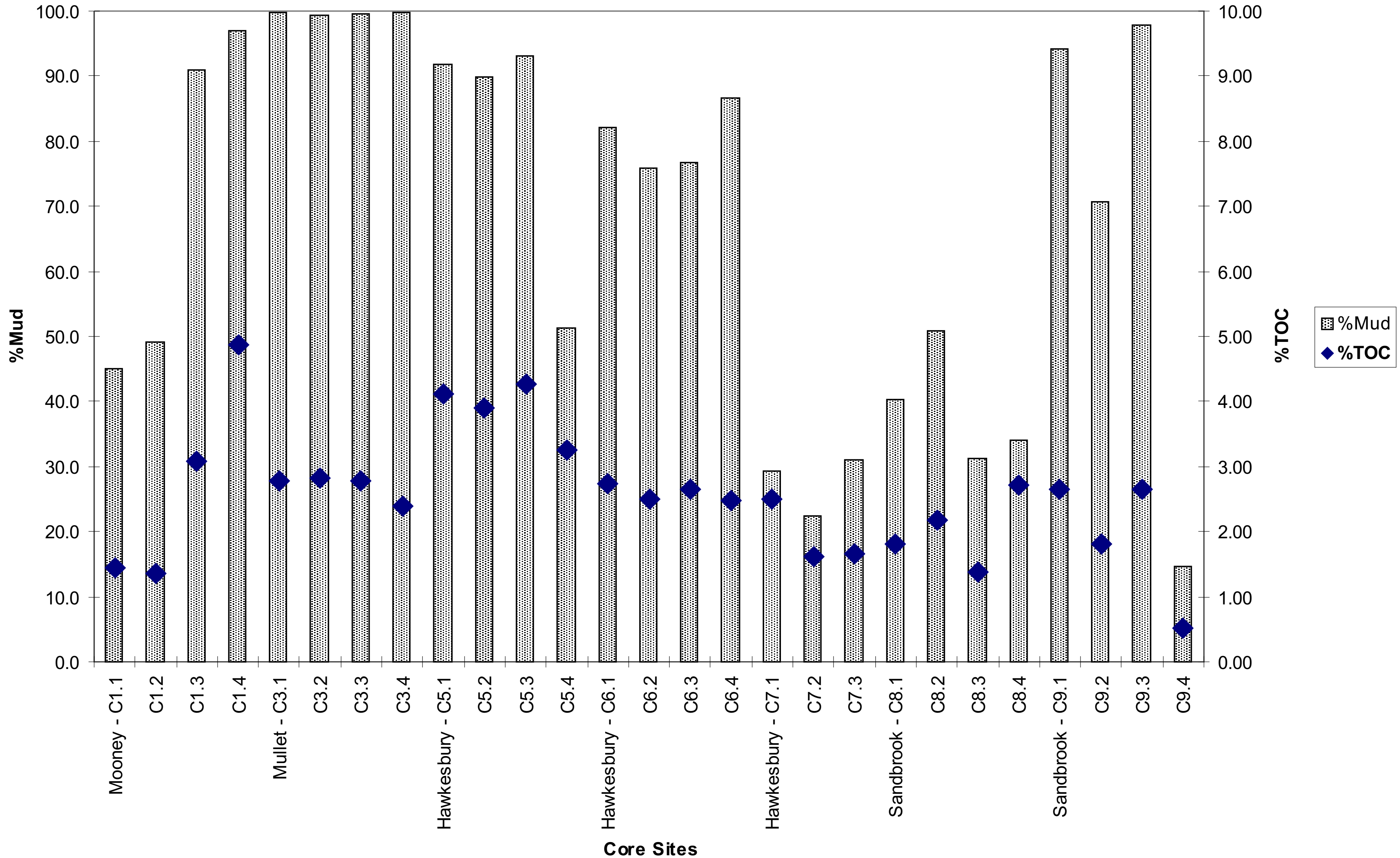

Source: Coastal & Marines Geosciences (2002)

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Report No. 2002/20

METAL ANALYSIS OF CORE SAMPLES

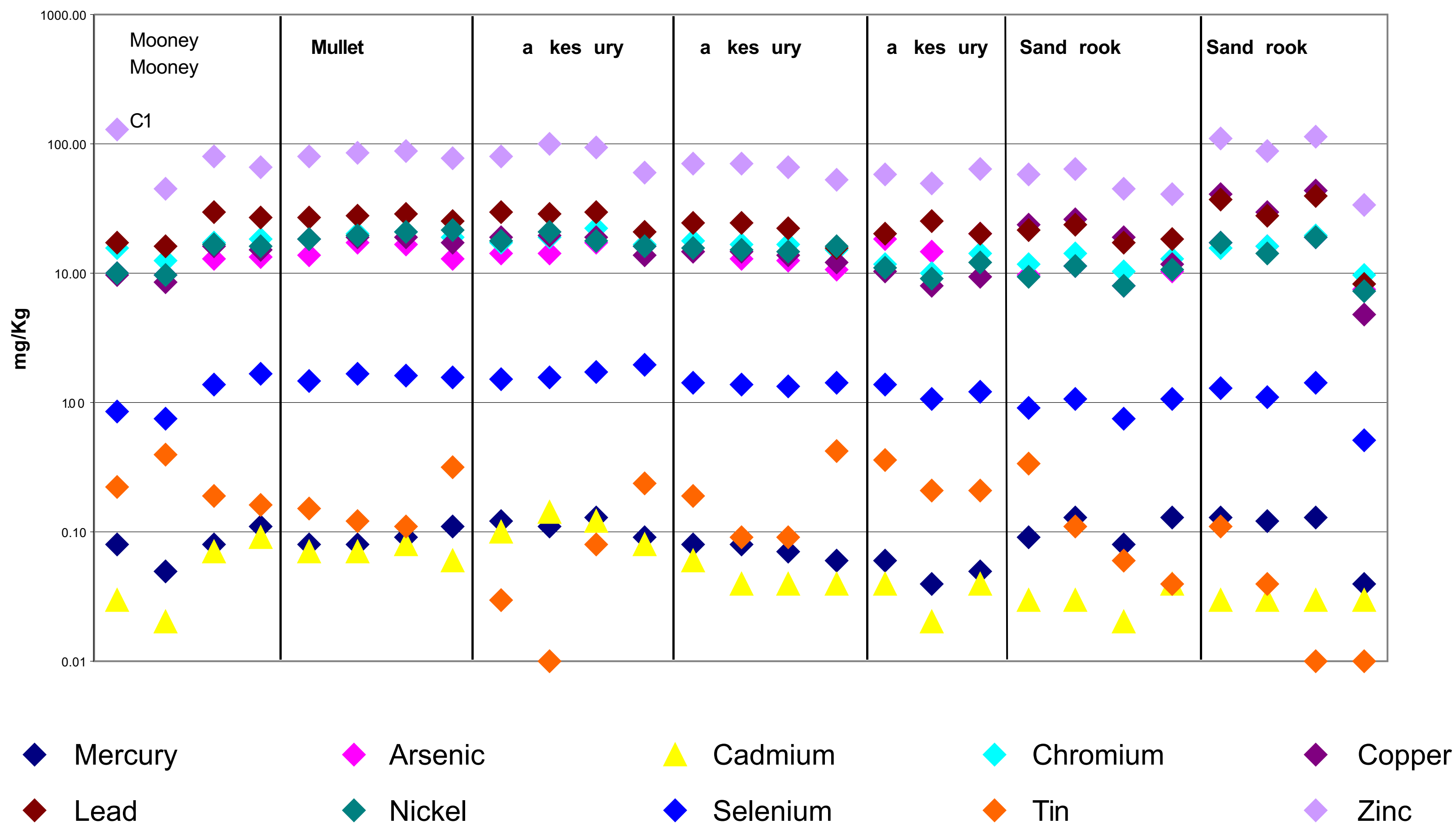
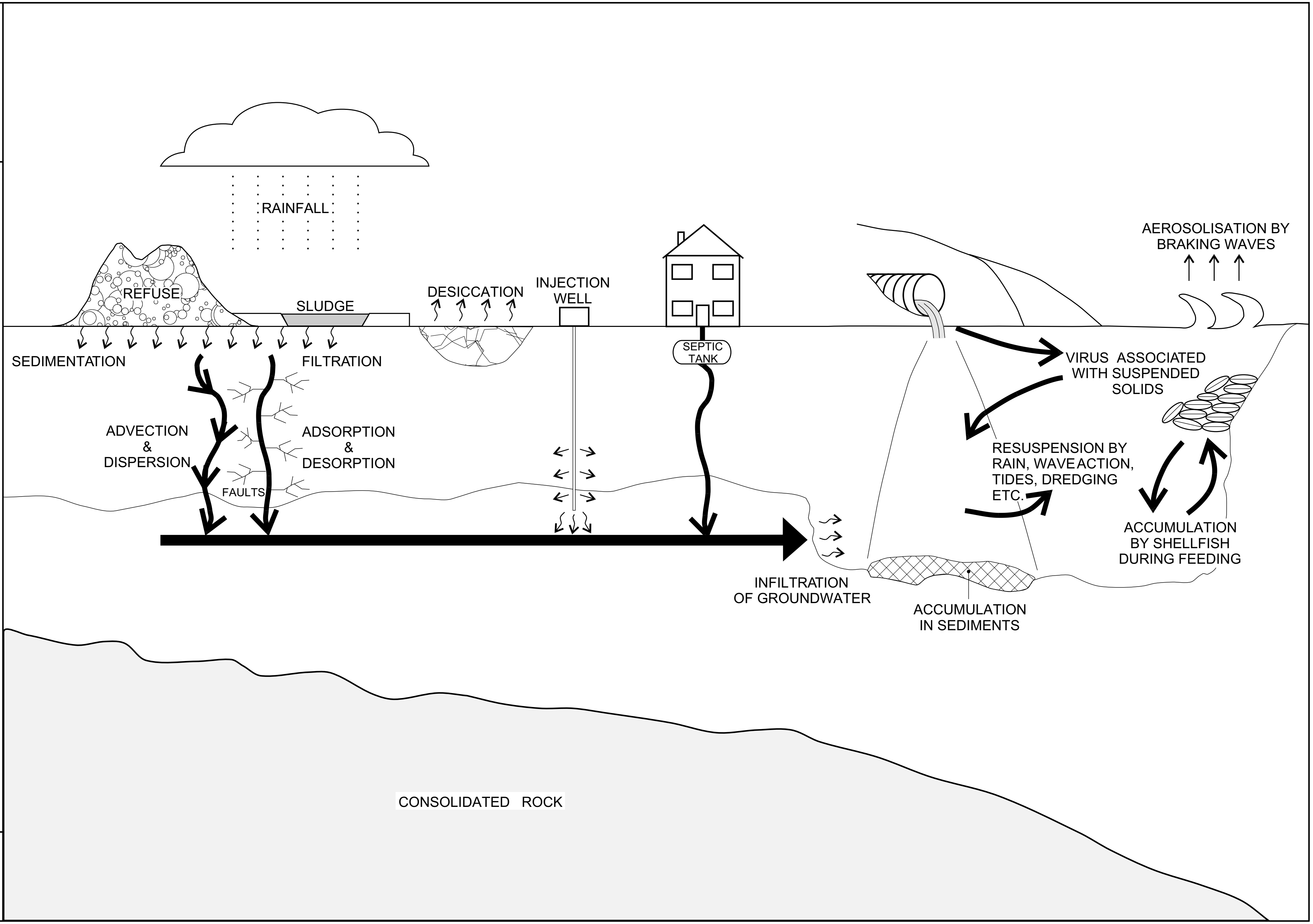


Figure 5.5

00758-05-05.cdr

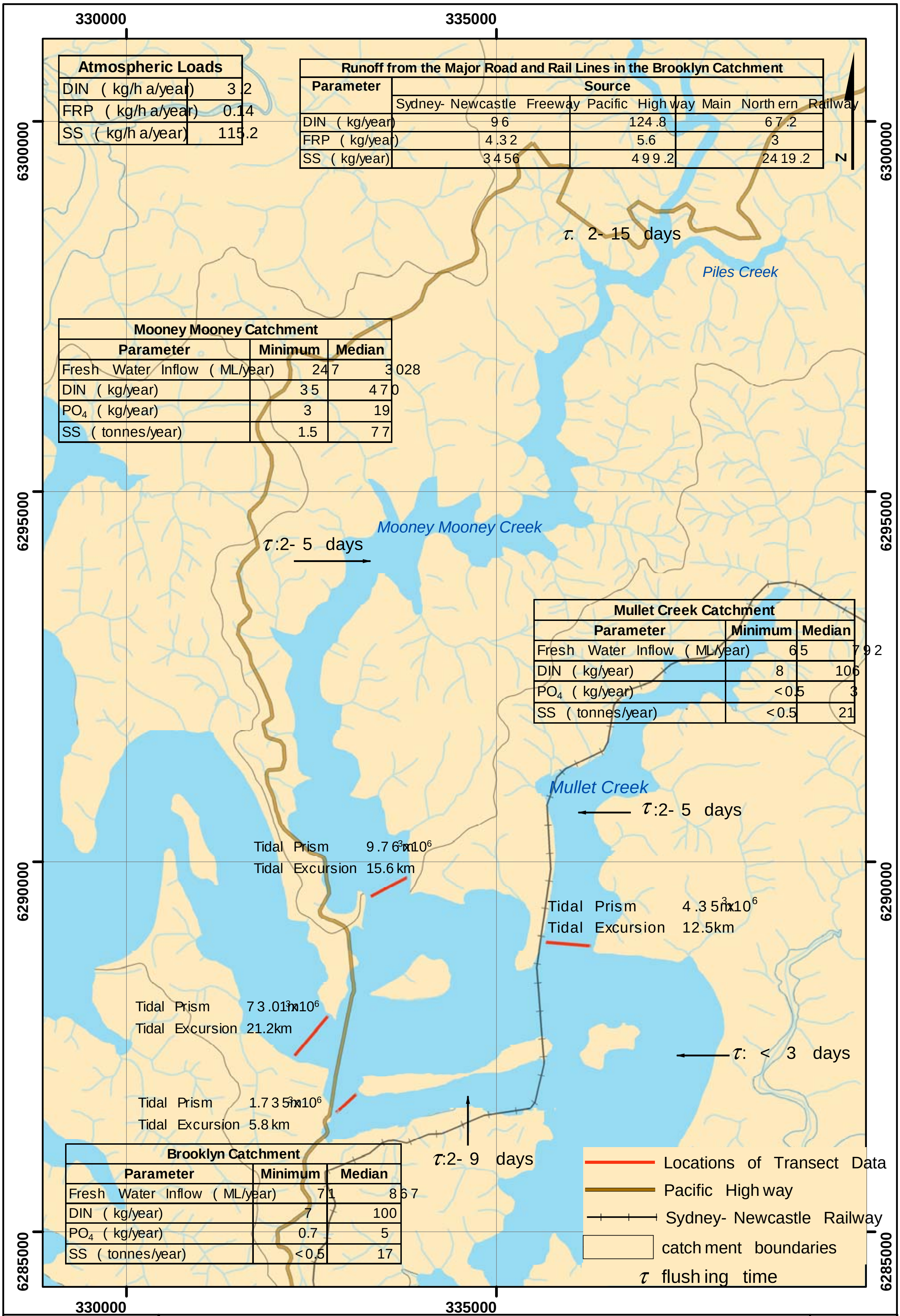


WRL
Report No. 2002/20

PROCESSES/ FACTORS INFLUENCING THE ENTRY, SURVIVAL AND MIGRATION OF VIRUSES IN GROUNDWATER AND ESTUARINE ENVIRONMENTS

Figure 5.6

00758-05-06.cdr



Atmospheric Loads	
DIN (kg/ha/year)	3.2
FRP (kg/ha/year)	0.14
SS (kg/ha/year)	115.2

Runoff from the Major Road and Rail Lines in the Brooklyn Catchment

Parameter	Source		
	Sydney-Newcastle Freeway	Pacific Highway	Main Northern Railway
DIN (kg/year)	96	124.8	67.2
FRP (kg/year)	4.32	5.6	3
SS (kg/year)	3456	499.2	2419.2

Mooney Mooney Catchment

Parameter	Minimum	Median
Fresh Water Inflow (ML/year)	247	3028
DIN (kg/year)	35	470
PO_4 (kg/year)	3	19
SS (tonnes/year)	1.5	77

Mullet Creek Catchment

Parameter	Minimum	Median
Fresh Water Inflow (ML/year)	65	792
DIN (kg/year)	8	106
PO_4 (kg/year)	< 0.5	3
SS (tonnes/year)	< 0.5	21

Brooklyn Catchment

Parameter	Minimum	Median
Fresh Water Inflow (ML/year)	71	867
DIN (kg/year)	7	100
PO_4 (kg/year)	0.7	5
SS (tonnes/year)	< 0.5	17

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SUMMARY OF CATCHMENT LOADS AND FLOWS

Figure 5.7

fig5_7.mxd

6. ECOLOGICAL PROCESSES

6.1 Introduction

The Brooklyn Estuary Management Committee has identified several issues relating to aquatic ecological processes that may pose a threat to the environmental, social and economic values and community expectations for the Brooklyn estuary. The key issues were:

- Aquaculture and fishing - industry impacts and threats (eg. acid sulfate runoff, biotoxins);
- Impacts of the rail causeway on tidal flushing in Sandbrook Inlet;
- Maintaining the ecological quality of the waterway including benthic diversity and protection of aquatic habitat (e.g. seagrasses, mangroves, saltmarsh, and associated biota);
- Protection of high conservation areas such as hanging swamps, pristine creeks, fish spawning sites and habitats;
- Protection of fish habitats and fisheries resources.

To address these issues, a team of environmental scientists was commissioned by Hornsby Shire Council to undertake the Brooklyn Estuary Process Study. The team was lead by Water Research Laboratories (WRL), in conjunction with Manly Hydraulic Laboratories, The Ecology Lab Pty Ltd, The Centre for Research on Ecological Impacts of Coastal Cities (CEICC), and Coastal and Marine Geosciences.

The Ecology Lab undertook field, laboratory and desktop studies in collaboration with The Centre for Research of Ecological Impacts of Cities at the University of Sydney. The CEICC studied macroinvertebrates within mangrove habitats and The Ecology Lab focussed on habitat mapping, fish and oyster bioaccumulation issues.

The scope of works undertaken by The Ecology Lab included:

1. A summation and assessment of existing information on riparian and aquatic flora and fauna and fisheries relevant to the study. This was done using topographic maps and recent aerial photographs supplied by the client, recent maps of aquatic habitats (e.g. West *et al*., 1985) and microphyte data recently collected by NSW Fisheries. Additional information was sourced from WRL's extensive library, Hornsby Council's resources, relevant government departments and agencies (e.g. NSW EPA, DLWC, NPWS and The Australian Museum), published and unpublished reports, and research conducted at Universities and research centers. This summarised information served as a basis for refining field investigations.

2. A series of qualitative and quantitative field studies including:

    - *Qualitative habitat assessment of the Brooklyn area*. Data was collected on aquatic habitats including flora (seagrass, saltmarsh and mangrove) and fauna (fish and mobile invertebrates) populations. This information was then mapped using GIS and combined with existing data to assess the extent habitat changes over time.

- *Quantitative intertidal survey of macrofauna and flora*. An intertidal survey of the biota either side of the rail causeway was commissioned as part of the Brooklyn Rail Upgrade EIS and was included in this report as additional information.

- *Quantitative survey of benthic macrofauna associated with fringing mangroves*. The Centre for Research on Ecological Impacts of Coastal Cities (EICC) undertook a baseline survey of the benthic invertebrate assemblages using samples collected with hand-held cores in the Brooklyn region of the Hawkesbury river.

- *Quantitative sampling of fish and macroinvertebrates*. Basic information on the distribution patterns and abundance of fish and invertebrates, especially those of economic significance that utilise intertidal mudflats was not available. As a result, fish populations and assemblages were analysed to assess their temporal and spatial variation within the estuary. The diversity and abundance of fish and mobile invertebrate were examined by sampling using beam trawls. The aim of this study component, therefore, was to collect information on fish and invertebrates associated with inundated intertidal mudflats adjacent to mangroves at various locations throughout the Brooklyn study area.

- *Study of bioaccumulation in oysters*. The uptake of contaminants by sessile animals was examined by studying the bioaccumulation of heavy metals and Polycyclic Aromatic Hydrocarbons (PAH) in oysters. Results were analysed to assess spatial variation within the estuary.

3. An assessment of ecosystem health including the compilation and summation of the main processes known or predicted to be driving the ecological functions of the Brooklyn area.

This chapter presents the findings from these three stages of the aquatic ecological components and processes in Brooklyn area. It describes the principle factors influencing the spatial and temporal variability of aquatic vegetation and aquatic fauna communities. Key issues outlined by The Brooklyn Estuary Management Committee which required special management consideration were identified and assessed.

6.2 Aquatic Habitats

6.2.1 Review of Information

6.2.1.1 Seagrasses and Algae

Recent research has emphasised the importance of seagrasses to the ecology of shallow estuarine environments (reviewed by Larkum *et al*., 1989). Briefly, seagrasses stabilise sediments (Fonesca *et al.,* 1982), provide an important habitat for juvenile fishes and mobile invertebrates, many of which are of commercial or recreational importance (Bell and Pollard, 1989), and are significant components in the cycling of nutrients within estuaries (Kenworthy *et al.*, 1982).

Eelgrass (*Zostera capricorni*) is the only species of seagrass that has been recorded in Brooklyn area, though West *et al*., (1985) included paddle weed (*Halophila* spp.) in the key to the map for the study area. Strapweed (*Posidonia australis*) has been recorded recently by Williams & Watford (1999), scattered in beds of the adjacent Cowan Creek catchment. Eelgrass occurs in most estuaries of NSW, including the Tweed River in the north to the Womboyn River on the southern border. Strapweed is a southern temperate species in Australia, confined to embayments south of Wallis Lake on the mid north coast of NSW and extending around southern Australia to Shark Bay in the west. In NSW it is generally restricted to sandy and muddy estuarine habitats and protected embayments. Strapweed particularly favours hyposaline (marine) conditions, and is absent from intermittently open lagoons (McNeil, 1997). Paddle weed occurs in a wide range of habitats throughout temperate and tropical Australia (Larkum *et al*., 1989). Species of paddle weed appear to have seasonally effected growth rates, can grow in very shallow or deep waters, and often occur in small patches and/or at low densities (Larkum *et al*., 1989).

West *et al*. (1985) recorded seagrass beds at the head of Mullet Creek (Figure 6.1). These were also recorded by Williams & West (2001) (Figure 6.2), who found additional beds to the east of Kangaroo Point and south of Dangar Island not previously recorded by West *et al*. (1985). Seagrass beds also occur to the east of the railway causeway between Brooklyn and Long Island (Nexus, 2000; SMEC, 2000) (Figure 6.3). These discrepancies in the distribution of seagrass communities recorded in the estuary may have occurred for several reasons. First, seagrass communities may have developed within the estuary during the 16 years between the four studies. Alternatively, aerial photographs over time may have differed in factors such as the time of day, tidal conditions, season, scale, size of the seagrass bed and turbidity of the water.

Using field techniques, The Ecology Lab (1997) estimated the area of seagrass in Sandbrook Inlet to be 0.64 ha consisting of a single bed which was 90 m in diameter, and partially exposed during low tide. This was similar to an estimate of 0.7 ha by Williams and Watford (1999) (Figure 6.4) using aerial photography.

Although the bed does not appear in Williams & Watford (1999) (Figure 6.4), a seagrasses bed occurs east of the causeway (Figure 6.3). Analysis of an aerial photograph (Nexus, 2000) determined the extent of this bed as 1.7 ha. The bed (2.37 ha) was mapped in detail by The Ecology Lab (2002) and consisted of *Zostera capricorni*. The density of shoots of *Zostera* was moderate near the middle of the bed but became sparse closer to the margins. Shoots ranged in length from approximately 10 to 30 cm. Overall, the seagrass appeared “healthy” with a low epiphyte load (i.e. filamentous algae and sessile fauna attached to the blades of the shoots). The bed essentially follows the –1.0 m AHD contour and much of the bed occurs within the boundary of oyster leases 123-209 and 123-211.

Physical characteristics of the seagrasses have also been recorded for the bed in Sandbrook Inlet (The Ecology Lab, 1997). The average shoot length was 21.5 cm and each plant had an average of 4.3 shoots. Similar findings were reported for other studies in the Sydney region (The Ecology Lab, 1994). Seagrass health, as shown by chlorophyll *a* fluorescence, was better in the adjacent Berowra Creek affected by sewage effluent, than the unaffected

Cowan Creek to the other side of Brooklyn area (Silberschneider, 1997). A possible explanation could be that the effluent provided additional nutrients for seagrass growth.

Six taxa of algae occurring within the intertidal zone were recorded at three sites in the Brooklyn estuary (The Ecology Lab, 1988; The Ecology Lab, 1997). *Enteromorpha intestinalis* was reported at Kangaroo Point, the mouth of Seymours Creek, and the southwest tip of Long Island. Blue-green algae (no species given), *Bostrychia* sp. and *Caloglossa* sp. were reported at Kangaroo Point and the mouth of Seymours Creek. *Catanella* sp. occurred at the former and latter site, and *Cystophora* sp. was reported from the latter site only. Algae were also reported as being arboreal (i.e. on mangroves) or attached to a hard or mud substratum. The green alga, *E. intestinalis*, has unbranched, hollow, tubular, green fronds, is often found at the edges of fresh water soaks, and can be abundant in polluted areas with high nutrient levels (Edgar, 1997). Hutchings *et al*. (1977) also recorded the tufted red alga *Catanella* sp. attached to the pneumatophores of grey mangroves (*Avicennia marina)*. Different epiphytic algal species were also recorded by Silberschneider (1997) in the adjacent Berowra and Cowan Creeks.

6.2.1.2 Mangroves

Mangroves grow along the shores of many NSW estuaries, with the general exception of those that are intermittently opened and closed (West *et al*., 1985). They often occur seaward of saltmarshes and are subject to regular tidal inundation. They can form dense intertidal forests where sediment accumulates to form a thick soil matrix capable of supporting the roots of many large trees. Another common growth form of mangroves is called “fringing mangroves” in which trees grow in narrow bands along the edges of tidal creeks, often one or two trees deep, as seen in the upper sections of Berowra Creek (The Ecology Lab, 1997). The flora of mangroves is limited to the trees themselves and a variety of algae, which provide habitat for fish, crabs, birds and other animals.

Mangroves are thought to contribute significantly to estuarine productivity, trap sediment and pollutants (Burchmore *et al.,* 1993), and act as sinks for contaminants (Tam & Wong, 1995). They also stabilise shorelines from erosion. The plants and animals of mangrove forests are considered to be fundamental to the production and cycling of nutrients within estuaries.

Both grey mangroves (*Avicennia marina*) and river mangroves (*Aegiceras corniculatum*) occur in the Brooklyn area (Hutchings *et al*., 1977; The Ecology Lab, 1988; 1997; Saintilan, 1997; Williams & West, 2001). The grey mangrove is the most common of all mangroves in NSW, occurring in most permanently open estuaries around mainland Australia (Edgar, 1997). River mangroves are much less common, occur further upstream in NSW estuaries, and range from the Queensland border south to Merimbula. Shoot biomass of these species is reported to decline, and root/shoot ratios increase, with increasing substratum salinity in the Hawkesbury River (Saintilan, 1997). In addition, a biomass of 40 $kg.m^{-2}$ for grey mangroves in the Hawkesbury River is the highest recorded for temperate mangrove communities (Saintilan, 1997).

A survey of the Hawkesbury River by West *et al*. (1985) (Figure 6.1) estimated mangroves covered almost 11 km^2. The amount of each type of vegetation along major waterways such as the Brooklyn area, however, was not presented. Comparisons with maps produced by Williams & Watford (1999) for Sandbrook Inlet, Spectacle Island and Mooney Mooney Point (Figure 6.4), and those produced by Williams & West (2001) (Figure 6.2) for the remainder of the Brooklyn area, provides insight into apparent changes in mangrove distribution.

Sandbrook Inlet has remained relatively unchanged in mangrove distribution for about the last 15 years (compare Figures 6.1 and 6.4) (West *et al*., 1985; Williams & Watford, 1999), however fairly large mangrove communities have appeared on the west of Spectacle Island and around Mooney Mooney Point. The map produced by Williams & West (2001) (Figure 6.2) shows that the mangrove stands around Mooney Mooney Point are comprised solely of grey mangroves, but those mapped by West *et al*. (1985) (Figure 6.1) on Spectacle Island are not apparent, perhaps because of the difference in scales between the two maps. Distributions of mangroves in Mullet and Mooney Mooney Creeks have also remained relatively unchanged (compare Figures 1 and 2) (West *et al*., 1985; Williams & West, 2001). The most recent map (Figure 6.2), however, shows that the mangrove stands at the mouths of those creeks are comprised of grey mangroves, while upstream both mangrove species exist.

Grey and river mangroves occur together in Sandbrook Inlet, with stands varying from between 360 m in width at the mouth of Seymours Creek (Hutchings *et al*., 1977) to individual trees fringing Long Island and other shores within the inlet (The Ecology Lab, 1988). Declines in mangrove distribution within the inlet prior to 1985 probably occurred as a result of land reclamation. The construction of the Sydney-Newcastle Freeway, may have increased siltation and caused ‘suffocation’ of pneumatophores (Hutchings *et al*., 1977). After completion of the Freeway in 1978, mangroves recovered rapidly, and presently cover greater levels than previously recorded (The Ecology Lab, 1997). The large stand at the mouth of Seymours Creek forms a buffer zone between the creek and the inlet, trapping sediments washed down the creek. This area is listed by the National Herbarium as being of ‘high conservation value’ (Dove *et al*., 1986). In addition, Sydney’s Regional Environmental Plan (SREP) 20- Hawkesbury/Nepean River No 2-1997 amends a number of environmental planning instruments to cover this sensitive and threatened estuarine environment, addressing such issues as wetlands protection (Farrier *et al*., 1999).

6.2.1.3 Saltmarsh

Saltmarshes are estuarine habitats that occur high on the shore between the average high water of spring and neap tides. They consist generally of soft sediments occupied by grasses, succulents, herbaceous and rush plants. Saltmarshes are usually waterlogged and frequently flooded during tidal inundation. In NSW, saltmarshes may form zones. The lowest zone is generally occupied by samphire (*Sarcocornia quinqueflora*) which sometimes grades into the edge of the mangrove forest in areas where both habitats coincide. The upper zone is often colonised by sedges and rushes. Further landward, the saltmarsh grades into adjacent terrestrial vegetation such as she-oaks (*Casuarina glauca*) and paperbarks (*Melaleuca* sp.) (Adam, 1981).

Limited information is available on the ecology of Australian saltmarshes. Knowledge of the factors influencing distribution and abundance of the plants and animals is imprecise (McGuinness, 1988). Nonetheless, saltmarshes are thought to have important physical and biological functions in estuarine systems. Physically, they are thought to trap sediments and pollutants from the water column. Biologically, they contribute to estuarine productivity through the export of organic material (Middleton, 1985).

Samphire, (*Sarcocornia quinqueflora)*, sea rush (*Juncus kraussii*), and sand couch (*Sporobolus virginicus*) have been reported among mangroves near the road causeway at Sandbrook Inlet (Hutchings *et al*., 1977), however, no quantitative data were recorded. SMEC (2000) reported three additional species; native reed (*Phragmites australis*), swamp oak (*Casuarina glauca*), and broad-leafed paper-bark (*Maleleuca quinquenervia*) at the landward margins of mangrove stands in Sandbrook Inlet.

West *et al*. (1985) (Figure 6.1) recorded 1.126 km^2 of saltmarsh within the Hawkesbury River, but again the amount along major waterways such as Brooklyn area was not specified. In addition, the map presented for this study area did not show any saltmarsh habitats. However, saltmarsh communities in the Brooklyn area have been mapped recently at Brooklyn, Long Island and Spectacle Island (Williams & Watford, 1999) and the head of Mooney Mooney Creek (Williams & West, 2001). These communities were always adjacent to and shoreward of mangrove stands (Figures 6.4 and 6.2, respectively). A recent review of 28 surveys in southeast Australian estuaries concluded that the widespread decline in saltmarsh communities is often associated with invasion by grey mangroves (Saintilan, 2000), and the fate of these habitats is uncertain.

6.2.1.4 Riparian Vegetation

Smith & Smith (1990) identified six riparian vegetation communities from Brooklyn and Dangar Island. The only other information available for riparian vegetation in the study area also comes from Brooklyn. Appendix E lists all plants observed within approximately 5km of Brooklyn (NSW NPWS Wildlife Atlas). The vegetation is influenced primarily by aspect and drainage, and has a high floristic diversity that is typically associated with Hawkesbury Sandstone settings (The Ecology Lab, 1998b). The most extensive communities are tall open forest, open forest and woodland formations (adjacent to residential areas of Brooklyn and on ridgetop areas of Dangar Island) and are as follows (Smith & Smith, 1990):

- Community A: open forest with a dominance of Sydney peppermint (*Eucalyptus piperita*) and smooth-barked apple (*Angophora costata*), predominantly found in gullies and sheltered slopes.
- Community D: woodland with a dominance of grey gum (*Eucalyptus punctata*), red bloodwood (*E. gummifera*), scribbly gum (E. *haemastoma*) and smooth-barked apple restricted to exposed slopes.
- Community P: tall open forest with a dominance of blackbutt (*Eucalyptus pilularis*) and rough-barked apple (*Angophora floribunda*), restricted to alluvial flats on the western end of Dangar Island.
- Community Q: open forest with a dominance of rough-barked apple and forest oak (*Allocasuarina torulosa*), on the steep lower slopes fringing the estuary.
- Community S: woodland with a dominance of smooth-barked apple, red bloodwood and bastard mahoghony (*Eucalyptus umbra*), on easterly steep slopes with exposure to salt breezes.
- Community T: woodland dominated by yellow bloodwood (*Eucalyptus eximia*), on steep, exposed, north-facing slopes.

Nexus (2000) reported that the bushland areas of McKell Park at Brooklyn are analogous to Community S of Smith & Smith (1990). Nexus (2000) also noted some introduced species, including African lovegrass, couch, kikuyu and dandelion. Similar findings were reported by SMEC (2000). The Ecology Lab (1988) noted that 22% of the 97 species recorded from the western foreshores of Brooklyn were introduced, however, the majority of the area was covered by native vegetation. A full list of species and their abundance scores is presented in Appendix D.

6.2.1.5 Birds

Appendix D lists all the birds observed within 5 km of the Brooklyn area (NSW NPWS Wildlife Atlas). In addition, Hutchings *et al*. (1977) reported the grey teal (*Ardea giberifrons*), the common egret (*Egretta alba*), and the yellow-billed spoonbill (*Platalea flavipes*) from casual observations at Brooklyn made over eight years. The Ecology Lab (1988) also recorded a pied currowong (*Strepera graculina*) and an australian magpie (*Gymnorhina tibicen*) from Brooklyn. Some of the most common sea birds and river birds are shown in Powell & Powell (2000) along with notes about some of their more interesting characteristics.

A total of 207 species of birds have been recorded for the estuary, including five species listed as endangered under the Threatened Species Conservation (*TSC)* Act: the bush stone-curlew (*Burhinus grallarius*); little tern (*Sterna albifrons*); regent honeyeater (*Xanthomyza phrygia*); Gould's petrel (*Pterodroma leucoptera*); and swift parrot (*Latahamus discolor*). Fifteen species were listed as vulnerable under the Act including: osprey (*Pandion haliaetus*); black bittern (*Ixobrychus flavicollis*); sooty oystercatcher (*Haematopus fuliginosus*); pied oystercatcher (*H. longirostris*); glossy black-cockatoo (*Calyptorhynchus lathami*); rose-crowned fruit-dove (*Ptilinopus regina*); superb fruit-dove (*P. superbus*); sooty tern (*Sterna fuscata*); black-breasted buzzard (*Hamirostra melanosternon*); turquoise parrot (*Neophema pulchella*); terek sandpiper (*Xenus cinereus*); barking owl (*Ninox connivens*); powerful owl (*N. strenua*); masked owl (*Tyto novaehollandiae*); and sooty owl *(T. tenebricosa*).

In addition, three species listed as threatened, and covered by the migratory provisions of the *EPBC* Act (1999), are likely to occur within the vicinity of Brooklyn area. They are the southern-giant petrel (*Macronectes giganteus*), the northern-giant petrel (*M. halli*) and the shy albatross (*Thalassarche cauta*).

6.2.1.6 Threatened Species

In NSW, the TSC Act (1995) is aimed at protecting animals and plants considered vulnerable or endangered from human activities. The legislation provides for the listing of threatened species, populations and ecological communities and has replaced the endangered fauna list known as Schedule 12 of the *National Parks and Wildlife* Act, 1974. 'Threatened' species, now listed in Schedules 1 and 2, are defined as endangered and/or vulnerable species, respectively. New Commonwealth legislation, the *Environment Protection and Biodiversity Conservation* (*EPBC*) Act (1999) also lists threatened species. Threatened species identified in each of these pieces of legislation within approximately 5 km of Brooklyn area are highlighted in Appendix D.

Eight endangered and twenty vulnerable fauna species, and two endangered and nine vulnerable plant species identified under the *TSC* Act (1995) have been recorded within 5 km of Brooklyn area. A search of the *EPBC* Act (1999) database found nine endangered and twenty-nine vulnerable species of flora and fauna. The search also detected a number of animals protected under other sections of the *EPBC* Act (1999) including: 3 marine birds; 5 marine species; 6 terrestrial species and 2 wetland bird species covered by the migratory provisions of the Act; and 11 birds; 21 fish and 3 reptiles covered by the marine provisions of the Act (Appendix D).

6.2.2 Habitat Mapping Methods

A qualitative habitat assessment was compiled based on observations made in the field between 18 and 20 September 2001. Ecologists visited various parts of the estuary by boat, allowing easy access to the shoreline when necessary. The perimeter of the study area was inspected, and for ease of observation and reference, it was divided into four sections; Mullet Creek, Mooney Mooney Creek, Sandbrook Inlet and the main channel of the Hawkesbury River. Within each section the topography and characteristics of the surrounding land, foreshore and subtidal habitats was summarised. Within each of these habitats, the type and extent of aquatic and fringing flora and fauna was noted. General observations on the presence of birds, fish and other fauna and on the types and magnitude of foreshore development were also recorded.

The results of the habitat assessment were described in detail and based on field observations. Many seagrass beds were shallow and could be observed from the boat, while deeper beds such as the one south of Dangar Island required diving. Recent mapping of estuarine habitat by NSW Fisheries (Williams and Watford, 1999; Williams and West, 2001) was compared to field observations. Any changes noted since those maps were prepared are discussed below.

6.2.3 Habitat Mapping Results

The following sections provide a general description of the subtidal, intertidal and fringing terrestrial habitats of the study area assessed during the site inspection described above. These results are not definitive, rather they are indicative of the most dominant assemblages occurring during the site visit. They describe the major sections of the estuary moving upstream from Croppy Point along the northern banks, Mullet and Mooney Mooney Creeks, Dangar Island, Spectacle Island, Sandbrook Inlet, then back along the southern banks to Parsley Bay.

6.2.3.1 Main Channel of the Hawkesbury River

This section included the foreshore upstream from a line between Croppy Point and Parsley Bay, to Peats Ferry Bridge, excluding Mooney Mooney, Mullet Creeks and Sandbrook Inlet. Narrow foreshores of sandstone rubble backed by steep sloping hillsides dominated the shoreline, with sandstone boulders and rocky outcrops common in intertidal and subtidal areas. Typical hillside vegetation consisted mainly of eucalypts and she-oaks (*Casuarina glauca*), interspersed with wattle (*Acacia* spp.) and grass trees (*Xanthorrhoea* spp.). Intertidal rocks were heavily to moderately encrusted with oysters (*Saccostrea commercialis*) and mussels (Family Mytilidae). Periwinkles (*Bembicium* spp.) were common higher in the intertidal areas and the limpets *Siphonaria denticulata* and *Patelloida mimula* were often scattered amongst oysters. Sargassum (*Sargassum* spp.) and kelp (*Ecklonia radiata*) were common in subtidal areas. The green alga *Codium fragile* was occasionally found growing in low intertidal areas, as were small patches of *Caulerpa filiformis*.

The foreshore between Brooklyn Wharf and Parsley Bay is well developed with a marina and public boat ramp, respectively. The intertidal rock rubble and concrete seawall in this area had an almost continuous band of oysters. These were interspersed with periwinkles and barnacles, and were located high on intertidal rocks with occasional patches of green filamentous algae. An orange sponge occurred extensively on low intertidal rocks in Parsley Bay, and again sargassum and kelp dominated the subtidal environment.

Some of the common birds seen within the main estuary included: great cormorants (*Phalacrocorax carbo*); little pied cormorants (*P. melanoleucos*); maned ducks with ducklings (*Chenonetta jubata*); mallards (*Anas platyrhynchos*); Australian pelicans (*Pelecanus conspicillatus*); silver gulls (*Larus novaehollandiae*); pied oystercatchers (*Haematopus longirostris*); Australian ravens (*Corvus coronoides*); Australian magpies (*Gymnorhina tibicen*); and pied currawongs (*Strepera graculina*).

Occasionally grey mangroves (*Avicennia marina*) were noted growing out of the rocky foreshore areas. These were primarily individual plants separated by as much as several hundred metres. However, there were no mangrove forests mapped in the main channel section of study area as these were not significantly different from those mapped by NSW Fisheries (Figure 6.1 – 6.4).

There were two large patches of seagrasses in the main estuary. One occurred immediately to the south of Dangar Island and the other was found to the east of the railway causeway, within Brooklyn Harbour. The area of seagrass in Brooklyn Harbour mapped by Nexus (2000) was 1.7 ha and 2.37 ha by the Ecology Lab (2002). This indicated that the bed has increased in size.

Oyster leases occurred in three main areas: (1) north of Little Wobby Beach, (2) east of the railway causeway at Brooklyn, and (3) outside the breakwater in Parsley Bay. One of the leases in the first area appeared to be derelict, whilst the remaining leases were operational and had six to ten oyster sticks to a stack, indicating that they were being used for catching oyster spat. Foreshore development was mainly concentrated along Little Wobby Beach, and from between Brooklyn Wharf and Parsley Bay. Little Wobby Beach had private hillside residencies with sandstone seawalls and wooden jetties, some private boat harbours, slipways with boatsheds, scattered moorings and one public wharf. Brooklyn Wharf has an extensive marina development. A rocky wall bounded two sides of Brooklyn Harbour and there were also some wooden jetties, several dozen moorings, and a public baths enclosure. The remaining foreshore in the main estuary was largely undeveloped.

6.2.3.2 Dangar Island

Hillside and foreshore topography, and animal and plant assemblages of Dangar Island were similar to the main estuary, except that the northeast point of the island and Coolongolook Point to the south had large intertidal mudflat areas. The entire foreshore had private hillside residences with jetties and moorings. Two beaches on Dangar Island easily accessible to the public are Bradley's Beach and North Beach located west of the public wharf. Oyster leases occurred over a small area of the northern shore.

A large seagrass bed (*Zostera capricorni*) covered much of the mudflat at Coolongolook Point. Shoots of most plants were short, and individual plants were sparse along the western, northern and eastern fringes, with occasional dying/dead patches higher on the mudflat. The southern tip of the mudflat has dense eelgrass with long shoots that extend further south in small patches into deeper areas.

6.2.3.3 Mullet Creek

Mullet Creek extends north and east from Alison and Cogra Points on the Hawkesbury River. Narrow sandstone rubble foreshores backed by steep sloping hillsides dominated the fringing terrestrial topography on the eastern shores of the creek. Western foreshores along the entire length of the creek were wider, and there were artificial rock rubble seawalls along which the main northern railway line ran. A thin strip of weedy riparian vegetation occurred between the waters edge and the railway line. Typical hillside vegetation on both banks consisted mainly of eucalypts and she-oaks, interspersed with wattle and grass trees, and the occasional banksia. Intertidal rocks, both artificial and natural, were encrusted with oysters above low water levels and scattered mussels occurred below. Periwinkles were common higher in the intertidal zone, whilst sargassum was often attached to subtidal rocks. Grapsid crabs (*Sesarma erythrodactyla*) were occasionally seen crawling over the rocky foreshore on the natural eastern banks.

Birds observed in Mullet creek included the common estuarine forms listed in the previous section, as well as: white-bellied sea-eagles (*Haliaetus leucogaster*); wrens (Family Maluridae); and glossy black cockatoos (*Calyptorhynchus lathami*). Fishes commonly seen included: mullet (Family Mugilidae); yellowfin bream (*Acanthopagrus australis)* toadfish (Family Tetraodontidae); garfish (Family Hemiramphidae); and sting rays (Family Dasyatididae). Jellyfishes (*Aurelia* sp.) were also spotted occasionally.

Tucked into the backs of most bays along the eastern foreshore were small stands of mangroves ranging from thirty square metres at the head of Mullet Creek to approximately eighty square metres at bays near the mouth. Mangrove stands at the head of Mullet Creek comprised both grey mangroves and river mangroves, whilst those at the mouth comprised only grey mangroves. Where both species occurred small, river mangroves less than 2 m tall were backed by large grey mangroves up to 10 m tall. Stands of grey mangroves consisted of scattered juvenile plants fronting mature trees.

An extensive bed of patchy seagrass occurred over the sand shoal at the head of Mullet Creek. Eelgrass dominated this bed, and some paddleweed (*Halophila* sp.) also occurred. In shallow areas, eelgrass was sparse with short shoots, whilst deeper areas had a more consistent cover of plants with longer shoots and high epiphyte loads. Eelgrass also occurred within the adjacent two bays to the south and east of the head of Mullet creek, as narrow bands of scattered plants along the subtidal edge of mudflats.

Oyster leases extended south from Wondabyne Station along both sides of the creek. Oyster stacks appeared to have between one and six sticks of oysters indicating both depot leases and catch leases respectively. The largest areas of oyster leases occurred around the mouth of Mullet Creek where there was no foreshore development. Less than a dozen private residencies occurred along the entire length of Mullet Creek. These were concentrated mainly around the area of Wondabyne Station where there was a wharf, a grassy park with stone statues, and some dumped rubbish. Associated with the private foreshore properties were occasional sandstone seawalls, jetties and moorings.

6.2.3.4 Mooney Mooney Creek and Spectacle Island

Mooney Mooney Creek extends upstream from Cogra Point and Peats Ferry Bridge on the Hawkesbury River, and includes Spectacle Island. As in other areas, narrow sandstone rubble foreshores backed by steep sloping hillsides dominated the shoreline. Sandstone boulders and rocky outcrops were common in intertidal and subtidal areas between embayments, whilst within bays extensive intertidal mudflats were more common. Typical hillside vegetation did not differ from that described for the main estuary, and neither did the typical rocky intertidal assemblages.

Birds seen in Mooney Mooney Creek again included the common estuarine forms, as well as: eastern whipbirds (*Psophodes olivaceus*); bellbirds (Family Pachycephalidae); wedge-tailed eagles (*Aquila audax*); and hawks (Family Accipitridae). White-faced herons (*Ardea novaehollandiae*) were seen in moderate numbers, feeding over each of the mudflats within the creek, particularly on the extensive mudflats to the west of Spectacle Island. These mudflats also had a large number of ocypodid crabs (*Heloecius cordiformis*).

Mangrove stands backed each of the bays within Mooney Mooney Creek and behind intertidal mudflats. At the junction of Mooney Mooney Creek and Piles Creek, mangroves flanked both shores. Bays to the north of Fox Bay had mixed mangrove stands comprising both grey and river mangroves, whilst mangroves in Fox Bay and other bays to the south comprised solely grey mangroves. Again, river mangroves were much smaller than grey mangroves, and usually occurred in front of and sometimes interspersed amongst them. Mangrove stands ranged from about thirty square metres in small bays, to several hundred square metres at the head of the creek, and on the western fringe of Spectacle Island. Individual grey mangroves did not exceed 10 m in height, and river mangroves did not exceed 3 m. Some mangrove stands on the western banks at the head of the creek had erosion stepped foreshores, whilst some eastern bays to the south had extensive sedimentation, evidenced by the burial of derelict oyster leases adjacent to a mangrove stand opposite Native Dog Bay, a fringe of scattered eelgrass plants with long shoots extended approximately one hundred metres. This was the only seagrass bed mapped within Mooney Mooney Creek.

Oyster leases extended to the mouth of Mooney Mooney Creek south of Two Dollar Bay, and immediately to the south of Spectacle Island. Again, there were stacks of one to six oyster sticks, indicating depot and catch leases respectively. Similarly, foreshore development was also scattered along this length of the creek, with the exception of the township of Mooney Mooney, which was heavily built-up. The entire headland at Mooney Mooney was covered with private hillside residences having sandstone seawalls, wooden jetties, slipways with boatsheds, scattered moorings and one public wharf.

6.2.3.5 Sandbrook Inlet

Sandbrook Inlet extends south and east from Kangaroo Point at Peats Ferry Bridge to between the Brooklyn shore and Long Island. It is closed at the lower end by the railway causeway.

The inlet was shallow with extensive mudflats at low tide and the occasional oyster-covered rock. There were extensive areas of fringing grey mangroves along the Brooklyn and Long Island shores. Individual trees were up to 8 m in height. Mangrove stands occurred at the mouth of Seymours Creek and midway along the Brooklyn shore. The foreshore behind varied from gently sloping hills to steep sandstone cliffs with eucalypt forests. Hillside eucalypts were interspersed with casuarinas, acacias and other typical native vegetation types described for the main estuary. On Long Island small sandy beaches were interspersed between large areas of intertidal sandstone boulders and fringing grey mangroves.

Oyster leases occurred midway along the Brooklyn shore, at the lower end of the inlet, and on the southwest edge of Long Island. Stacks of single oyster sticks indicated that they were depot leases. The entire foreshore along the Brooklyn shore had private hillside residences with numerous wooden jetties, moorings, marinas and other businesses. Brooklyn Park was located along this foreshore with its 'Sydney Coastal Estuary Swamp Forest Complex' boardwalk. The eastern end of Long Island was developed with railway infrastructure and an electricity substation. The remaining foreshore in Sandbrook Inlet was largely undeveloped. Long Island is a nature reserve and as such was entirely undeveloped. There were up to 300 boats moored in the inlet (not including those at berths).

6.2.4 Discussion

None of the aquatic fauna species recorded near Brooklyn Causeway are protected species under the Threatened Species Conservation Act, 1995 or Fisheries Management Act, 1994. Marine vegetation, however, is protected and if harm to marine vegetation is imminent, a permit needs to be obtained from NSW Fisheries (under the NSW Fisheries Act, 1994).

In general, the flora and fauna communities observed were well represented throughout the Study area. The hillside vegetation, intertidal communities and riparian vegetation were similar throughout Mooney Mooney Creek, Mullet Creek, the main estuary and Sandbrook Inlet. More bird species were observed along Mullet Creek and Mooney Mooney Creeks compared to the rest of the Study area, although this is based only on qualitative observations.

The coverage of mangrove forests has remained relatively unchanged over the last 15 years, while the cover of seagrass appears to have increased in Brooklyn Harbour, Sandbrook Inlet and at the head of Mullet Creek. Although saltmarsh cover was recorded for the entire Hawkesbury River (West *et al*,. 1985) no estimates were made of cover for smaller zones until recently (William & Waterford, 1999 and William & West, 2001). Therefore, the change in cover for specific patches of saltmarsh cannot be estimated.

6.3 Intertidal Invertebrates

6.3.1 Review of Information

Benthic invertebrates are common in saltmarshes, mangroves, seagrass beds, intertidal and subtidal mudflats, sandflats, and on rocky substratum. They exhibit a wide range of sizes which are commonly used to categorise them as macrofauna (> 1mm diameter), meiofauna (< 1mm but > 0.062 mm) and microfauna (< 0.062 mm). They are an important component of estuarine fauna, providing a food source for each other and a variety of predators (e.g. birds and fish). They also play an important role in pathways of detrital and nutrient recycling and are good indicators of environmental disturbances such as pollution. Benthic invertebrates can also be categorised according to where they live. 'Infauna' live within the sediment, and 'epifauna' live on the surface of sediments or plants such as seagrasses, mangroves, etc.

Benthic macrofauna typically comprise invertebrate animals such as marine worms (polychaetes), shells (bivalves and gastropods) and crustaceans which live on or in the seafloor (often termed the 'substratum').

Hutchings *et al*. (1977) recorded 27 species of benthic invertebrates along transects through mangrove and saltmarsh habitats at Brooklyn. The largest groups were brachyuran crustaceans (crabs) and gastropod molluscs, but also recorded were species of bivalve molluscs, shrimps, isopod and amphipod crustaceans, and polychaete worms. The animals along the transect at the entrance of Seymour's Creek were much more specious than those along a foreshore transect directly south of the inlet, which was reported to have a highly anaerobic substratum. However, transects at each site were not replicated.

The Ecology Lab (1988) surveyed intertidal and subtidal benthos along twelve randomly placed transects in mangrove stands at Brooklyn, by collecting replicate benthic cores from twelve stations within Sandbrook Inlet. No intertidal polychaetes were sampled in this study, however arboreal and hard substratum barnacles were recorded. A more limited study carried out almost a decade later in the same area recorded only fourteen species (The Ecology Lab, 1997).

A count of 475 individuals from 26 invertebrate species was recorded from the 48 subtidal benthic cores collected by the Ecology Lab (1988). Numbers of crustaceans collected from the man-made marina sites were significantly greater than from the natural sites. The dominant species at all sites were the polychaetes *Nephtys australiensis* (Nephtyidae), *Notomastus torquatus* (Capitellidae) and *Terebellides stroemi* (Trichobranchidae), and the bivalve *Notospisula trigonella*. These species also dominated many of the samples from other parts of the Hawkesbury River as shown by Jones *et al*. (1986). However, the benthos of Sandbrook Inlet was relatively depauperate by comparison. This reduction in species may be due to repeated dredging of the maintenance channel over the last 20 years. Seaward transects of the Hawkesbury River were usually more speciose than those further upstream, though not always significantly so, and there was no clear pattern with sediment grade (Jones *et al*., 1986; Jones, 1988). In addition, a temporal study of the Hawkesbury benthos produced unrepeatable, seasonal and annual differences in species numbers and individuals at all sites (Jones, 1987). This suggested that factors such as space, time, salinity and sediment interact with other variables to produce unpredictable results.

Subtidal benthos was also sampled pre- and post-maintenance dredging and after spoil disposal at Brooklyn (Jones, 1986). Densities of animals decreased as a result of dredging, and species differed in their rates of recolonisation. Dominant species survived spoil disposal (e.g. the trichobranchid polychaete *Terebellides stroemi*). Polychaetes collected from this study and other studies such as the Hawkesbury River Survey and Cowan Waters Survey by the Australian Museum over several years were studied for taxonomic purposes (Hutchings & Murray, 1984). A taxonomic key was provided and 28 new species and 4 new genera were described.

More recently, intertidal and subtidal benthic organisms were sampled in Brooklyn Harbour to assess the effects of maintenance dredging and partial foreshore reclamation (The Ecology Lab, 2002). Fewer benthic taxa from subtidal soft sediment were found in Brooklyn Harbour compared to two reference locations (Parsley Bay and Dangar Island). This suggested that the subtidal infaunal assemblages in the harbour were depauperate relative to nearby areas. This finding was consistent with Jones (1986) who found fewer species and abundances of benthic invertebrates in Brooklyn Harbour compared to a control location in the Hawkesbury River.

Life history parameters and the population biology of the dominant bivalve *Notospisula trigonella* have been determined in the Hawkesbury River (Jones *et al*., 1988). Spatial and temporal differences in their abundance were weakly correlated with salinity, water depth and sediment grade.

Other abundant benthic invertebrates from the estuary have also been used in bio-indication experiments. The tidal amphipod, *Corophium* sp. (Hyne & Everett, 1998) and the semaphore crab *Heloecius cordiformis* (MacFarlane *et al*., 2000) were examined as suitable indicators of sediment toxicity. Field and lab experiments on the Sydney rock oyster (*Saccostrea commercialis*) conducted in the lower Hawkesbury, showed that Sandbrook Inlet had the highest rates of oyster mortality and shell deformation when compared with other sites (Scammel, 1987). The higher mortality rate in Sandbrook Inlet was likely due to the high concentration of the contaminant TBT (tributyl tin) in the inlet. Sandbrook Inlet was found to have the longest residence time for contaminants in the study area (refer to section 6.6.4). TBT can concentrate in molluscs up to 250,000 times higher than surrounding sediments or seawater. Affected molluscs, such as oysters, have deformed shells, slow growth rates and poor reproduction rates. Since 1989 there has been an Australian ban on the use of TBT for antifouling vessels smaller than 25 m in length. TBT takes up to ten years to degrade to safe levels (ANZECC, undated). It can be expected that environmental impacts from TBT have reduced in recent years.

6.3.2 Intertidal Rocky Shore Invertebrate

The Ecology Lab sampled intertidal flora and fauna on the rocky causeway to identify if significant differences existed in species types and abundance between the Brooklyn Harbour and the Sandbrook Inlet side of the causeway.

6.3.2.1 Sampling Methods

Intertidal flora and fauna were sampled at low tides between 30/01/02 and 01/02/02 as part of a separate study for the EIS prepared on the Central Coast Rail upgrade (Halliburton KBR, in prep.). Three sites were sampled: (1) on the eastern and western sides of the railway causeway at Brooklyn, (2) between the Hawkesbury River railway station and (3) at Long Island (Figure 6.10). Those sites sampled on the eastern side of the causeway are referred to as “outer” or Brooklyn Harbour side, and those on the Sandbrook Inlet side were referred to as “inner” or Sandbrook Inlet side of the causeway (Figure 6.10).

At each location, a hand-held Global Positioning System (GPS) was used to record the location of sampling sites and to estimate the distance between sites (Appendix D). Qualitative descriptions included: weather conditions; rock type and topography; and any other obvious identifying features. The dominant fauna and flora were quantified for each of the zones and photographs were taken to record notable features of the intertidal assemblages.

On each side of the causeway sites were selected 50 to 100 m apart. At each site sampling was done at two heights on the shore denoted as:

- The highshore littorinid zone, and;

- The lowshore oyster zone.

In each zone, samples were taken in 10 quadrats (50 x 50 cm) placed randomly on the substratum. Percentage covers of primary algae (attached directly to the substratum) was estimated using 100, evenly-spaced points per quadrat. Numbers of live and dead oysters were counted within each quadrat. The abundance of sessile and slow-moving-mobile animals (e.g. barnacles and gastropods) was recorded within each quadrat. The presence of highly mobile animals such as crabs and isopods were also noted for each quadrat, but not counted. The abundance of individual taxa were analysed using univariate analysis of variance to elicit spatial patterns (refer to Appendix D). In the analyses the factor 'zone' (height on shore) and 'location' were considered fixed and orthogonal, while sites were random and nested within location.

6.3.2.2 Invertebrate Results

The intertidal organisms observed on the rocky substratum of the rail causeway were typical of those from estuarine habitats. They were dominated by littorinid snails (*Bembicium auratum),* Sydney rock oysters (*Saccostrea commercialis)*, honeycomb barnacles (*Chamaesipho tasmanica)* and small patellid limpets (*Patelloida mimula* and *Patelloida insignis).*

The lower shores of the causeway in Sandbrook Inlet were composed of a muddy surface and interspersed oyster-covered rocks. The shells of Oysters were high and rounded. In contrast, on the Brooklyn Harbour side, there was no mud at the low tide zone and the oysters were more flattened against the rocks. The differences in oyster shape and size may be due to the smaller size of the rocks and the greater prevalence of mud on the Sandbrook Inlet side, or to differences in tidal flushing, wind and wave exposure.

The diversity of organisms on the lower shore of the Brooklyn Harbour (nine species) was significantly greater than on the lower shore of Sandbrook Inlet (four species). Patterns of organisms abundance varied according to shore height and locations (within sites), but on the Brooklyn side of the causeway significantly more organisms were found in the low zone compared to the high intertidal zone (Figure 6.5). Significantly more live and dead oysters were counted in the low intertidal zone on the Brooklyn Harbour side of the causeway than in the comparable habitat on the Sandbrook side (Figure 6.5). The two species of littorinid snail (*Bembicium nanaum* and *B. auratum*) were more abundant on the lower than upper shore and were more numerous on the Sandbrook Inlet side. The mussel, *Mytilus edulis*, was found only on the Sandbrook Inlet side and was more abundant high on the shore (Figure 6.5). More of the limpets, *Patelloida mimula*, were found on the Brooklyn Harbour side, (as they are known to be associated with live and dead oyster shells) (Edgar, 1997) (Figure 6.5).

Some differences in abundance were apparent at different sites along the causeway. On the Sandbrook Inlet side, more honeycomb barnacles (*Chamaesipho tasmanica*) were present at the site closest to the railway bridge (Figure 6.5). On the Brooklyn Harbour side, more purple periwinkles (*Noddilitorina unifasciata*) were counted at site three (closest to the Brooklyn marina) than at the two sites closer to the railway bridge (Figure 6.5). These results suggest that a relatively large difference in patterns of diversity and abundance occurs in intertidal flora and fauna on either side of the causeway.

6.3.2.3 Discussion

The Brooklyn Harbour side and Sandbrook Inlet side of the causeway were different in terms of the number of species, abundances and distribution of intertidal organisms.

Overall, significantly fewer individuals and species of intertidal invertebrates were present on the Sandbrook Inlet side of the causeway than the Brooklyn side. This may be due to the restricted flushing and water flow of the Sandbrook Inlet side compared to Brooklyn Harbour. However, a number of processes or factors could account for the differences observed. Further work involving experimental manipulation would need to be done to provide evidence supporting any specific model of distribution. Further studies could focus on the following processes that might be affecting the distribution of organisms on rocky shores: current regimes influencing the availability of larvae and nutrients on either side of the causeway; differences in the substratum such as differences in complexity, texture and orientation; variations in sunlight and wind; anthropogenic pressures; and effects of competition and predation between organisms.

Periodic sampling and assessment of soft-bottom intertidal invertebrates is recommended as a cost efficient and reliable strategy for detecting disturbances. However, the same sites should be sampled each time to eliminate variation due to location. Decreased tidal flushing in Sandbrook Inlet could possibly explain the different intertidal assemblages observed either side of the causeway. A more complex intertidal sampling design addressing other possible processes influencing the distribution and abundances of intertidal organisms on rocky shores is recommended.

6.3.3 Intertidal Soft Sediment Invertebrates

The Centre for Research on Ecological Impacts of Coastal Cities located at the University of Sydney studied benthic invertebrates occurring in the Brooklyn area. The objective of this study was to collect baseline data on the benthic invertebrate assemblages associated with the low-shore area of fringing mangrove forests in the Brooklyn region of the Hawkesbury River. Samples collected from two locations in the poorly flushed Sandbrook Inlet were compared with those from two reference locations adjacent to the main channel of the Hawkesbury River. Previous studies around Sydney have shown that poorly flushed mangrove forests support fewer invertebrates than well-flushed locations (Chapman and Underwood, 1996a, 1996b). It was therefore predicted that the assemblages in the Inlet would differ from those found at the two reference locations.

6.3.3.1 Sampling Methods

Samples were collected from four locations: (1) at the eastern end of Sandbrook Inlet, (2) towards the western end of Long Island opposite Spectacle Island, (3) to the north of Mooney Mooney Point and (4) from the second embayment inside Mullet Creek (Figure 6.10). Sandbrook Inlet sites were considered to be potentially impacted and locations in Mooney Mooney Creek and Mullet Creek were reference places. At each location, five replicate 0.1 m^2 quadrats were collected from the low-shore area of two sites, approximately 30 metres apart. This sampling design enabled differences in assemblages to be identified at three spatial scales: among quadrats metres apart, between sites tens of metres apart and among locations hundreds to thousands of metres apart. In previous studies, these have been shown to be important scales for interpreting data about fauna in mangroves.

The numbers of conspicuous organisms (e.g. mangrove saplings, pneumatophores, mussels, oysters and gastropod snails) in each quadrat were recorded and the percentage cover of leaf-litter, algae and oysters measured under a grid of 100 points (Appendix D). The leaf-litter and sediment in each quadrat were then collected to a depth of 1 - 2 cm, preserved and returned to the laboratory. Each of these samples was subsequently divided into coarse (> 1 mm) and fine (> 500 μm but < than 1 mm) components by sieving. Invertebrates in each component were removed, identified and counted. Common taxa, such as molluscs, crabs, amphipods and isopods, were identified to species or morphospecies, polychaetes to family, oligochaetes to class, and less common taxa, such as nemerteans and nematodes, were identified to phylum. Previous studies (Warwick, 1988; Olsgard *et al*., 1997; and Chapman, 1998) have shown that identification of animals to species level is not needed to detect differences in assemblages among locations.

Asymmetrical analyses of variance were used to compare the total number of various types of animals and abundances of specific taxa found at each location in Sandbrook Inlet with the average at the two reference locations (Underwood, 1997). Multivariate analyses were used to examine patterns in assemblages within and among locations (nMDS), identify the taxa which contributed to the dissimilarities among assemblages in different places (SIMPER), and test hypotheses about the overall structure of the invertebrate assemblage (NPMANOVA) (Clarke, 1993; Anderson, 2001); though pertinent results are given below additional information can be found in Appendix D.

6.3.3.2 Results

51 taxa representing 5 phyla were sampled. The six most abundant taxa, oligochaetes, nephythidae, nereidae, sabellidae, insect larvae and amphipod 3, accounted for 84 % of the total number of animals collected. The total number of nereid, sabellid and oligochaete worms at the eastern end of Sandbrook Inlet were greater than the two reference sites averaged together (Fig 6.5 - Pneumatophores). Pneumatophores and nereid worms were significantly more abundant at the reference sites, but crab holes were less abundant at the western end of Sandbrook Inlet. A marked difference in the number of crab-holes was also evident between the sites in this location.

The assemblages at the eastern end of Sandbrook Inlet differed from those at the western end, however, they both differed from assemblages found at the reference locations (note the separation of symbols representing these locations in Figure 6.5 - Nereids). The major contributors to the dissimilarity between assemblages at the eastern end of Sandbrook Inlet and the other locations were the number of oligochaetes, nereids, sabellids, crab-holes and amphipod 3. Oligochaetes and nereids were forty times more abundant and sabellids and amphipod 3 four times more abundant on average at the eastern end of the inlet (Appendix D). The assemblages found at the two sites at the western end of the inlet also differed. The major taxa responsible for the dissimilarity in these assemblages were crab-holes, oweniids, sabellids, nephthyids and the oyster *Saccostrea commercialis*. Crab-holes, nephtyids and oysters were all more abundant at site one. The dissimilarity in assemblages was generally smaller within than between locations except at the western end of Sandbrook Inlet. The dissimilarity in the assemblages at two sites in Sandbrook Inlet, one at the eastern end and the other at the western end, were greater than at the other sites. The dissimilarity in assemblages between sites was greater at the western end of Sandbrook Inlet than at the other locations (Appendix D).

6.3.3.3 Discussion

Assemblages of benthic invertebrates in fringing mangroves in the Brooklyn region of the Hawkesbury River varied greatly and differed significantly at the spatial scales examined. The assemblage at the eastern end of Sandbrook Inlet differed from the western end of the Inlet and both of these differed from the two reference locations. These differences were due to variations in the abundances of the dominant taxa. Certain taxa were significantly more abundant at the locations in Sandbrook Inlet than at the two reference locations. Nereid worms were the only group of animals to show a consistent trend, being more abundant at both locations in the Inlet. Sabellids and oligochaetes were more abundant at the eastern end of the Inlet, whereas pneumatophores were more abundant at the western end of the Inlet than at the reference sites. Although the assemblages in Sandbrook Inlet differed from those at the two reference locations, there was no evidence to suggest that they were depauperate, as is the case in other poorly-flushed mangrove forests in the Sydney region (Chapman and Underwood 1996a; 1996b).

Previous studies on benthic assemblages in soft-sediment habitats have shown that spatial patterns are not consistent over either short- or long-term temporal scales and that temporal patterns vary with spatial scale (Warwick and Uncles, 1980; Livingston, 1987; Morrisey *et al*., 1992a; 1992b). The results presented above cannot, therefore be regarded as either definitive or representative. A sampling programme incorporating adequate small- and large-scale temporal replication in addition to appropriate scales of spatial replication is needed to gain a better understanding of the variability in invertebrate assemblages (Appendix D). The differences in benthic macrofauna outlined above cannot be attributed to any particular effect, because a number of different natural and anthropogenic factors are known to influence the abundance and distribution of benthic fauna. Well-designed manipulative experiments are required to test hypotheses about how such factors, acting singly or in combination, cause and maintain the variations in fauna observed between Sandbrook Inlet and the reference locations.

6.4 Fisheries

There are only a few minor contentious issues with respect to commercial and recreational fishing within Brooklyn. However, there is reported to be occasional low level conflict between commercial fishers using mesh nets and recreational fishers at the road bridges (P. Scheutrumpf, pers. comm. 2001) NSW Fisheries have received complaints from residents along Wobby Beach due to the noise of commercial fishing boats. The theft of commercial mud traps and hoop nets have also been reported.

6.4.1 Recreational Fishing

Recreation fishing occurs throughout the study area but tends to be concentrated around the main channel of the Hawkesbury River (P. Schuetrumpf, pers. comm. 2001). Figure 6.5 identifies some of the regular fishing spots for most species caught within the study area. Many of the preferred target species are caught year around, although some fishers have their own secret seasons and locations for individual species. For example, a good time for jewfish is believed to be during spring tides in either full or new moon conditions at varying times due to tidal characteristics. The major species targeted include: yellow fin bream, flathead, hairtail, leatherjackets, luderick, mulloway or jewfish, tailor, whiting, juvenile snapper and occasionally Australian bass (Ross, 1995). Jewfish are a common target of recreational anglers, and, as they are often large and abundant, the Hawkesbury River is famous for this species (Ross, 1995).

Weekends are the busiest times for recreational fishers with over 300 boats fishing within the estuary, particularly in summer and on Public Holidays (P. Scheutrumpf, pers. comm. 2001). Boats can be chartered from a number of outlets in Sandbrook Inlet. Many people also fish from their own boats or from the shore. Boat launching areas are available in

Sandbrook Inlet, and Parsley Bay, and many fishers use the ramp to the west of the bridge at Mooney Mooney Point (Ross, 1995).

The compliance rates for recreational fishers appear to be high with only 5-10% of people being caught with undersized fish. Furthermore, over 80% of recreational fishers in Brooklyn have current recreational fishing licences. Recreational fishers are not allowed to trawl for prawns anywhere in NSW. They can, however, use a hand-hauled prawn net or push/scissor nets in some areas, but the nets must be registered with NSW Fisheries. Crab trapping is also permitted (P. Scheutrumpf, pers. comm. 2001).

Best estimates from NSW Fisheries for recreational fishing in the Hawkesbury River indicate that there are approximately 150,000 recreational fishing outings in the Hawkesbury River each year. Of these, 18% occur from the shore and 82% are boat based. Initial results also suggest that the catch retained by fishers in the Hawkesbury Estuary is approximately 580,000 fish per annum, with about twice that number returned to the water. Ten of the most commonly caught species are whiting, flathead, bream, leatherjacket, flounder or sole, yellowtail, tailor, catfish, jewfish and trevally. The most commonly caught crustaceans are blue swimmer crabs and the most commonly collected molluscs are cockles.

6.4.2 Commercial Fishing

In 2001, estuarine fisheries in NSW were worth $19.6 million and produced over 5,000 tonnes of fish (Tanner & Liggins, 2000; 2001). The Hawkesbury River, which supplied over 268 t of fish in 1998/1999, is the 4th largest in NSW after the Clarence River, Wallis Lakes, and Port Stephens/Myall Lakes (Tanner & Liggins, 2001).

Commercial fishers who operate in the Hawkesbury area provide NSW Fisheries with information about their catches, but this information is not specific to Brooklyn. Any attempt to get more specific information about catches solely within Brooklyn would require specific surveys with agreement from commercial fishers and NSW Fisheries. For the purposes of stock management, however, specific information on commercial exploitation in Brooklyn will probably not prove useful because there is almost certainly considerable movement of fish species between Brooklyn and nearby waterways. That is, because fish are highly mobile, it will only be sensible to manage or to try to understand the fishery on a large spatial scale, such as the entire Hawkesbury region, or perhaps even larger scales for certain species.

Over the past 15 years, 66% of the total commercial catch for the Hawkesbury River has been finfish, followed by crustaceans (27%) and molluscs (6%). Over the past 15 years, the most commonly caught finfish species were sea mullet (40% of the total finfish catch, by weight), followed by bream (9%), mulloway (6%), luderick, trevally, whitebait and silverbiddy (each 4%). The mollusc catch is dominated by squid (97%) and crustaceans are dominated by prawns (76%) followed by blue swimmer crabs (7%) and mud crabs (4%) (Tanner and Liggins, 2001). Additional information regarding the numbers of fishers, fish caught per annum or fish species can be obtained from the NSW Fisheries website at http://www.fisheries.nsw.gov.au/commercial/statscom.htm.

The number of commercial fishers in the Hawkesbury, the number of days fished and the commercial catch (kg) are presented for the past 15 years in Figures 6.6 and 6.7. The number of fishers in the Hawkesbury decreased from over 100 during the early 1990s to 80 in 1999-2000.

There is no hauling within Sandbrook Inlet, and prawn trawling is not permitted between Croppy Point and the railway bridge due to high abundances of juvenile jewfish and heavy boat traffic (P. Scheutrumpf, pers. comm.. 2001). Furthermore, prawn trawling is not permitted on weekends and public holidays.

6.4.3 Oyster Farming

6.4.3.1 Description of Oyster Farming Practices

Of the 28 oyster farmers in the Hawkesbury, 15 operate and farm Sydney Rock Oysters within the Brooklyn area. Most of these leases are located within Mooney Mooney and Mullet Creeks, but there are leases in other areas of the estuary (Figure 6.8). The Lower Hawkesbury River is the second largest oyster producing area in NSW and cultivation methods have changed considerably since the early days when sandstone rocks, easily found in the area, were used to catch spat (juveniles). Since then, fibro slats or tarred (no phased out) hardwood stakes have replaced mangrove sticks during spat collection. In the last ten years there has been a concerted move towards cemented 1 foot x 1 foot sticks for catching spat. In this method the oysters are grown to a medium size and then removed and placed on trays to complete their growing cycle (www.oysterfarmers.asn.com). Oyster farmers do not exclude fish from their leases by netting.

Oyster spats are collected in the main estuary (e.g. Brooklyn Harbour) and the sticks are then broken up and moved up the creeks to mature. From there, they are sent to a depot for depuration. Oysters racks are predominantly found outside Brooklyn, within Marramarra Creek, at Coba Bay and at other sites labelled on Figure 6.8.

Natural spatfalls of oysters are not frequent enough to sustain the industry within the Brooklyn area. Oysters at various stages of growth are therefore purchased from growers in other estuaries. This is a common practice for oyster farming in NSW where strict controls and inspections are carried out by NSW Fisheries to ensure the practice does not lead to widespread contamination of estuaries either with diseases or by the introduced Pacific oysters (*Crassostrea gigas*). NSW Fisheries Officers regularly inspect the leases and issue notices if farmers fail to remove Pacific oysters. They also work with growers to ensure leases and adjacent foreshores are kept free of Pacific oysters.

As part of a Quality Assurance Program (QAP), farmers are required to depurate their oysters with clean salt water (min 18ppt) for 36 hours prior to market delivery for sale for human consumption. Water for purging is drawn from the inlet adjacent to the farmers sheds. Any potential threat to the purity of the water could potentially cause problems for the farmers. To ensure compliance with food safety standards, farmers are required by the QAP to conduct water and meat sampling each week.

Oysters can concentrate metals and other contaminants many times in excess of the ambient water levels and thus, poor water quality can be a problem for oyster farmers (Nell, 1993). Levels of metals (except arsenic), phenols, and PAHs were not significantly elevated in wild oysters collected from the Hawkesbury when compared with another reference area at

Port Stephens, and an area studied previously adjacent to the steelworks on the Hunter River (Lincoln, Smith & Cooper, in prep.). Interestingly, arsenic levels in both reference areas were about twice that of the study location. Mackay *et al.* (1975) also found elevated levels of arsenic at sites within Wagonga inlet, three times in excess of the recommended limit. The arsenic source was unclear, but it was suggested that timbers treated with arsenate preservative compounds have been used in oyster cultivation. The possibility of contamination from that source was suggested as an area warranting further investigation (Mackay *et al.,* 1975).

Oyster farming practices in NSW are presently the subject of a major review. To cover the management of the oyster industry a draft Management Plan is being prepared by ACIL Economics after consultation with industry representatives, NSW Fisheries and the NSW EPA.

6.4.3.2 Oyster Production Data

The NSW oyster industry is characterised by a large number of small producers (Nell, 1993). In NSW, oysters are grown in 41 estuaries with a total lease area of about 4 700 ha. Figure 6.9 demonstrates the variability in NSW oyster production since 1940. During the 1950's and 1960's, the NSW Sydney rock oyster industry exhibited consistent growth as production methods improved and the total lease area increased. Oyster production then peaked in the 1970's largely due to the practice of transporting oysters between estuaries to take advantage of differences in the timing of prime growing or fattening conditions. Since then, production has stabilised to around 80 to 90 thousand bags per year (Nell, 1993).

The production of oysters from the Hawkesbury River has also been somewhat variable since 1940 (Figure 6.9). Oyster production in the Hawkesbury generally declined until the mid-1950’s. Since then, it has followed the same general trend as the total NSW oyster production, peaking in the 1970’s, and most recently in 1997/98.

The Hawkesbury River is the second largest producer of Sydney Rock Oysters in the NSW (after Wallis Lakes). During the 2001/2002 period, the total value of Sydney Rock Oysters for all NSW estuaries was $29.5 million of which $4.3 million (15%) was from the Hawkesbury River (NSW Fisheries - Aquaculture Production Report 2001/2002).

6.5 Fish and Mobile Invertebrates

6.5.1 Review of Information

Mobile invertebrates and fish are discussed together here because the techniques used to sample them are usually the same. Mobile invertebrates include those animals that are found either associated with a habitat, such as seagrass, or in the water column, and include animals such as crabs, prawns and squid. Estuarine fish are known to utilise a variety of habitats such as seagrass beds and algal beds as nursery grounds during juvenile stages. Studies of marine vegetated habitats such as seagrasses and mangroves have received considerable attention in scientific literature (e.g. West *et al*., 1985; Bell and Pollard, 1989; Larkum *et al*., 1989; Skilleter, 1996). By comparison, very little information exists on intertidal mudflats common in Australian estuaries despite the fact that they are thought to provide important foraging habitats for some species of fish (when inundated) and wading birds (when exposed). An exception to this, however was a review of intertidal mudflats ecology by Inglis (1995). Whilst this review provides a comprehensive description of the benthic infauna and some of the factors affecting the distribution and abundance of animals that occur on intertidal mudflats, the utilisation of these habitats when inundated at high tide by fish or mobile invertebrates (e.g. crustaceans), was not considered. West *et al*. (1985) provides a good example of how intertidal mudflats are often overlooked in scientific surveys. They mapped estuarine habitats including seagrasses, saltmarshes and mangroves occurring throughout 133 estuaries along the NSW coastline but provided no information on any areas of intertidal mudflats.

Replicate beam trawl, beach seine and gill net collections were made by The Ecology Lab (1988) within Sandbrook Inlet at several sites. In contrast to the infauna (see previous section), the epifauna was diverse and abundant. A count of 87,351 individuals from 21 invertebrate species, and 553 individuals from 14 fish species were collected from the beam trawls. The mysid shrimp, *Rhopalophthalumus brisbanensis* comprised 58-99% of the abundance. The next most dominant species was again the bivalve, *Notospisula trigonella*, and other abundant species included the king prawn (*Penaeus plebejus*), the sergestid shrimp, *Acetes sibogae australis*, and the bivalve, *Theora fragilis*. Importantly, three prawn species found as juveniles at most stations, are of commercial value. The fish fauna was dominated by species of gobies. Beach seines collected 27 fish and 5 crustacean species, and gobies were again the most abundant group, however, 16 of the fish and 3 crustacean species were of commercial or recreational value. Gill netting caught very few fish (8 individuals) all of which were common in collections by other methods.

Overall, 31 species of fish were collected in Sandbrook Inlet during the study referred to above, whereas 36 and 29 (45 overall) species of fish were collected in beach seines from the adjacent Berowra and Cowan Creeks, respectively (Booth & Schultz, 1997). In both studies, mullet, bream, whiting, tailor, flounder and leatherjackets were some of the most abundant fish species of economic importance.

In the entire Hawkesbury-Nepean River 164 fish species have been recorded (Gehrke & Harris, 1996), varying from 90 species near Broken Bay, to less than 15 species in upstream freshwaters. The composition of by-catch (fish caught incidentally to a targeted species) from prawn trawling in three areas of the Hawkesbury showed trends with respect to salinity and recorded 75 species of fish, 13 species of crustaceans and 5 species of molluscs (Gray *et al*., 1990). Forty-two species were recorded as commercially valuable.

Juveniles of the commercially important mulloway, *Argyrosomus japonicus*, were examined for their distribution and growth characteristics in the Hawkesbury River (Gray & McDonall, 1993). They were most abundant during autumn to winter in the mid sections of the estuary. Gut content analyses determined the diets of commercially valuable leatherjackets in Berowra and Cowan Creeks (Silberschneider, 1997). Encrusting bryozoans were the most abundant source of food for the six-spined leather jackets, *Meuschenia freycineti*, whilst the major food items of fan-belly leatherjackets, *Monacanthus chinensis*, were small crustaceans. Only one size class was examined for each species, which limits the generality of conclusions.

The *Fisheries Management* (*FM*) Act, 1994, protects fish species listed as endangered or vulnerable. Three vulnerable species of fish that potentially use the estuary during part of their lifecycle are the grey nurse shark (*Carcharias taurus*), the great white shark (*Carcharadon carcharias*) and the black rock cod (*Epinephelus daemilii*). The *Fisheries Management* Act, 1994, also provides protection for estuarine habitats including seagrass and mangroves, both of which occur in Brooklyn area.

6.5.2 Beam Trawl Sampling Methods

The Ecology Lab sampled small demersal fish and invertebrates to determine differences in the abundance and types of species occurring throughout the Brooklyn study area. Small demersal fish and invertebrates were sampled in muddy subtidal habitats on two occasions using a beam trawl (Figure 6.10). The first (17-19/09/01) sampling event was commissioned specifically for the Brooklyn EPS. Halliburton KBR commissioned the second sampling event (29-31/01/02) for the Central Coast Rail Upgrade EIS (The Ecology Lab, 2002). Identical sites and methodologies were used for both studies permitting a combined data analysis.

Small fish and invertebrates were sampled using a beam trawl, which comprises a conical shaped net (1.5 m x 0.6 m x 2.0 m) with a mesh size of 1 mm attached to a metal sled. The beam trawl was towed by a small boat over a distance of 50 m at the average boat speed of about 1.5 – 2 knots. Shots were less than 5 minutes. All sampling was done within 1 hour of the high tide.

Five replicate trawls were collected at 2 sites within each of 5 locations on two occasions. Two locations were within Sandbrook Inlet, two within Mooney Mooney Creek and one within Mullet Creek. In all cases, trawls were within 50 m of fringing mangrove forests. The sixth location was selected to provide additional information for the Central Coast Rail Upgrade (Halliburton KBR, in press). Trawls were generally inshore of oyster leases, except at one site near the entrance to Sandbrook Inlet and at another near the mouth of Mooney Mooney Creek.

All material collected in the beam trawl was placed in plastic bags and preserved in approximately 10% formalin in seawater. Samples were sorted in the lab and animals were identified to the lowest practical taxon.

Abundant taxa, total abundance, and species richness were analysed using univariate analysis of variation to elicit temporal and spatial patterns in abundance. In the analysis, the factors ‘time’ and ‘location’ were considered random and orthogonal while ‘sites’ were random and nested in locations. The entire assemblage at each site was analysed using multivariate tests to elicit community patterns (refer to Appendix E).

6.5.3 Beam Trawl Results

In total, the beam trawl samples contained at least 46 species, including six species of commercial value (Appendix E). These six species were yellowfin bream (*Acanthopagrus australis*), leatherjacket (*Acanthaluteres sp*.), sandy sprat (*Hyperlophus vittatus*), eastern king prawn (*Penaeus plebejus*), school prawn (*Metapenaeus macleayi*) and greasyback prawn (*Metapenaeus bennettae*). These commercial species accounted for 2.2% of the 11,859 individuals counted in total. The three numerically dominant species were pelagic shrimp (*Acetes sibogae australis*), glass goby (*Gobiopterus semivestita*) and Opossum shrimp (*Rhopalopthalmus brisbanensis*). Together, these three species accounted for more than 81% of the total number of individuals sampled. None of the species collected in the beam trawl samples are listed as protected under the Threatened Species Conservation Act, 1995.

6.5.3.1 Multivariate Analyses

The community structures of the fauna assemblages caught in the Beam Trawls significantly differed over the two sampling times and between locations. However, the analysis was not able to identify which location differed because of the large variation.

The differences between the Times and Sites are represented pictorially in the MDS ordination of Figure 6.11. Glass gobies (*G. semivestita*) were the most abundant species and their increase at two sites (inner South Sandbrook Inlet and inner North Sandbrook Inlet) accounted for significant site differences over time.

6.5.3.2 Univariate analyses

Changes over time in the abundance of fish significantly differed between Locations. These differences were mainly attributed to the glass goby (*G. semivestita*). Changes over time in the number of taxa, number of fish species, the number of economic species, percent abundance of economic species and abundance of opossum shrimp (*R. brisbanensis*) significantly differed between sites, but not between Locations. There was an overall increase in the number of invertebrate species over time, which occurred at similar magnitudes across all Sites and Locations. Invertebrate abundances did not differ significantly (Appendix E).

6.5.4 Discussion

The assemblage of demersal fish and mobile invertebrates near Brooklyn Causeway were not unique and were well represented in other parts of the estuary. That is, the assemblages in Sandbrook Inlet were similar to those at Mullet Creek and upper Mooney Mooney Creek.

The species of economic significance (bream, leatherjacket, sandy sprat and 3 species of prawns - Eastern King, School and Greasy Back) only represented 2.2% of the total catch.

At both sampling times, the mouth of Mooney Mooney Creek contained quite different assemblages of demersal fish and mobile invertebrates compared to the Mooney Mooney Creek Upper site and the inner Sandbrook Inlet site. The difference was primarily due to variations in the abundance of widespread species such as the glass gobies (*G. semivestita*). This result indicates that distance from urban development is not a sufficient criterion for choosing reference locations. It is recommended that if impact studies are envisaged, the mouth of Mooney Mooney Creek might not be an appropriate study site because of its significant differences to other locations.

In the scientific literature, there have been many factors suggested to explain the variability among fish and mobile invertebrate assemblages, including microhabitat preferences, influence of adjacent habitats, distance from mouth of estuary, predation pressure, larval settlement patterns and fish behaviour to mention a few (summarised in Bell and Pollard, 1989). Without additional experimental studies, it is not possible to assess further the contribution of these factors to the spatial pattern of fish and invertebrate assemblages in Brooklyn area.

The overall increase in mobile invertebrate species numbers over time at all sites and locations suggest a large-scale process affected the whole estuary. This may include a larvae recruitment episode or other factors related to seasonal variations.

The numbers of species of both invertebrates and fish were significantly different between sites within locations, while their abundances were not. This indicated the presence of significant medium-scale variability in species diversity. Significant variability between sites could hide variation between locations.

The other three survey locations (the entrance to Sandbrook Inlet, Mullet Creek, and upper Mooney Mooney Creek) were not significantly different from each other. This suggests that demersal fish and mobile invertebrate assemblages across the Brooklyn area were similar.

Information on demersal fish abundances and distributions in the Brooklyn region was gained through beam trawl sampling. Demersal fish targeted using beam trawl sampling are likely to remain in the same area as they are less mobile than open water schooling fish caught with different sampling techniques. Beam trawling studies (The Ecology Lab, 1988; 2002) have collected consistent fish numbers which suggest stable populations. Therefore, reduced tidal flushing in Sandbrook Inlet does not affect the type of demersal fish species and their abundances. It is likely that fishing and possibly assemblages of economically valuable fishes would have been previously affected by changes to habitat, boating pressure and fishing pressure. However, given the large swimming range of many fish and the number of factors that can influence fish distributions, it is believed that further sampling might not provide additional information.

6.6 Pollution & Bioaccumulation

6.6.1 Review of Information

Water and sediment sampling by The Ecology Lab (1998a) indicated that turbidity, levels of nutrients and levels of chlorophyll-*a* were relatively high within Sandbrook Inlet with greatest levels often occurring in the southeast corner near the railway causeway. Nutrient levels were also elevated outside Sandbrook Inlet, at the entrance to Mooney Mooney Creek. Cadmium, copper and lead concentrations in water samples exceeded ANZECC (1992) guidelines for the protection of marine waters at some sites within the inlet. Concentrations of arsenic, mercury and TBT exceeded low values of ANZECC (1997) interim guidelines for sediment quality, but no contaminants exceeded the high ANZECC criteria. This indicates low to moderate pollution in Sandbrook Inlet sediments and based on ANZECC (1997) criteria further investigations should be undertaken.

Birch *et al*. (1998) used concentrations of copper, lead and zinc from sediments as indicators of anthropogenic effects and found that the most polluted areas of the Hawkesbury were the headwaters of Berowra Creek, Cowan Creek and southeast Pittwater. By comparison, sediments in Sandbrook Inlet were generally moderately polluted.

Hardiman and Pearson (1995) found that there were significantly greater concentrations of contaminants, particularly cadmium, copper, zinc, DDT and TBT in oysters collected from Sandbrook Inlet, but variation among sites within the inlet was large. In addition, the only metal above the food standard was copper. Lincoln Smith & Cooper (in prep.) found that most heavy metals, phenol and PAH concentrations in wild oysters sampled from reference locations in the Hawkesbury River and Port Stephens were generally not different from oysters sampled near a steelworks in the Hunter River. The trace metal arsenic, however, was present in oysters from both references in concentrations twice that of oysters collected adjacent to the steelworks.

6.6.2 Oyster Bioaccumulation Study Methods

The uptake of contaminants by oysters was examined to quantify concentrations of contaminants and to determine spatial and temporal differences in bioaccumulation in the Brooklyn study area. Wild oysters (i.e., not from oyster leases) were sampled twice (12/11/01 and 05/02/02) to measure bioaccumulation of metals and polycyclic aromatic hydrocarbons (PAHs). Four locations were sampled at each time (Figure 6.10). Two of the locations (Sandbrook Inlet and Brooklyn Harbour) were in areas of extensive boating activities and urban development. The other two locations (Mullet Creek and Mooney Mooney Creek) were more remote from human disturbance. Within each location, sampling was done at two sites. The sites, which were < 100 m apart, were used to provide a measure of small scale variation in contaminant levels.

Four replicate samples of oysters were collected at low tide for each site. Each replicate consisted of a composite oyster sample to provide sufficient oyster tissue for analysis. The composites consisted of clumps of oysters (between 2 and 8 oysters) occurring on intertidal rocks or other suitable surfaces. The spatial scale of oysters within composites was < 0.5 m, while that between composites was 5 – 10 m. Wild oysters were removed from rocks using a small chisel and were stored on ice on the day of collection. Wild oysters were then frozen pending dissection. Oysters were opened using stainless steel equipment. At least 30 g of oyster flesh was obtained per replicate and dispatched to the Australian Government Analytical Laboratories (AGAL) for analyses. The metals analysed included copper, lead, zinc, cadmium, chromium, nickel, arsenic, mercury and selenium. Polycyclic aromatic hydrocarbons were analysed for all Sandbrook Inlet samples only at each time. Samples were analysed by AGAL following standard procedures.

Individual metals were analysed using univariate analysis of variance procedures to elicit spatial and temporal concentration patterns (refer to Appendix E). In the analysis, the factor ‘time’ was considered random and orthogonal, ‘location’ was fixed and orthogonal, and ‘site’ was random and nested.

6.6.3 Oyster Bioaccumulation Results

Heavy metals were detected in oysters from all locations sampled in the Hawkesbury estuary and at all sites within each location. However, mercury was the only contaminate slightly above the detection limit. Analysis of variance found significant differences in heavy metal concentrations between locations for copper, arsenic, selenium and zinc. The average concentrations of copper from oysters at Sandbrook Inlet and Brooklyn Harbour, and arsenic concentrations from oysters at Brooklyn Harbour exceeded the ANZFA food standards maximum permitted concentrations (ANZFA, 2000).

Zinc concentrations at Brooklyn Harbour were significantly greater than at all other locations and significantly increased during the two sampling event at all locations (Appendix E). The concentration of selenium at time 1 was significantly greater at Sandbrook Inlet than other locations. Selenium concentrations at time 2 were significantly smaller at Mooney Mooney Creek than at other locations (Figure 6.12). Brooklyn Harbour had significantly greater arsenic concentrations at time 2 than at other locations. There was no significant difference in arsenic concentration between locations at Time 1.

Although no significant difference in copper concentrations was detected between locations in the Analysis of Variance, the data does suggests greater concentrations of copper in Sandbrook Inlet and Brooklyn Harbour compared to other locations. This may be due to cooper used as an antifoulant agent and further studies with adequate spatial/temporal replication in Brooklyn harbour and Sandbrook Inlet are recommended.

Apart from differences among Locations, the results indicated some variability at the smaller spatial scale of Sites within Locations. Significant differences between sites were detected for selenium at Sandbrook Inlet, and for copper at Brooklyn Harbour (Figure 6.12).

No detectable concentrations of PAH (>0.05 mg/kg) were measured in samples from Sandbrook Inlet at either times.

6.6.4 Discussion

Similar concentrations of most heavy metals except for arsenic, copper, zinc and selenium were detected in the oyster meat at locations near Brooklyn (Sandbrook Inlet and Brooklyn Harbour), compared to more remote locations (Mooney Mooney Creek and Mullet Creek).

Bivalves use small amounts of copper in the oxygen carrier hemocyanin. However, the non-significant but greater concentrations of copper found at locations nearer the causeway suggest an anthropogenic effect. Since copper is used in antifouling paints found on boat hulls, extensive boating and maintenance activities are likely to have contributed to increased copper concentration in Brooklyn Harbour and Sandbrook Inlet. The significant difference between sites in Brooklyn Harbour could indicate a large variability at the small scale or insufficient power in the analysis. Therefore, recommendations for future studies include greater numbers of replicates to increase the power of the analysis.

Increased arsenic and selenium concentration occurred in urban locations, although these were not consistent in time and over small scales. The concentrations of arsenic found in the Brooklyn region overall were similar to those found by Lincoln Smith & Cooper (in prep.) in the Hawkesbury River and were significantly greater than concentrations found in the Hunter River. Although the source of arsenic in the Hawkesbury River is not confirmed, arsenate treated timber used in oyster leases, has been suggested as a possible source.

The increase in zinc concentrations at all locations over the two sampling periods, combined with its consistently higher concentrations in Brooklyn Harbour, supports the model that Brooklyn Harbour has more zinc contamination than other parts of the study area. The solubility of zinc is dependent on several factors including the concentrations of suspended solids, carbon content, dissolved oxygen levels, temperature, pH, bioturbation and wave action. With high wave action, velocity, or bioturbation resuspension of zinc can be expected. Temperature increases generally decrease oxygen content and AVS so zinc solubility may increase in summer. Zinc is also higher in mixing zones (freshwater to salt water) but this may be attributable to increased residence time. Overall zinc solubility in seawater depends on competing ions, soluble ligands, and the availability of binding sites on sediments.

A number of models could explain the increased concentrations in remote locations including the greater diffusion range of zinc compared to other metals. Many additional factors could be affecting the distribution of heavy metals in the estuary. This may include natural factors such as a large scale 'process' acting on the system (e.g. seasonal variations in water temperature and currents).

The proximity of Sandbrook Inlet and Brooklyn Harbour to the Brooklyn urban area and associated roads and railways could explain the higher concentrations of heavy metals detected. Road and rail runoff is a complex mixture of litter, dust, heavy metals (e.g. lead and/or zinc), and organic matter.

Scanes & Roach (1999) found similar results at sites in the Hawkesbury in 1998 for concentrations of chromium, lead and arsenic and these were significantly different to industrial sites in the Hunter estuary (Lincoln, Smith & Cooper, 2001). Zinc and nickel concentrations were less in the present study in comparison with sites in the Hawkesbury River taken in 1988 (Scanes & Roach, 1999). Concentrations of zinc and nickel were also significantly different to sites in the Hunter River (Lincoln, Smith & Cooper, 2001).

PAHs are potentially carcinogenic chemicals that are formed during the incomplete burning of coal, oil and gas, garbage, or other organic substances like tobacco or charbroiled meat. The absence of detectable levels of PAHs at the Sandbrook Inlet location corresponds to the non-industrial and low level urban development status of the study area.

Brooklyn Harbour and Sandbrook Inlet locations accounted for most of the significant increases in heavy metals detected in oysters. This supports the conclusion that locations nearer the causeway had more contaminants than remote locations. However, small scale and temporal variation suggested no consistent pattern in results. Moreover it is likely that environmental threats to aquaculture have decreased since TBT was banned. The reduced tidal flushing in Sandbrook Inlet would increase the residence time of pollutants. It is recommended that long term concentrations of heavy metals in oysters are further investigated and monitored.

6.7 Ecosystem Health

The Brooklyn region is part of the expansive Hawkesbury River estuary system with a water body greater than 100 km^2 and a large opening to the sea. Estuarine health in the Brooklyn region is influenced by a variety of factors ranging from urban development, such as loss of habitat, sewage seepage from septic tanks, and storm water runoff, to inputs from agriculture, coal mining and industrial discharges (Mercer *et al*., 1993).

The medium level urban foreshore development at Brooklyn Harbour, Sandbrook Inlet and Dangar Island are likely to have a negative effect on the ecosystem health of the region. In contrast, the undeveloped aspect of Mullet Creek and Mooney Mooney Creek would have a low negative impact on ecosystem health.

A conceptual ecosystem model of Brooklyn Estuary is provided in Figure 6.13.

Most of the foreshore development consisted of private hillside residences with jetties, slipways and moorings. A consequence of residential development is the potential for sewage seepage from septic tanks into the estuary following heavy rainfall. This study did not assess ecological components of sewage contamination.

Mangrove forests are abundant throughout the study area and have increased over the last 25 years since the construction of the freeway bridge near Mooney Mooney Creek and land reclamation. The mapped areas of mangrove stands near the west fringe of Spectacle Island and at Mooney Mooney Point have increased significantly in size, however there was probably was not a "significant" increase as claimed by Williams and West (2001) due to lack of previous mapping. The leaf biomass for common grey mangroves in the Hawkesbury River of 40 $kg.m^2$ is the highest recorded for temperate forest communities. The distribution of mangrove forest in the study area and their general state of health are stable and positive.

Seagrass beds were present in the study area at a number of locations including Sandbrook Inlet, Brooklyn Harbour, Dangar Island and the Head of Mullet Creek. The dominant seagrass was *Zostera capricorni* (eelgrass). The cover of seagrasses has increased over the 16 years of available data (see Appendix E). Additional beds, not previously recorded by West *et al*. (1985), were noted east of Kangaroo Point and south of Dangar Island by William & West (2001). The seagrass bed in Brooklyn Harbour appeared healthy with a low epiphyte load (The Ecology Lab, 2002), while the beds in Mullet Creek had some epiphyte load. No other information exists on the health of seagrass beds. A better understanding of the health of seagrass beds could be gained by studying the maximum depth of beds, shoot density, shoot morphology and epiphyte cover of each bed. Decreases in water clarity affect the vertical distribution of seagrass. Seagrasses also require minimum concentrations of nutrients for growth. However, self shading caused by excess nutrients increase water turbidity and cause significant growth of epiphytic algae on seagrass leaves, which reduces the surface available for photosynthesis.

Only recent information from 1999 and 2001 is available on the distribution of salt marsh habitat in the Brooklyn study area. The largest stands of saltmarsh were located at the head of Mooney Mooney Creek, although small stands exist on both banks in Sandbrook Inlet. No conclusions can be drawn regarding the stability of saltmarsh distribution without earlier data. The saltmarsh species present were typical for the area. No information exists on the state of health of these saltmarsh communities. In summary, the area of wetland vegetation has remained constant or shown some increase in different parts of the study area, suggesting that the habitats are being maintained.

Intertidal benthic assemblages from mangrove habitats were different between the eastern and the western ends of Sandbrook Inlet (Lasiak & Underwood, 2002). These locations were also different to locations in Mooney Mooney Creek and Mullet Creek. Different taxa, rather than lower abundances, accounted for most of this difference. A study by Jones *et al*. (1986) found the benthos of Sandbrook Inlet to be depauperate compared to other locations in the Hawkesbury River. Lasiak & Underwood (2002) did not sample Brooklyn Harbour, which was found to be depauperate compared to locations further from human disturbances (Jones, 1986; The Ecology Lab, 2002). Many factors could be influencing the abundance and distribution of benthic animals including the level of anthropogenic disturbances, the degree of tidal flushing, and larvae availability and predation. Generally, low species diversity is typical of highly disturbed environments.

The intertidal rocky shore invertebrate communities were significantly different either side of the causeway. This difference could be the result of a number of natural factors as well as anthropogenic pressures. To better understand what influences the distribution of animals on intertidal rocky shores in the Brooklyn area, further studies that involve more locations with similar natural aspects (rock type, wave, wind and sun exposure) could be undertaken.

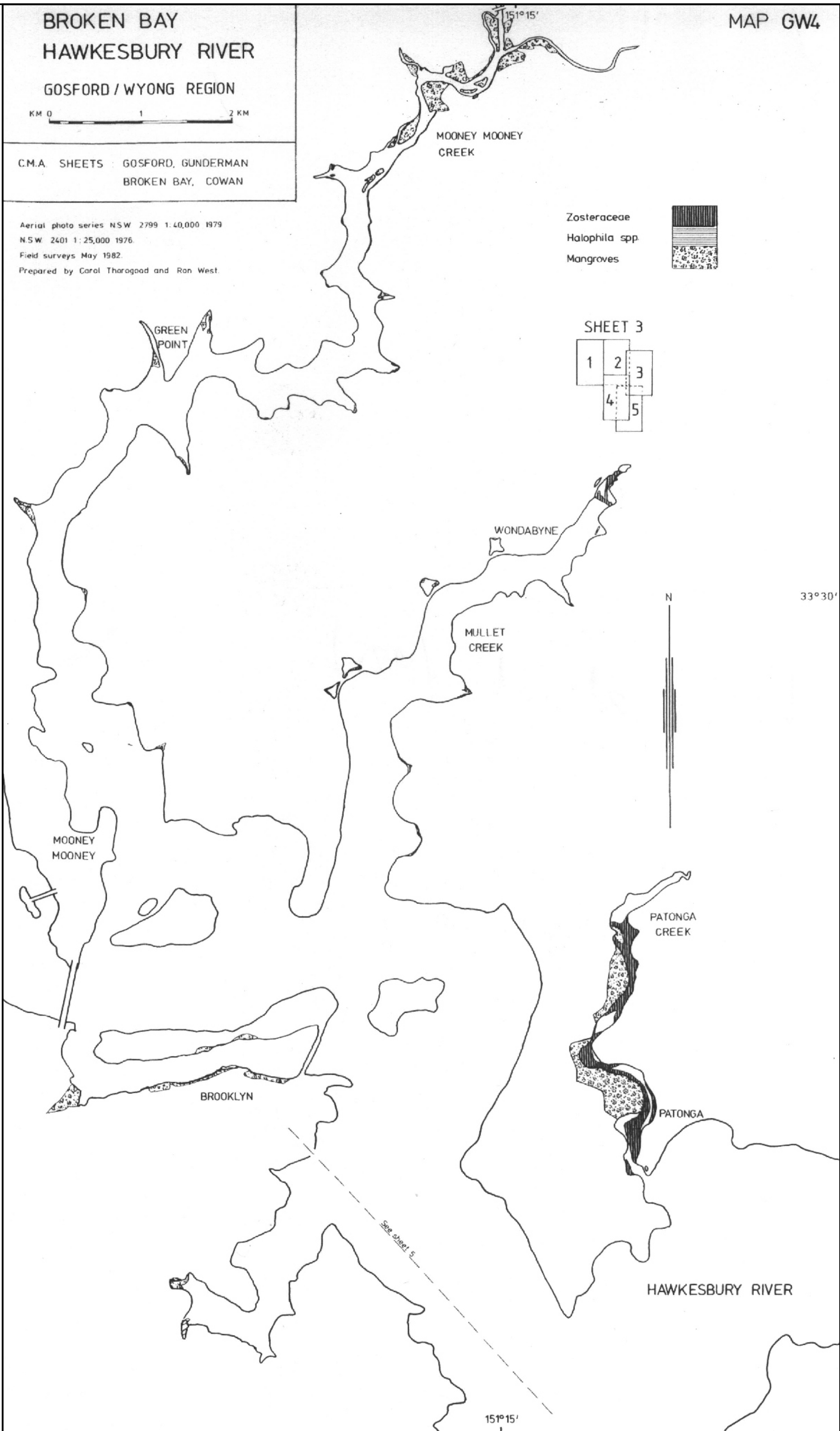
The state of the Brooklyn region in terms of demersal fish species distributions and abundances is difficult to assess given the highly variable catch rates from beam trawling and beach seines studies (Appendix E). The Ecology Lab did, however, find similar species of fish in this and the 1988 study suggesting some stability in populations. The assemblages of demersal fish and mobile invertebrates found in Sandbrook Inlet and Brooklyn Harbour in the present study were not different to other parts of the estuary. Therefore, factors other than proximity to urban developments (e.g. habitat cover or food availability) could be affecting the distribution of demersal fish and mobile invertebrates in the Brooklyn area. No information is available on the health of fish populations in the region. Information on the size and age of individual fish as well as the size of whole populations and their movements through time would be required to assess fish stock health.

Gobies were the most abundant group of fishes (Gehrke & Harris, 1996; The Ecology Lab, 1988), while shrimps were the most abundant demersal invertebrate group (The Ecology Lab, 1988; 2002). Fishes of economic importance collected in the Brooklyn area included mullet, bream, whiting, tailor, flounder, leatherjacket, mulloway and sandy sprat (Booth & Schultz 1997; Gehrke & Harris, 1996; The Ecology Lab, 2002). Demersal invertebrates of economic importance included eastern king prawns, school prawns, greasyback prawns and king prawns (The Ecology Lab, 1988; 2002).

Significantly greater concentrations of some heavy metals (i.e. zinc) were detected in wild oysters compared to remote locations at Sandbrook Inlet and Brooklyn Harbour. Though not significant the higher copper concentration found in oysters from Brooklyn Harbour indicates that copper, used in antifouling paints on boat hulls in Brooklyn Harbour, is probably having an impact on oyster populations.

The higher copper concentrations in Sandbrook Inlet compared to Mooney Mooney Creek and Mullet Creek are most probably due to the large number of boats in Sandbrook Inlet. A previous study (The Ecology Lab, 1997) on water quality in Sandbrook Inlet found copper and arsenic levels to be in excess of ANZECC (1992) guidelines. Boat traffic is probably greater during the weekends and holiday seasons when the number of recreational boat users increases. It is recommended that potential sources of heavy metal contamination be investigated and monitored.

Copper and arsenic concentrations in oysters from Sandbrook Inlet and Brooklyn Harbour exceeded maximum ANZFA (2000) food standards. The reduced tidal flushing in Sandbrook Inlet could increase the residence time of pollutants within the inlet. Since TBT was partially banned, this particular environmental threat to aquaculture has decreased. Further studies are recommended to assess long-term trends in pollutants.



Source: West et al. (1985)

WRL

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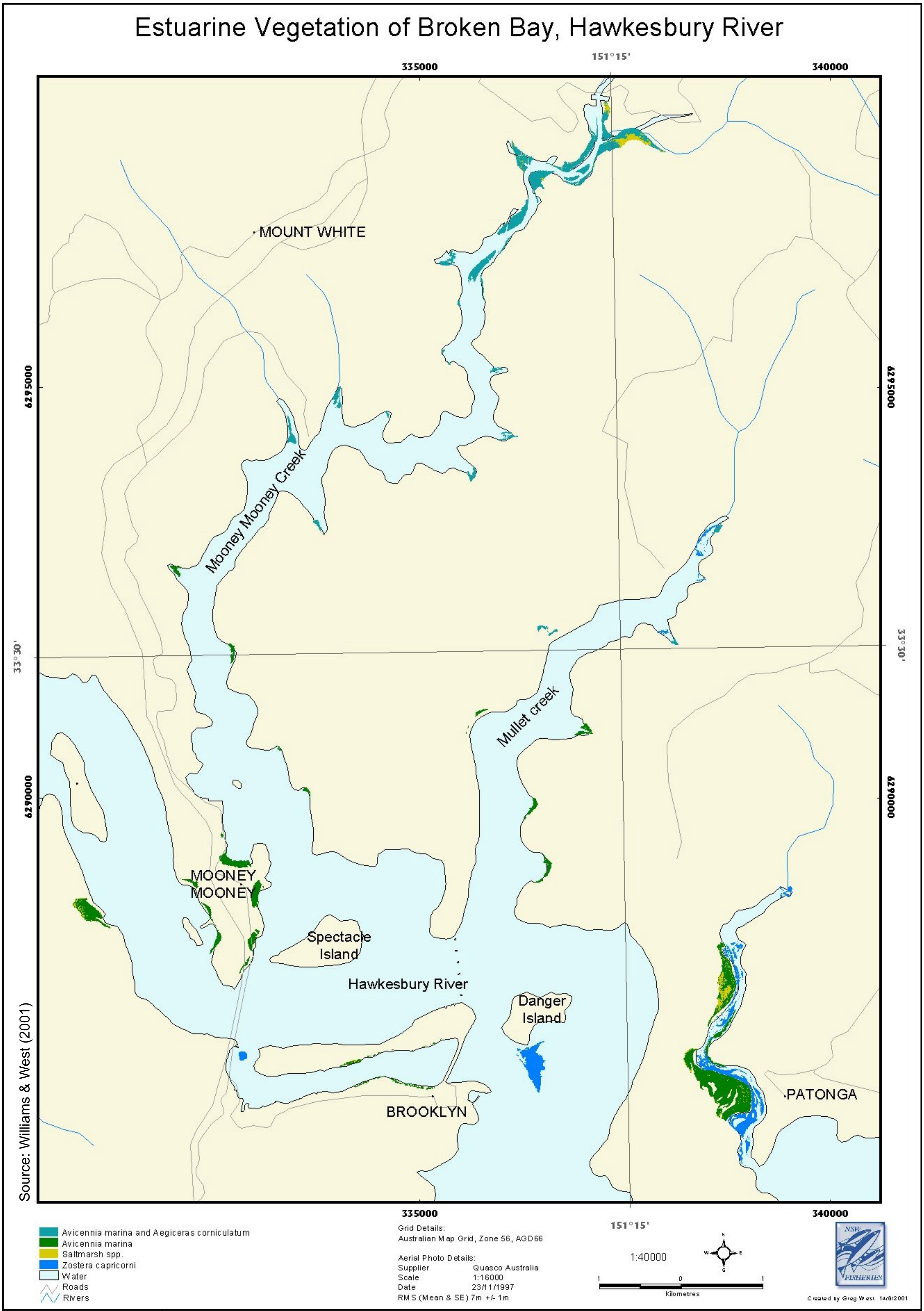
MAP OF BROOKLYN ESTUARY SHOWING HABITATS MAPPED BY WEST *ET AL.* 1985

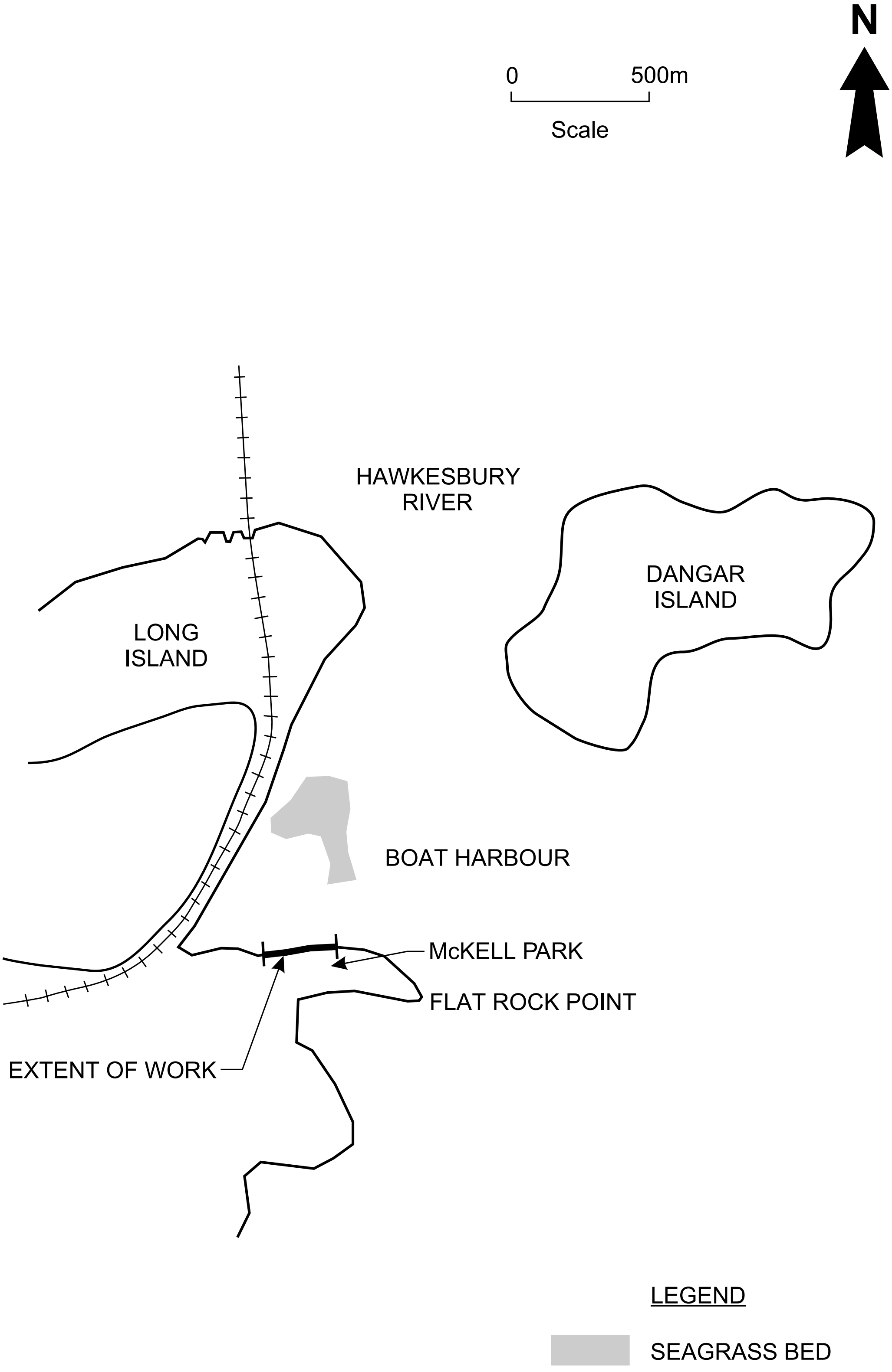
Figure

6.1

00758-06-01.cdr

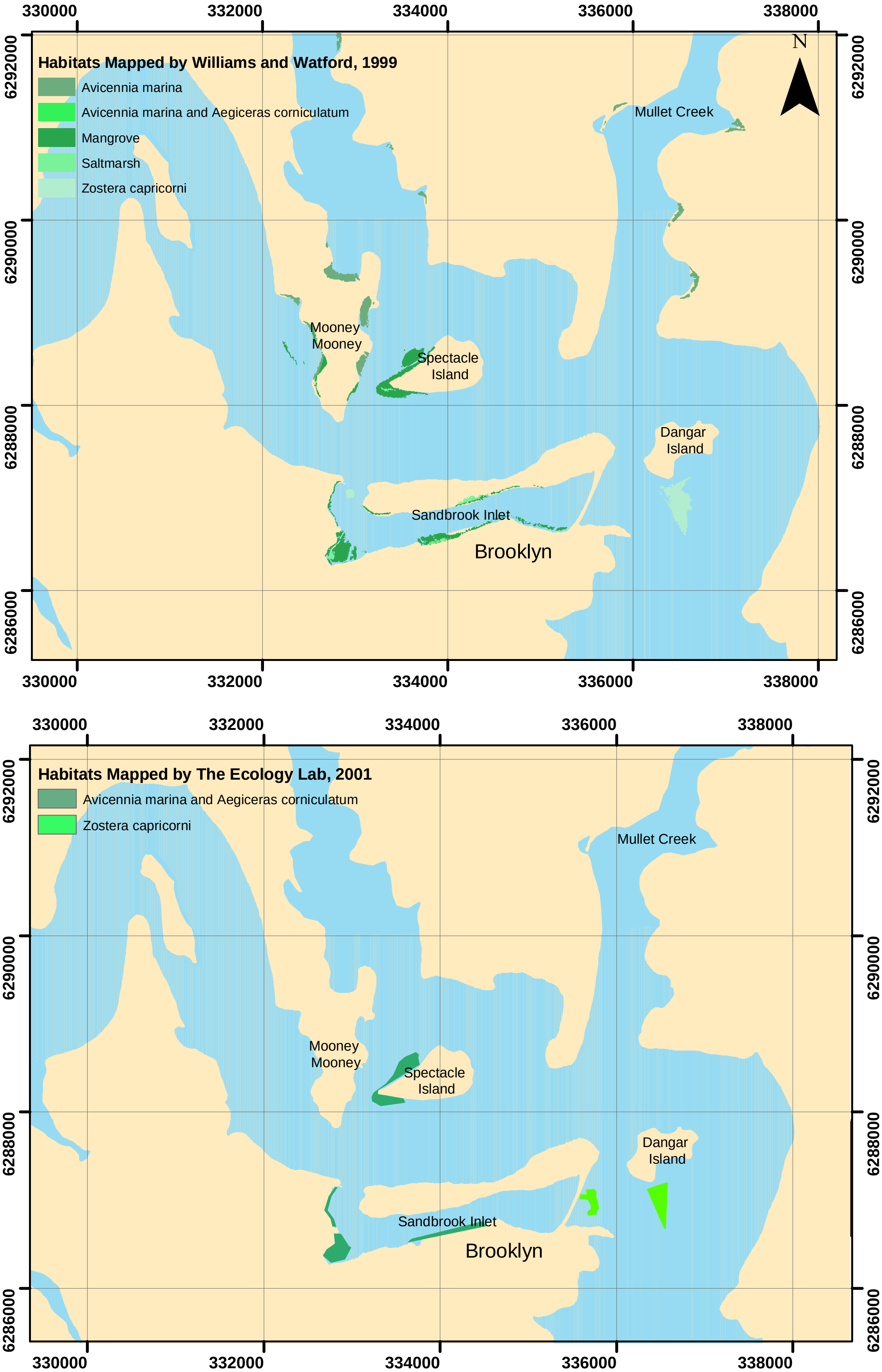


WRL Report No. 2002/20	MAP OF BROOKLYN ESTUARY SHOWING HABITATS MAPPED BY WILLIAMS & WEST 2001	Figure 6.2 00758-06-02.cdr



Source: Nexus 2000

WRL Report No. 2002/20	MAP OF BROOKLYN ESTUARY SHOWING HABITATS MAPPED BY NEXUS 2000 AND SMEC 2000	Figure 6.3 00758-06-03.cdr

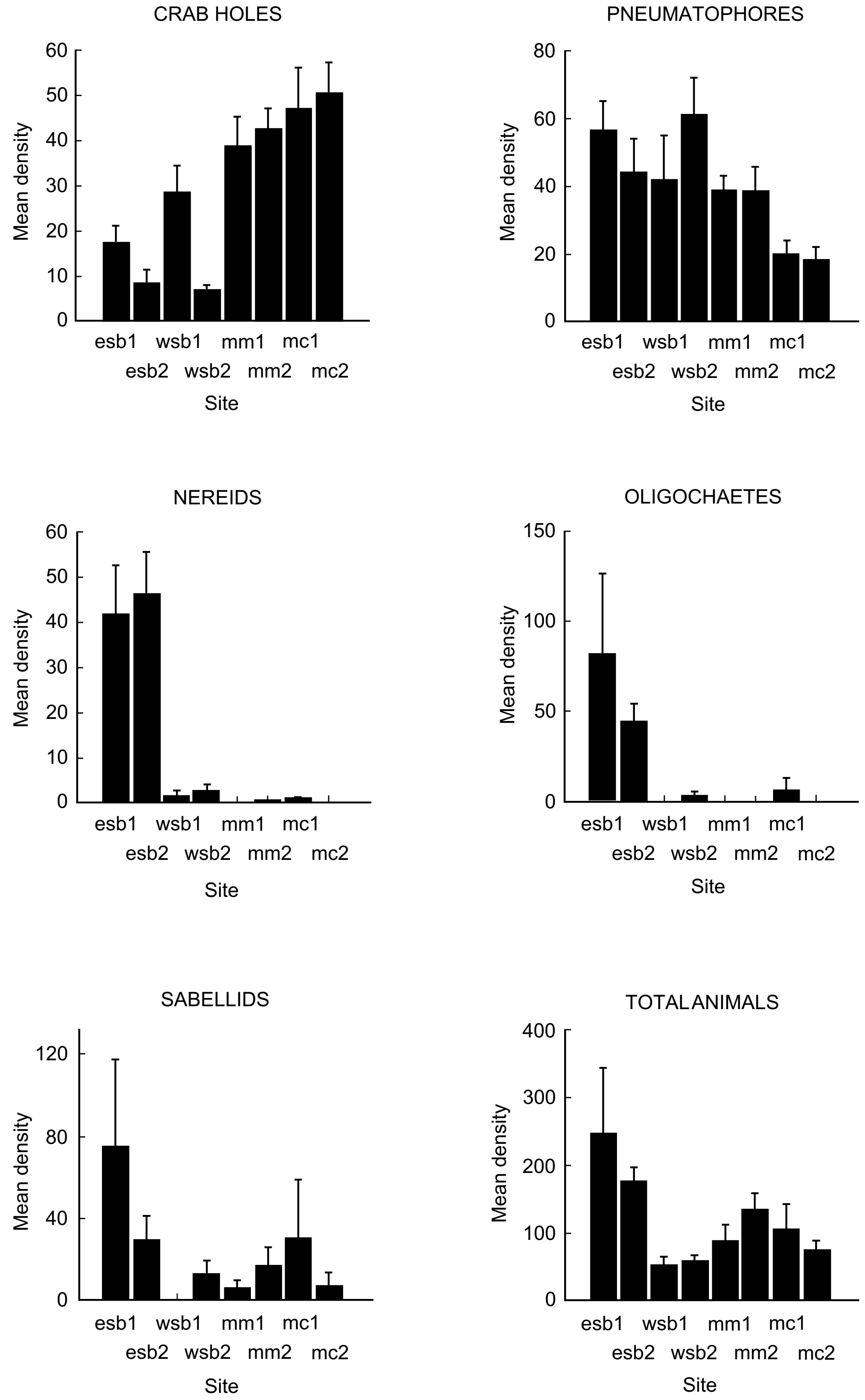


WRL
Report No. 2002/20

MAP OF BROOKLYN ESTUARY SHOWING HABITATS MAPPED BY WILLIAMS & WATFORD 1999 AND THE ECOLOGY LAB 2001

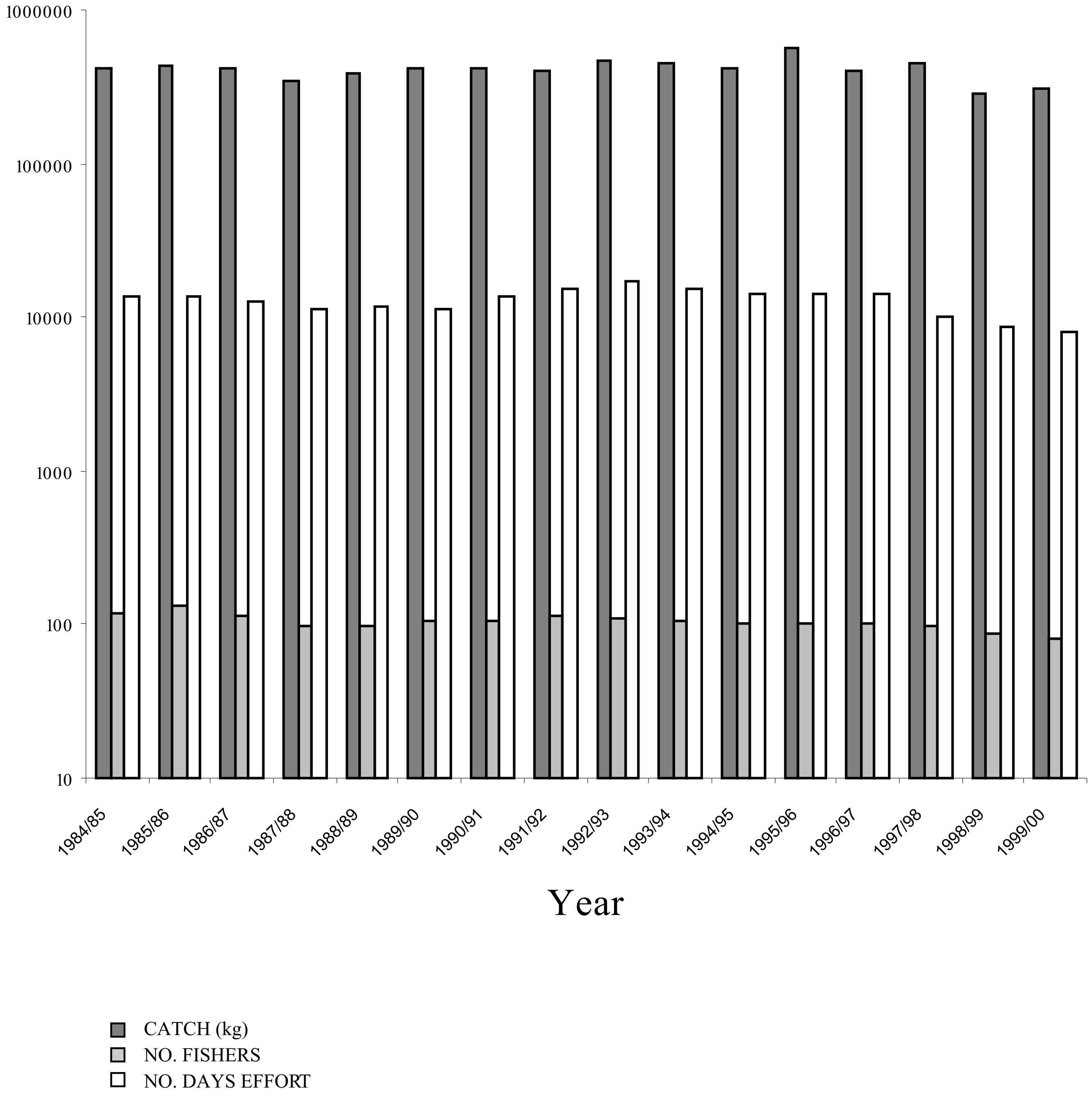
Figure 6.4

fig6_4.mxd



esb1	Eastern end of Sandbrook Island - site 1	mm1	Mooney Mooney Creek - site 1
esb2	Eastern end of Sandbrook Island - site 2	mm2	Mooney Mooney Creek - site 2
wsb1	Western end of Sandbrook Island - site 1	mc1	Mullet Creek - site 1
wsb2	Western end of Sandbrook Island - site 2	mc2	Mullet Creek - site 2

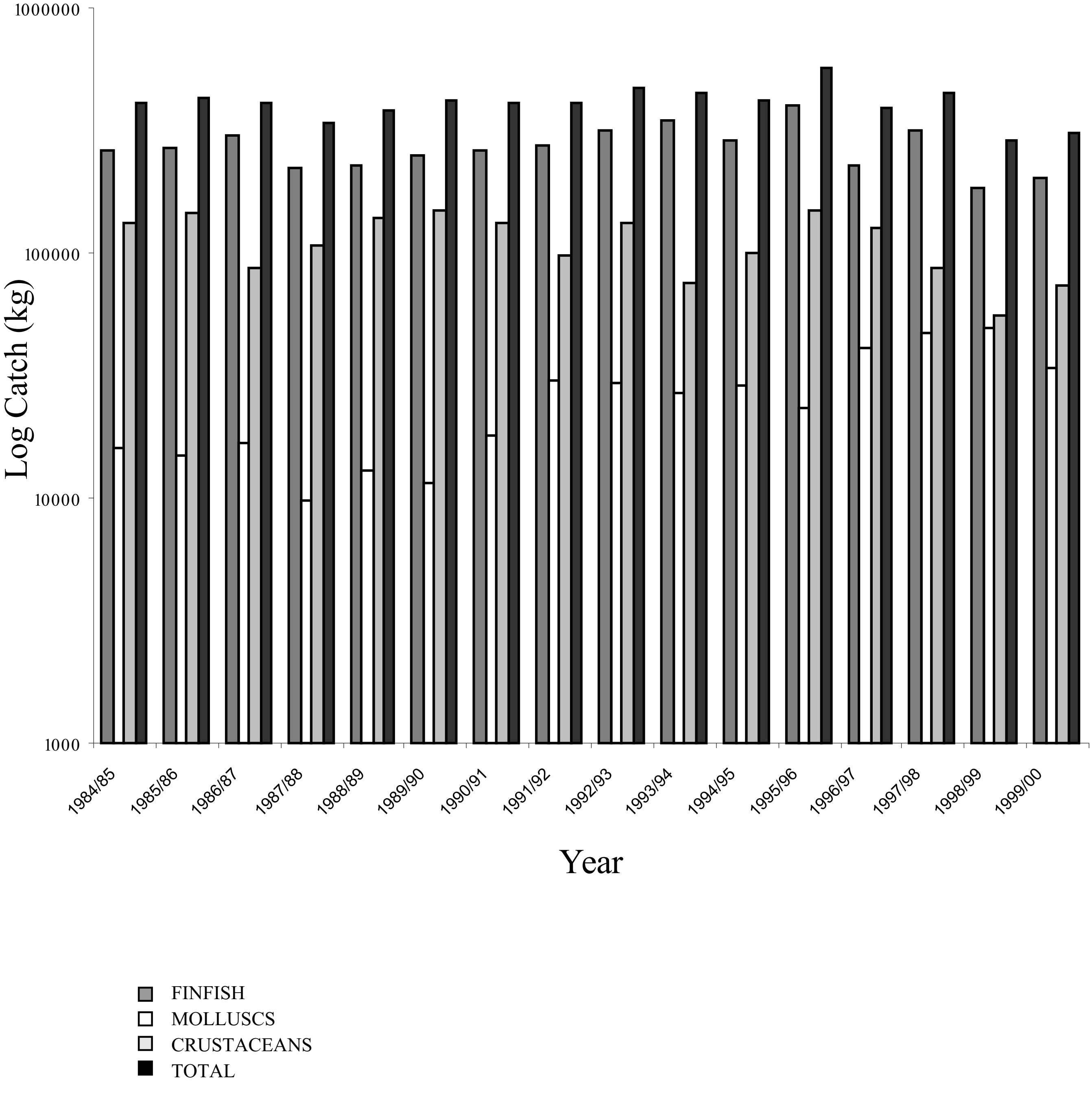
WRL Report No. 2002/20	MEAN (± SE) NUMBERS OF CRAB HOLES, PNEUMATOPHORES, NEREIDS, OLIGOCHAETES, SABELLIDS AND TOTAL ANIMALS FOUND AT EACH SITE IN EACH LOCATION	Figure 6.5 00758-06-05.cdr



Source: Tanner & Liggins (2001)

WRL Report No. 2002/20	TOTAL CATCH, NO. OF FISHERS AND NO. OF DAYS EFFORT FOR THE HAWKESBURY RIVER BY YEAR IN LOG FORM	Figure 6.6

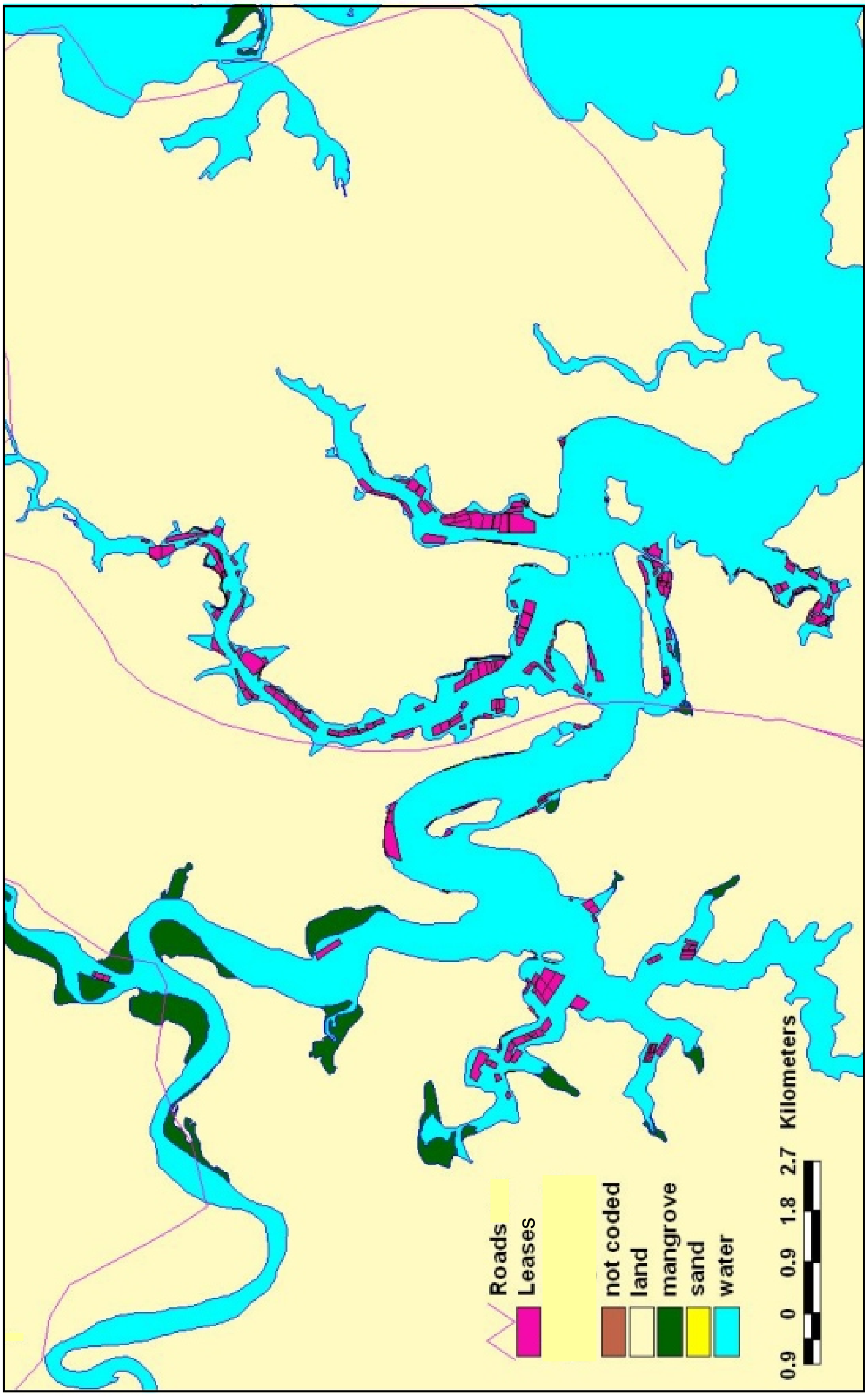
00758-06-06.cdr



Source: Tanner & Liggins (2001)

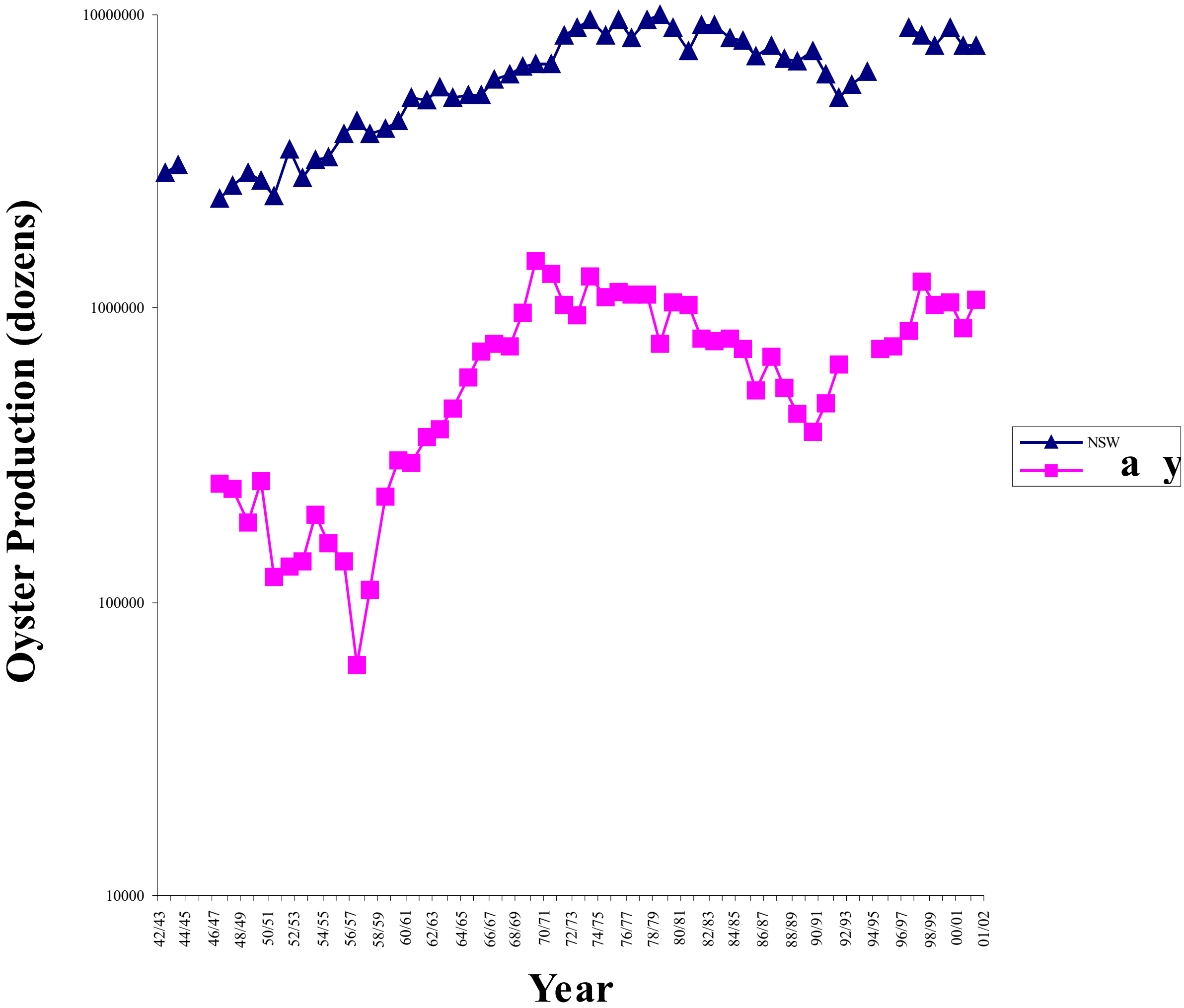
WRL Report No. 2002/20	HAWKESBURY COMMERCIAL CATCH (KG) BY YEAR IN LOG FORM	Figure 6.7

00758-06-07.cdr



Source: NSW Fisheries

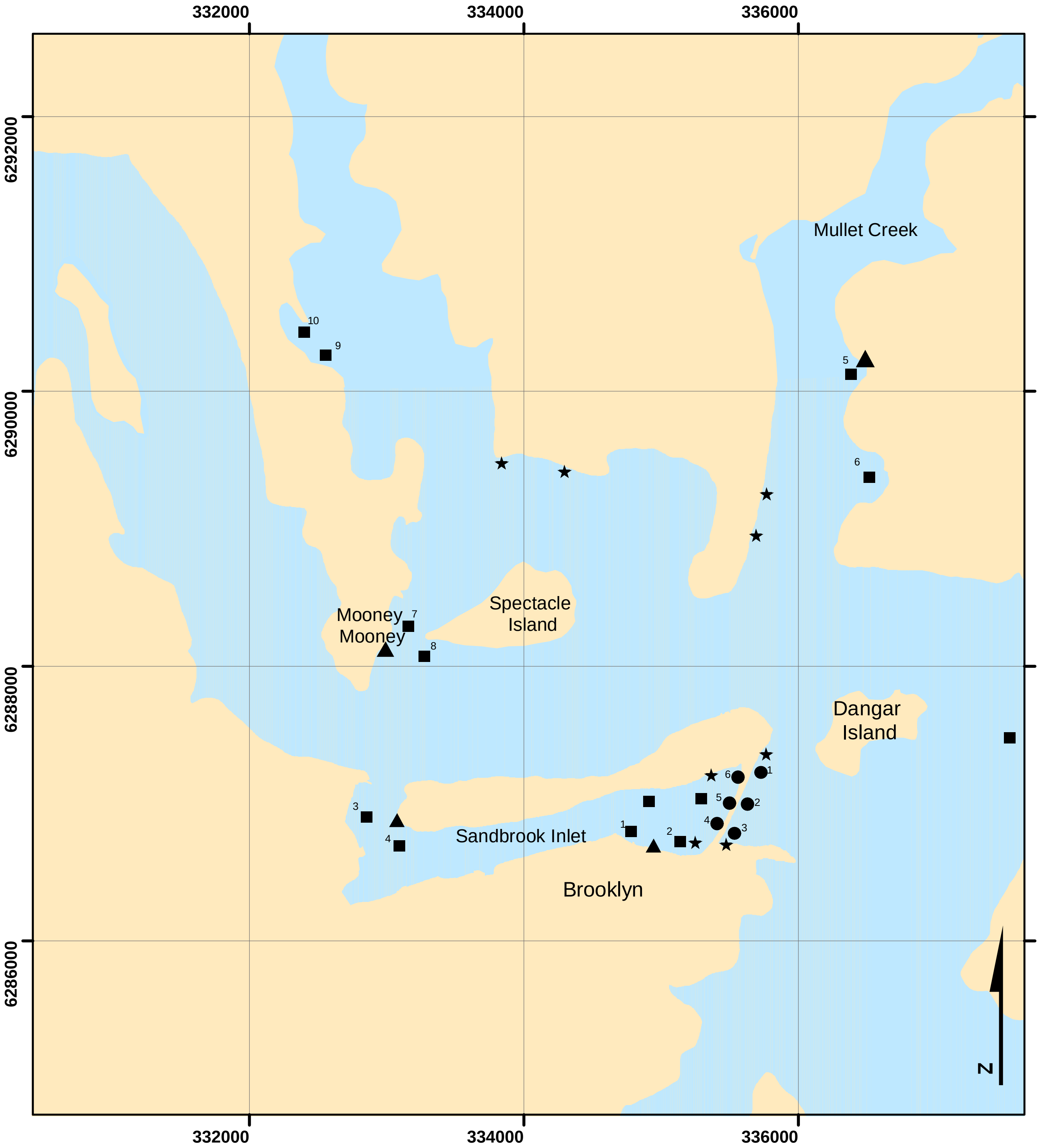
WRL Report No. 2002/20	MAP OF OYSTER LEASES IN THE HAWKESBURY RIVER	Figure 6.8 00758-06-08.cdr



(No data available for the 1942/43, 1943/44 and 1993/94 financial years)

Source: NSW Fisheries Commercial Fisheries Statistics

WRL Report No. 2002/20	PRODUCTION OF SYDNEY ROCK OYSTERS BETWEEN 1940 AND 2000 FOR NSW AND THE HAWKESBURY	Figure 6.9 00758-06-09.cdr



■ Beam Trawl Sampling Locations
note: beam trawl site numbers correspond to site numbers in Figure 6.11

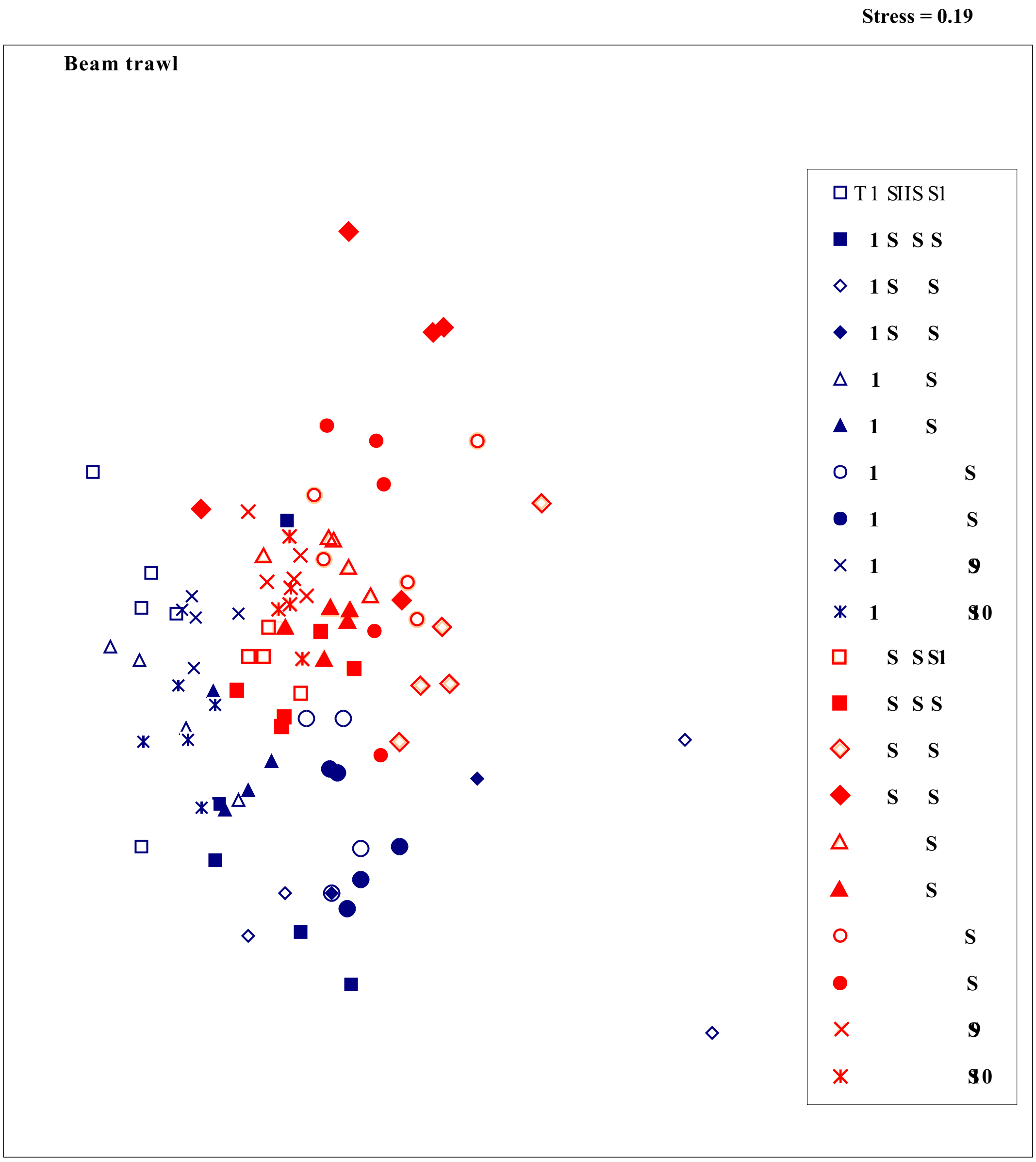
★ Oyster Bioaccumulation Sampling Locations

● Rocky Shore Intertidal Sampling Locations

▲ Soft Sediment Intertidal Benthos Sampling Locations

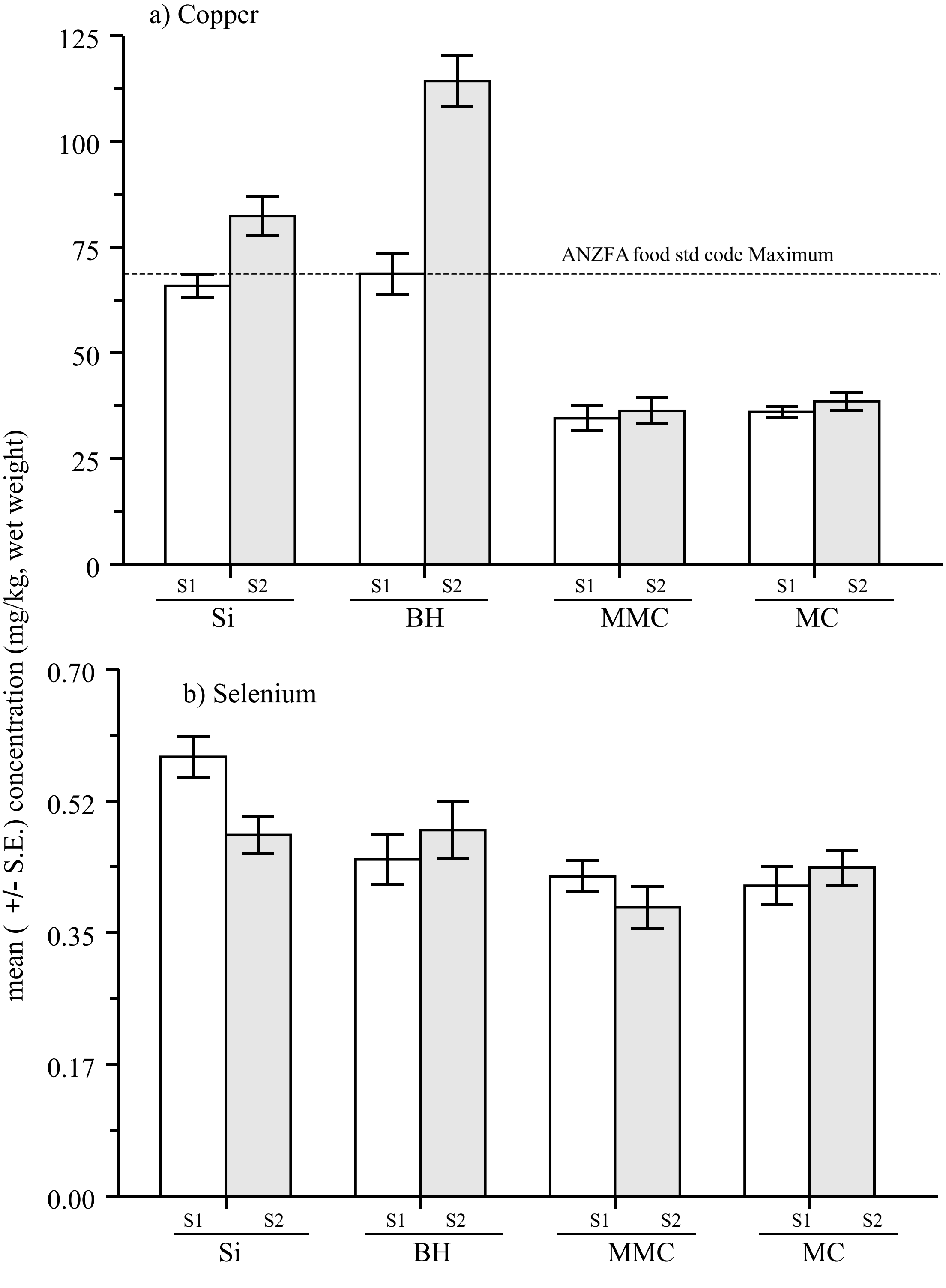
WRL Report No. 2002/20	TRAWL AND SAMPLING LOCATIONS	Figure 6.10

fig6_10.mxd



NOTE:
Proximity of symbols indicates similarity between samples.

WRL Report No. 2002/20	TWO-DIMENSIONAL nMDS PLOTS OF THE BEAM TRAWL SAMPLES	Figure 6.11 00758-06-11.cdr



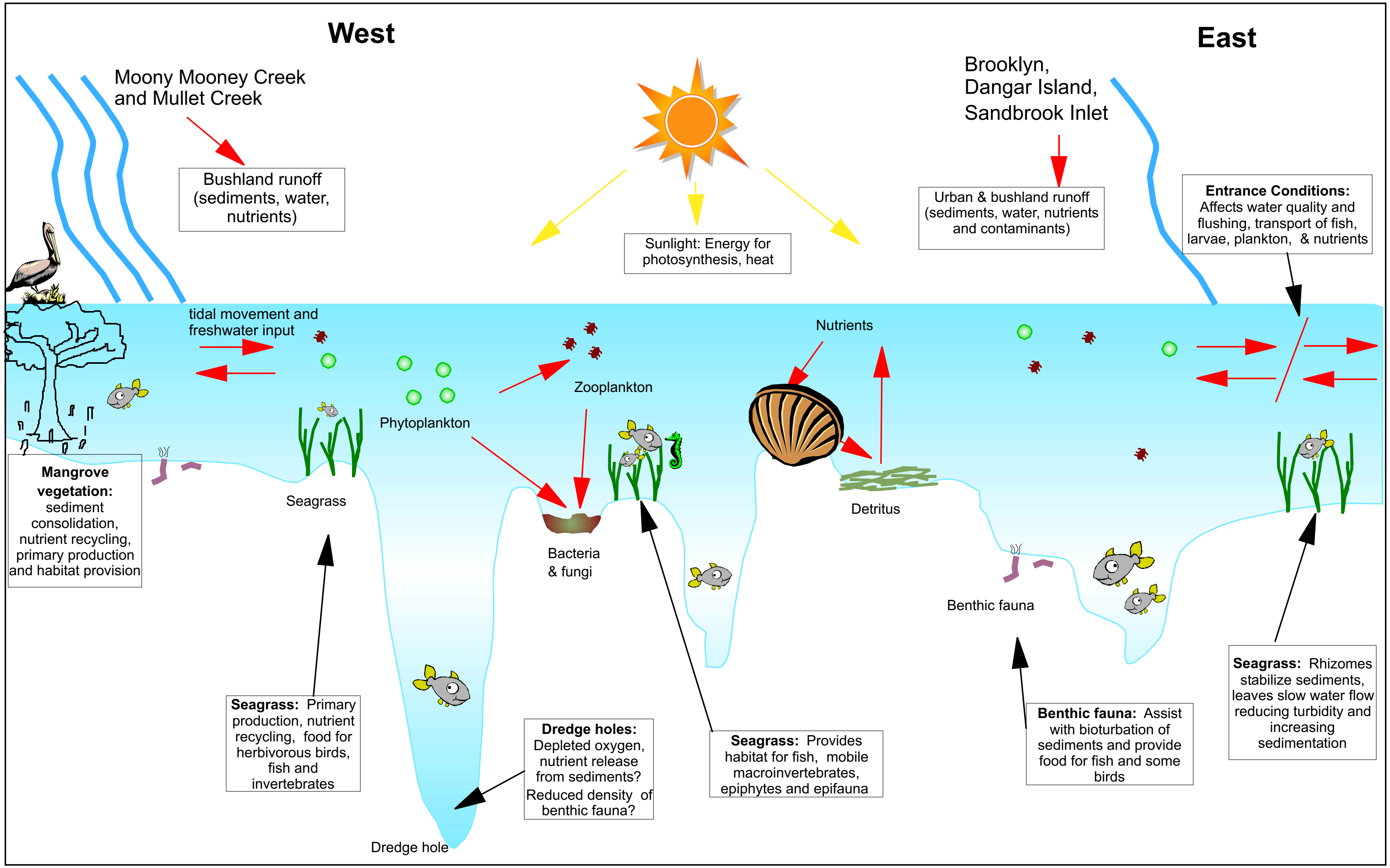
S1	Site 1
S2	Site 2
Si	Sandbrook Inlet
BH	Brooklyn Harbour
MMC	Mooney Mooney Creek
MC	Mullet Creek

WRL Report No. 2002/20	MEAN CONCENTRATION OF COPPER AND SELENIUM IN OYSTERS FROM 2 SITES AT EACH OF 4 LOCATIONS IN THE BROOKLYN REGION, n=8	Figure 6.12 00758-06-12.cdr

WRL

Report No. 2002/20

CONCEPTUAL ECOSYSTEM MODEL OF BROOKLYN ESTUARY



Source: Ecology Lab Pty Ltd

Figure 6.13

00758-06-13.cdr

7. HUMAN USAGE AND ACTIVITIES

As a popular recreational, economic and residential area the Brooklyn estuary is influenced by human usage and activities. Chapter 7 analyses these impacts by reviewing existing literature on human usage, providing temporal and spatial patterns of waterway usage and the environmental impacts of these activities, identifying human activities which have impacted upon the estuary, and determining the European and Aboriginal cultural sites within the study area. An assessment of current visual amenities within the Brooklyn estuary is also given at the conclusion of this chapter.

7.1 Summary of Available Data

7.1.1 Review of Existing Literature

The Hawkesbury-Nepean catchment is a vital socio-economic resource for the state of New South Wales and has been impacted upon by a wide range of human activities. The impacts of these activities have been well documented and there exists a significant volume of literature describing the history of catchment development and, more recently, the impacts of this development.

Rosen (1995) provides a comprehensive history of the entire Hawkesbury-Nepean catchment from the time of European settlement, with an emphasis on the resulting environmental impacts. Similarly, Recher *et al*. (1993) provides an overview of the history of the Hawkesbury-Nepean catchment, specifically in terms of its biota. Valuable background information is also included relating to the prehistorical landscape, geology and vegetation. Changes to the catchment due to Aboriginal occupation and European colonisation are discussed separately, including a section relating to changes to the physical aquatic environment and its fauna.

Due to the small size of the Brooklyn Estuary study area in relation to the entire Hawkesbury-Nepean catchment, there is limited specific information provided in catchment-scale reports. Nonetheless, the Hawkesbury-Nepean Catchment Management Trust has identified environmental values for sub-catchments including the Mooney Creek Dam zone and a lower Mooney Mooney Creek/Mullet Creek zone (HNCMT, 1996) and the EPA has undertaken large-scale water quality and flow monitoring of the entire Hawkesbury-Nepean catchment, including sites within the study area. These results are reported with some discussion of possible causal mechanisms by the EPA (1994; 1997).

Hornsby Shire Council has provided a number of reports relating to management of its constituency, which encompasses solely the southern shore of the study area. These reports include the Brooklyn and Dangar Island Development Control Plans (HSC, 1994; 1996), the Brooklyn and Environs Management Plan (HSC, 1990), and the Brooklyn Waterway Planning Study (PWD, 1988). The Brooklyn Waterway Planning Study in particular, provides extensive background information on the waterway's environment and activities at the time of publication, but is outdated in some areas.

Gosford City Council had not been forthcoming with information regarding their constituency prior to preparing this report, however, a number of documents were found on their website that provide useful information. These include Development Control Plan No. 89 - Scenic Quality (GCC, 1996), which discusses geographic units within the LGA and development objectives for each, and the Gosford Planning Scheme Ordinance (GCC, 2002b), which lists heritage items within the Gosford LGA.

A further source of relevant information has been a number of development applications and their associated Environmental Impact Statements. These include assessments of the potential environmental and social impacts of the development proposal, as well as background information about the current state of the socio-economic, physical and cultural environments. Environmental Impact Statements (EIS) reviewed for this study include the Brooklyn and Dangar Island Priority Sewerage Program (SMEC, 2000), the Brooklyn Resort Tourist Facility (JBA Urban Planning Consultants, 1998), and the Boat Sewage Pumpout Facility at Kangaroo Point (MHL, 2000). The EIS for the Priority Sewerage Program contains an archaeology report detailing sites of Aboriginal heritage importance within the EIS study area.

With regard to the scenic amenity of the Brooklyn study area the Department of Urban Affairs and Planning report (DUAP, 1996), which identifies regions of the Hawkesbury-Nepean catchment that are of high scenic quality and significance, has provided useful information. This information is further discussed in Section 7.5.

7.1.2 Information Sources and Field Inspections

As some of the reports described above were prepared ten or more years ago, current information has been sought from a number of sources. The Waterways Authority and NSW Fisheries were contacted for mooring and berthing numbers and commercial fishing statistics, respectively. The National Parks and Wildlife Service was contacted for data from their Aboriginal Heritage Information Management System and the online State Heritage Inventory (NSW Heritage Office, 2002) was searched for European heritage items within the study area. The Boating Industry Association was also contacted for quantitative information regarding waterway facilities in the study area.

Field inspections were undertaken by boat in February and April 2002. In February launch ramp use in the study area was surveyed and in April a comprehensive identification of moorings, wharfs, marinas and water access locations was carried out.

7.2 Waterway Use and Access

The Brooklyn study area is a popular access point for waterway activities in the Lower Hawkesbury River. Sandbrook Inlet is a hub for waterway access and boating service activities due to its sheltered location, ready access to the river, access to major road networks and proximity to the town of Brooklyn. Other facilities are located at Parsley Bay, Flat Rock Point, Kangaroo Point and Mooney Mooney Point (Figure 7.1).

7.2.1 Public Access

Public access to the water is limited within the study area due to the large area of National Park and undeveloped land in the catchment, lack of road access in most areas, environmental features, such as steep topography, mangroves and mudflats, and private ownership of the foreshore in developed areas. Many foreshore areas of the estuary do not have road access and thus, are only accessible from the water. These include the settlements of Dangar Island, Cogra Bay and Little Wobby Beach.

In Brooklyn the foreshore is easily accessible to the public at Kangaroo Point, McKell Park and Parsley Bay. At Kangaroo Point a scenic viewing area provides extensive views of the Hawkesbury River and there is easy access to the rocks for fishing. McKell Park has open vistas of the river, access points for fishing, playground facilities and public tidal swimming baths, while Parsley Bay is popular for fishing off the rocks and breakwater, and has views of the river. The majority of the foreshore within Sandbrook Inlet is not readily accessible due to development and natural mangrove barriers. A large recreation area is situated on the waterfront in the centre of Brooklyn, known as Brooklyn Park, but mangroves and mudflats restrict access to the water. A boardwalk provides views of the water through the river flat swamp forest.

Public and commercial wharves provide public access to the waterway, however there is a lack of wheelchair access via these facilities. There is a ramp to the water at the end of Baden Powell Road where water access is possible but not suitable for boat launching. Land below mean high water mark, such as inter-tidal areas, is Crown Land and thus is available for public use.

The only other areas in the study area that are suitable for public access to the water from the road are located in and around Mooney Mooney. Mooney Mooney Point has a boat ramp and an extensive parking area where views up and down the Hawkesbury River can be enjoyed. There is a public wharf at the end of Point Road, Mooney Mooney, which is accessible by foot down a steep stairway. Between Mooney Mooney and Cheero Point the Pacific Highway comes close to the foreshore but views and access are again restricted by a natural mangrove barrier.

On Dangar Island the public beaches, Bradley’s Beach and the beach on the northern side of the island are accessible to the general public and are highly valued and patronised by the local community (D. Cameron, DLWC, pers. comm., 11/10/02). Visitors to the island can land on these beaches if they arrive in small vessels. There are also a number of easements leading to the shore that provide public access to the foreshore (D. Cameron, DLWC, pers. comm., 11/10/02).

Access to the Long Island and Spectacle Island Nature Reserves requires a permit and is only allowed for scientific and educational purposes (G. Meade, NPWS, pers. comm., 10/04/02).

7.2.2 Waterway Facilities

Public wharfs

Public wharfs are available for short-term mooring and passenger access at Kangaroo Point, the Brooklyn Wharf near Flat Rock Point, Dangar Island, Little Wobby Beach, and Mooney Mooney (Figure 7.1). At Dangar Island and Little Wobby Beach these represent the only public access to the shore. The wharf at Kangaroo Point is used by charter and cruise boats to pick up passengers and Brooklyn Wharf is used by ferries taking residents and visitors to Dangar Island and Little Wobby Beach. There are floating pontoons for public use located at Parsley Bay (2) and McKell Park, near the swimming baths.

Launching ramps

Public launching ramps are located at Parsley Bay, Mooney Mooney Point and Kangaroo Point (Figure 7.1). A survey undertaken on Sunday 10 February 2002 indicated that Parsley Bay has the highest utilisation. Table 7.1 provides information of the survey results.

Table 7.1
Brooklyn Launch Ramp Field Inspection 10 February 2002

		Numbers			
Location	**Time (summer)**	**Cars + Trailers**	**Boats on Trailers**	**Cars**	**Comments**
Mooney Mooney Ramp	0745	25	-		2 boats in water
Parsley Bay Ramp	0800	65	3	17	5 boats in water
Kangaroo Point	0840			3 top 15 compound 34 lower level	No sign of use of ramp
Parsley Bay Ramp	0900	65	-	16	3 boats in water
Mooney Mooney Ramp	0920	28	2		5 jet skis in water at ramp

The high number of cars noted at Kangaroo Point could be associated with residents who live upstream at Milson’s Passage, Sunny Corner and Bar Point as most charter boats are serviced by bus not individual cars *(per comm. A Fenwick)*. At Parsley Bay there are two loading pontoons and a loading dock administered by Hornsby Shire Council. A private launch ramp is also available for use with a charge at the Dolphin Boatshed marina.

Moorings

Moorings administered by the Waterways Authority are located at Sandbrook Inlet, Parsley Bay, Brooklyn Harbour (near Flat Rock Point), Mooney Mooney, Dangar Island, Little Wobby Beach and Cogra Bay (Figure 7.1). Details of the number and status of these moorings are listed in Table 7.2. Within Sandbrook Inlet and

Brooklyn Harbour there are a number of marinas that also provide moorings. These include Sandbrook Inlet Marina (22 moorings), Wharf St Marina (16 moorings) and Brooklyn Marina (40 moorings) within Sandbrook Inlet, and the Hawkesbury River Marina (21 moorings) in Brooklyn Harbour.

Table 7.2
Mooring Numbers and Status in the Brooklyn Study Area

Location	**Number of Moorings**	**Status**
Sandbrook Inlet	290	Ceiling limit is 290, there is a waiting list.
Parsley Bay	109	Ceiling limit is currently 111, this is a waiting list area.
Brooklyn Channel	42	No sites are currently being issued in this bay.
Mooney Mooney	32	No ceiling limit.
Dangar Island	62	For residents only, no ceiling limit.
Little Wobby Beach	11	For residents only, no ceiling limit.
Cogra Bay	4	No ceiling limit.
Total	**550**	

Source: (M. Tanner, Waterways Association, pers. comm., 16/04/02)

The majority of moorings are swing moorings, which are the least efficient use of waterway space. Fore and aft moorings require less space but can only be used in sheltered areas where wind, waves and currents are not likely to damage the boats or hinder access. Field inspection showed that approximately 25 % of the moorings within Sandbrook Inlet are fore and aft moorings. Pile moorings are available for larger vessels at Brooklyn Channel and are also used by some residents in Little Wobby Beach.

Marinas

There are 7 marinas within the study area which, except for the Hawkesbury River Marina, are all within Sandbrook Inlet (Figure 7.1). The Hawkesbury River Marina is located at Brooklyn Harbour near McKell Park. Also located in the Brooklyn Harbour are berthing facilities for commuters who are members of a Boating Co-operative. Table 7.3 outlines the number of berths and cradles available at each of the marinas from information provided by the Boating Industry Association (L. Schivella, BIA, pers. comm., 24/02/03), and observations of other facilities from a recent field inspection (02/04/02).

Table 7.3
Berthing Facilities at Marinas in the Brooklyn Study Area

Marina	**No berths**	**No Cradles**	**Other Facilities**
Brooklyn Marina	44	1	Slipway
Dolphin Boatshed Marina	30	1	Launch ramp Slipway and hardstand
Fenwicks Marina	60	10	Hardstand and travel Lift and crane
Hawkesbury River Marina	34	2	Slipway
Long Island Marina	40	2	Slipway
Sandbrook Inlet Marina	80	1	Slipway
Wharf Street Marina	32	1	Slipway

Source: Boating Industry Association and observations from field inspection (2/4/02).

Boat hire

There are several boat hire operations available in the Brooklyn area. These are often associated with marinas and can be difficult to separately identify. The hire operators that were visible from the water in a recent field inspection include Holidays Afloat (Long Island Marina), Luxury Afloat, Ripples Houseboats (Sandbrook Inlet Marina), Houseboat and day boat hire (Brooklyn Marina), Brooklyn Marine Hire and Engineering, and Brooklyn Central Boat Hire, all of which are in Sandbrook Inlet, and the Hawkesbury River Marina, located in Brooklyn Harbour. Vessels available for hire range from aluminium dinghies to large houseboats.

Charter Boats

Charter companies and boats known to operate in the study area include:

- Hawkesbury River Tourism Services P/L which owns and operates three vessels within the area. Their services include regular ferries to Little Wobby & Dangar Island, Last River Postman and other charter work.
- M V Islander runs Crab & Oyster cruisers daily.
- M V Bay Runner operated out of Dolphin Marina.
- M V Emily Melvyn runs charters within the study area and upstream daily.
- M V Gerry Bailey operates on a causal basis out of the Brooklyn area. Homeport is Sydney.
- M V River Princess operates from Berowra and within study area.
- Macquarie Princess operates from Berowra and within study area.
- Magic Charters operates out of Brisbane Water and casually uses Brooklyn.
- Palm Beach Ferries operates out of Pittwater and cruises regularly within study area.

7.2.3 Oyster Leases

Systematic rock oyster cultivation has been practiced in the Hawkesbury River since the late 1800’s. Oyster farming is now one of the primary industries in Brooklyn and Mooney Mooney, and may be considered to be the main source of employment in the area (PWD, 1988). Production figures are provided in Section 6.4.3.2.

Oyster leases are prevalent throughout the study area from Mooney Mooney Point to Croppy Point, including within Sandbrook Inlet and up Mooney Mooney and Mullet Creeks (Figure 6.8). Some of the leases marked on maps were not visibly active on a recent field inspection, including some near Croppy Point and Cogra Point. This may be due to the practice of encouraging oyster farmers to cultivate the more productive areas only and surrender leases in poor growing areas (PWD, 1988). Oyster depots and purification tanks are located in the eastern half of Sandbrook Inlet and at Mooney Mooney.

Shallow draft punts are used to transport materials and oysters to and from the oyster leases and these are a common sight in the study area. Oyster farmers have constructed long timber jetties in some locations to facilitate water access and provide mooring for the oyster punts (PWD, 1988).

Further information regarding oyster farming practices, oyster production, and pollution and bioaccumulation in oysters is provided in Section 6.6.

7.2.4 Commercial and Recreational Fishing

Commercial fishing on the Hawkesbury River comprises prawn trawling and netting for species such as sea mullet, bream and mulloway. Within the study area, waters north of Long Island are recognised as a major trawl fishing ground and Sandbrook Inlet has been found to provide nursery conditions for juvenile prawns and fishes. Downstream of the road bridges modified prawn nets are used to target squid and other commercially important by-catch include blue swimmer crabs, mud crabs, coral crabs, mantis shrimp, trumpeter whiting, catfish, shark, flounder and eels (JBA Consultants, 1998).

There is a mooring jetty for commercial fishing boats to the north of the Brooklyn Harbour along the rail causeway (Figure 7.1). This jetty provides mooring for 14 fishing vessels and other vessels are generally moored at swing moorings or small jetties adjacent to residences along the river (PWD, 1988). Along with oyster farming, the commercial fishing industry is one of the major employers of residents in the Brooklyn area (HSC, 1990).

Fish and prawns taken in the Hawkesbury River by members of the Hawkesbury River Fishermen’s Co-operative are generally landed in Brooklyn Harbour at the Co-operative’s jetty near its receiver station. The Co-operative handles approximately 70% of the total catch landed in the Hawkesbury River (PWD, 1988). PWD (1988) indicated that the waterway requirements of the Co-Operative should not alter significantly in the future due to stable levels of prawn and fish catches.

The Hawkesbury Trawl Association released a draft Environmental Management Plan in 2001 outlining their vision for a sustainable trawl industry (HTA, 2001). The document highlights the economic significance of the Hawkesbury River trawl fishery and sets objectives for an environmental policy aimed at sustainable management that meets community expectations and standards. Preliminary priority actions required to be undertaken by government and local agencies to meet these objectives are provided for retained and non-retained species, the fisheries ecosystem, water quality and water flow. The document is a first step towards the coordinated development of measures to ensure the sustainability of the Hawkesbury River trawl fishery.

The Brooklyn area is popular for recreational fishing and provides an important point of access to many popular fishing spots in the Hawkesbury River. Kangaroo Point and Parsley Bay are popular with land-based recreational anglers. The rocks at Kangaroo Point are one of the few spots on the lower river where car based fisherpersons can access deep water. Recreational anglers collect bait within

Sandbrook Inlet (JBA Consultants, 1998). The road and rail bridges are a popular location for recreational fishing from boats.

The recently released survey of Recreational Fishing in New South Wales is available on the NSW Fisheries website and provides information on numbers of fishers, fish species, fish catches and expenditures for NSW as a whole. Further information on recreational and commercial fishing practices and catch numbers in the study area is provided in Sections 6.4.1 and 6.4.2.

7.2.5 Constraints to Waterway Usage

The provision of further waterway facilities and the operation of current facilities are constrained by:

- inaccessibility of much of the foreshore, due to existing development and natural barriers;
- water depths, wave climate, physical features and land areas;
- environmental factors;
- social issues (PWD, 1988);
- funding availability.

There is currently very little available space in the Brooklyn area for further developments, and in its current state Brooklyn Harbour, in particular, is congested in terms of land access to facilities. The Mooney Mooney Point boat launching ramp has been developed to try to reduce traffic through Brooklyn, but is disadvantaged by wind and wave exposure during adverse weather conditions. The sandstone slopes that drop steeply to the waters edge in the majority of the study area contribute greatly to the scenic quality of the area but provide little land area for further development. Access to Dangar Island is constrained for visitors by the lack of a mooring pontoon as mooring at the public wharf is not permitted.

Natural river currents maintain water depths in the Hawkesbury River channels, with areas of erosion and accretion relating to the varying velocity of currents around the different landforms. Sandbrook Inlet and Brooklyn Harbour are poorly flushed and receive sediment from fluvial sources and deposition by river currents and are consequently infilling. PWD (1988) estimated that siltation at the entrance of Sandbrook Inlet was occurring at a rate of 10 to 20 mm per annum and in Brooklyn Harbour at a rate of 80 mm per annum. This infilling affects vessel navigation and potentially reduces the area available for boat mooring. As part of the Centenary of Federation project at McKell Park in 2001, a seawall was constructed that has stabilised sediments in this area. However, there has been no monitoring conducted before or after the seawall construction to quantify the effects on sedimentation in the harbour (Ross McPherson, Hornsby Shire Council, pers. comm., 26/11/02). Areas around Dangar Island, Cogra Bay, Spectacle Island and Mooney Mooney Creek are also very shallow and difficult to navigate (see Section 4.5 Sedimentation of Navigation Channels).

The ceiling limit for moorings in Sandbrook Inlet has been reached and there is currently a waiting list. This additional demand for moorings will be difficult to cater for due to insufficient available sheltered waterway areas. It was suggested that current moorings within the inlet should be progressively converted to fore and aft moorings to reduce the waterway area used by moorings and thereby, free the waterway for other uses (HSC, 1990). This has been trialled by the Waterways Authority and commercial operators since the early 1990s and was found to be very difficult for users (A. Fenwick, pers. comm., 03/10/02).

Environmental constraints on development include maintaining adequate water quality, mangrove areas, and oyster leases. Oyster leases currently occupy a significant area of Sandbrook Inlet in particular (approximately 25%), and may be reduced to increase waterway usage capacity and improve the visibility from the shore (PWD, 1988). Water quality in Sandbrook Inlet has been compromised by the reduced tidal flushing since the construction of the causeway, the construction of the highways and railway, and unsewered urban development. Good water quality is vital to the major industries of the area, including oyster farming, commercial and recreational fishing, and tourism. Areas of mangroves restrict access and visibility in many of the Crown-owned areas of foreshore, but should be retained as they play a vital role in the estuarine ecosystem.

The communities of Brooklyn, Dangar Island and Mooney Mooney require the maintenance and promotion of a social environment, which could be considered a constraint to future waterway development. Social issues include the need to preserve open spaces and improve public access to the waterway, and to encourage the development of improved services in the settlements (PWD, 1988). Aboriginal sites of cultural significance located within McKell Park and at Kangaroo Point need to be retained and considered in any proposals for future development.

The restricted space within the study area for the provision of waterway facilities also acts to create potential conflict between waterway users. Moorings within Sandbrook Inlet restrict navigation for vessels, including the path of oyster punts to depots in the east of the inlet. High concentrations of moored boats may reduce the natural visual amenity of the inlet and Brooklyn Channel for some, although many residents and visitors enjoy the view provided by boats on the water. Oyster leases may create an obstruction to boating passage within Sandbrook Inlet and in the Hawkesbury River where they occur in high concentrations, such as in Cogra Bay and the entrance to Mooney Mooney Creek. However, the areas occupied by oyster leases are often shallow and not always suitable for large boats. Brooklyn Channel is an area with particular spatial restrictions, with only a relatively narrow navigable channel between the land and a large oyster lease to the north (Figure 7.2). The public wharf and ferry wharf are at the end of this channel near the causeway, and thus, large vessels including ferries may at times have difficulty manoeuvring if other vessels are active in the channel.

Potential conflicts between waterway users are compounded by similarities among seasonal trends in activities (Figure 7.3). The summer months are most popular for recreational activities, such as boating and fishing, due to the warmer weather. Cruise boats are a common sight at weekends during the summer and houseboats are also popular for weekend or longer use in summer. Houseboat activity continues during winter when the hire rate is lower and more affordable for some, but the majority of cruisers are not used during winter when the opportunity is taken for maintenance (Waterways Authority, pers. comm.). Sailing clubs are active all year round but events such as the 3 Island Race and the Bridge to Bridge power boat races are concentrated in the warmer summer months. Residents commuting by boat from settlements such as Dangar Island and Little Wobby Beach are consistent throughout the year with the level of activity being highest during weekdays.

Data from the NSW Fisheries Commercial Fishing Database (pooled 1984/85 – 2000/01) suggests that the winter months (June to September) produce the lowest total catch levels, while catches increase in the warmer months and peak in April. The April peak relates almost entirely to a large increase in sea mullet numbers. Harvesting of oysters also peaks in March-April, with the majority of spat collection occurring in October-November.

7.2.6 Impacts of Waterway Activities

The large number of waterway activities that occur in the Brooklyn area have a variety of impacts on the surrounding environment. These impacts can be categorised as follows:

- reduced visual amenity
- direct water pollution, e.g. vessel effluent
- indirect water pollution, e.g. urban and road runoff from supporting infrastructure
- waste production
- potential dredging activity
- sustainability of fisheries
- loss of estuarine/fisheries habitat.

The high natural visual amenity of the study area, which is further discussed in Section 7.5, is affected by the level of waterway activities that exists in the Brooklyn Estuary study area. Steep forested slopes and striking sandstone cliffs and rock formations provide spectacular views to those residing in or travelling through the area. While many enjoy the added visual spectacle of boats moored on the water, others may consider that this detracts from the natural beauty of the area. Furthermore, the increasing popularity of the area is causing a rise in the number of properties being overdeveloped, with some older houses of sensitive design being replaced by larger, more visually obtrusive constructions (Figure 7.4). Design guidelines contained in the Brooklyn and Dangar Island Control Plans (HSC, 1994; 1996) are intended to promote buildings that enhance the character of the area and have regard to views from the water and surrounding properties. Gosford City Council's Development Control Plan No. 89 – Scenic Quality states that in the Brooklyn Estuary Landscape Unit the residential and informal scale of development should be retained with ridge tops, cliff lines and conspicuous slopes exempt from development (GCC, 1996). Throughout the study area the development objectives include encouraging new buildings to blend into the existing natural environment with darker colours preferred (GCC, 1996). It is desirable that all further construction in the area is designed to be sensitive to the natural landscape.

The large number of vessels operated in the study area creates the potential for pollutants to enter the estuary directly from vessels. Houseboats and other vessels on which people stay for extended periods are recognised as generating significant quantities of sewage, because they are fitted with toilets and have high usage in terms of number of persons and length of time on board. Ferries and charter boats similarly generate significant quantities of sewage, particularly when they are used for long cruises, because they are fitted with toilets and carry large numbers of passengers (MHL, 2000). As is discussed in Section 3.6.3, it is an offence to discharge untreated toilet wastes into waterways in NSW. There are currently six public vessel sewage pumpout facilities in The Hawkesbury-Broken Bay Region. Two pumpout stations are located in Brooklyn, while the remainder are out of the study area. The use of these facility is primarily free of charge to the public with fees applied to commercial vessels. These facilities provide a large number of recreational and commercial vessels with a means of legal and environmentally safe waste disposal and their provision should reduce the level of pollution from vessels and assist in improving water quality in the area. There is currently no information available on usage or compliance rates of the pumpout facilities. It is recommended that usage of the facility be monitored and water quality measurements, particularly bacterial levels, be taken regularly in the area to determine whether the provision of this facility is adequate to service the study area and surrounds. Information regarding the location, times, fees and availability of the pumpout stations can be found on the waterways website at www.waterways.nsw.gov.au/pumpouts-Hawks.html.

The infrastructure required to support the large array of waterway activities that take place in the Brooklyn Estuary also impacts on the estuary, in terms of water quality and catchment erosion. The effects of urban land use on water quality are discussed in Section 3.4.1, and include changes to nutrient loading and sediment delivery to estuarine waters that are greatest during the development stage. Construction directly on the foreshore, as is necessary for the provision of facilities such as marinas, wharfs and launch ramps, can cause particularly high sedimentation loads without appropriate controls, as there is no buffer between soil disturbance, construction materials and the water. The majority of the urban development in the area is unsewered, including Brooklyn, Dangar Island and Mooney Mooney, and studies have shown that the on-site wastewater treatment systems are contributing to water pollution problems in the area (AWT, 1999a; see Section 3.6 for further discussion). Impervious surfaces such as roads, carparks and hard stands increase the amount of runoff during rainfall and without good stormwater management, cause high levels of pollutants from cars and other vehicles to enter the estuary. Nutrient and sediment runoff from major road and rail networks in the study area is further discussed in Section 3.4.2.

The aggregation of human activities in an area inevitably creates issues with waste management. Additional to the waste production typical of urban areas, the waterway activities of Brooklyn produce waste from two sources of note that can potentially affect the quality of the estuarine environment. The first of these is waste from marinas, which includes antifouling materials from cleaning the hulls of boats, petrol spillage at marinas with fuel tanks, and disposal of sewage and litter from vessels, such as houseboats, that have been on long excursions. The second activity is oyster farming, which uses tar-coated sticks and racks to catch spat. The tar-sticks are a potential hazard that are difficult to dispose of and can be seen in large piles on the waters edge near to oyster depots, either drying for reuse or accumulating for disposal.

As discussed above, the channels in Sandbrook Inlet and Brooklyn Channel are infilling with sediment from fluvial sources and deposition by river currents and can be constrictive to waterway passage (see Section 4.5). Dredging has occurred in Brooklyn Harbour related to the redevelopment of the Hawkesbury River Marina and there has been significant debate regarding the advantages and disadvantages of dredging in Sandbrook Inlet (HSC, 1990). Dredging has the positive impact of improving and maintaining channel navigability and harbour flushing, which is important for the continued use of the area as an access point for the Lower Hawkesbury River. It has associated negative impacts including:

- the destruction of aquatic habitats of flora and fauna,
- turbidity associated with the removal of sediment from the channel bed,
- resuspension of polluted sediments and attached viruses,
- possible unsightly and noisy operations,
- extracted holes and channels encourage sedimentation in those areas thereby increasing the need for future dredging,
- sediment may affect oyster growth (HSC, 1990).

In addition there is the potential to expose acid sulphate soils during extractive activities such as dredging, with negative consequences on water quality and ecosystem health. Due to these potential adverse impacts any applications for dredging must be accompanied by a detailed statement of environmental impacts or an Environmental Impact Statement (HSC, 1990).

Fishing and oyster cultivation are economically and socially important activities in the study area and the sustainable management of these industries is important to the estuarine ecosystem and the culture of the area. If not appropriately managed the combined effects of recreational and commercial fishing, as well as degraded water quality, may significantly affect the future of the fishing industry. These effects may include (NSW Fisheries, 2003):

- Unsustainable harvesting with consequent decline in fish stocks.
- Unsustainable levels of incidental catch with impacts on the ecosystem.
- Impacts on threatened and preserved species, populations and ecological communities.
- Destruction of habitat by use of inappropriate fishing methods in area of environmental sensitivity.
- Unknown effects of trawling on the estuarine ecosystem.
- Conflict between the various commercial fisheries, recreational anglers and other waterway users.

Oyster farming is particularly sensitive to changes in water quality, as was seen in the 1980s when TBT contamination shut down the industry in Sandbrook Inlet for a number of years. The draft Environmental Management Plan released by the Hawkesbury Trawl Association (HTA, 2001) is the first step towards the coordinated development of measures that ensure the sustainability of the Hawkesbury River trawl fishery. In addition, NSW Fisheries have recently released fishing management strategies for the estuary prawn trawling fisheries and the estuary general fishery that apply throughout NSW. These strategies were developed following the preparation of comprehensive environmental impact assessments for each of the fisheries (NSW Fisheries, 2003).

The population of riverside settlements in the Brooklyn Estuary study area is steady with little change in the population figures for Brooklyn, Mooney Mooney and Dangar Island in at least the past 20 years (Bureau of Statistics data). Population projections produced in 1995 predict an increase in population between 1991 and 2021 of 21.9% in the Hornsby LGA and 18.2% in the Gosford LGA with an average annual increase of 0.66% and 0.56%, respectively (DUAP 1995). This level of population growth is not expected to occur in the small riverside settlements of the study area due to zoning restrictions and the constraints of the natural environment. Any small increases in local population that do occur in these areas are likely to result from consolidation of existing residential land and is not likely to result in the expansion of urban settlements. The ridge top settlements of Kariong and Somersby have the potential for greater population growth and changes in land use and thus must be carefully managed to prevent negative impacts downstream in Mooney Mooney Creek and the Brooklyn Estuary.

Tourist activities in the area are likely to increase due to population growth in the general Sydney area. The population in the total Sydney region is predicted to increase by 21.9% between 1991 and 2021 (DUAP 1995) and tourist numbers in popular holiday locations such as the Hawkesbury River may increase by a similar amount during holiday periods and on a seasonal basis. Increasing tourist numbers will place greater pressure on the existing infrastructure of towns such as Brooklyn and increased waterway activity concentrated at certain times of the year will impact on the state of the estuary if not carefully managed.

Issues related to the management of increased tourist numbers and population growth in ridge top settlements should be addressed in the estuary management study.

7.3 Impacts of Human Activity

7.3.1 History of Development

The history of human occupation in the Hawkesbury River catchment may date back as far as 30 000 years before present when Aborigines are thought to have first arrived in the area (Recher *et al*., 1993). European contact with the area began soon after settlement in Port Jackson when in 1788 a party of explorers ventured into Broken Bay and up the Hawkesbury River.

The history of human activity in the Hawkesbury-Nepean catchment and in the Brooklyn Estuary study area in particular is summarised in Table 7.4.

Table 7.4
Timeline of Development in the Hawkesbury-Nepean catchment and the Brooklyn study area (shaded)

> 4000 yrs BP	Aboriginal tribes used study area for food, occupation, water and shelter
1788	European settlement NSW, population 1,035
1788	First European contact with Brooklyn area – party lead by Governor Phillip landed on Mullet (now Dangar) Island
1794	Hawkesbury opened for settlement – indicates increased sediment and nutrient input from development of agriculture and animal waste
1800	NSW population 5,100
1805	Macarthur granted 2,024 ha at Camden
1809	All the best soils in the Windsor-Richmond area reported as being farmed
1810	Creation of five towns of Windsor, Richmond, Wilberforce, Pitt Town and Castlereagh
1810	2,389 settlers in Hawkesbury district
1813	Bridge over South Creek Windsor – indicates spread of development and increasing impact on Hawkesbury-Nepean catchment
1815	Cox constructs road over mountains
1817	Solomon Wiseman granted land at Wisemans Ferry
1819	Settlement west of Nepean River at Penrith
1820	NSW population 23,936
1823	Archibald Bell finds alternative route over the mountains through Kurrajong
1823	Windsor-Maitland road opened
1826	Great Northern Road to Hunter Valley started
1827	First punt at Wisemans Ferry
1836	First official resident in Brooklyn area (George Peat) – indicates start of development of study area
1841	NSW population 118,918
1844	Peats Ferry established at Kangaroo Point
1847	Construction commenced on road link between Peats Ferry and Sydney – indicates increasing development
1847	Dangar builds a house on Mullet (now Dangar) Island
1852	Government punt between Peats Ferry and Mooney Mooney Point established
1856	Road bridge over Nepean at Penrith opened
1861	NSW population 350,860
1863	Railway reaches Penrith – increasing development in Hawkesbury-Nepean catchment
1864	Blacktown-Windsor-Richmond rail line opened
1867	Rail bridge over Nepean at Penrith opened
1867	Penrith-Wentworth Falls rail line opened
1880	Upper Nepean water supply scheme constructed 1880-1935
1881	NSW population 749,825
mid 1880s	Construction of railway causeway linking Brooklyn to the eastern end of Long Island – restricts tidal flushing of Sandbrook Inlet and large sediment input during construction.
1887	Rail link from Sydney reached Brooklyn

1889	Hawkesbury rail bridge opened
1890	North Shore line St Leonards-Hornsby opened – urbanisation of North Shore
1894	Ku-ring-gai Chase National Park created
1901	NSW population 1,354,846
1903	Road bridge over Nepean at Picton
1921	NSW population 2,100,371
1927	Hornsby-Milsons Point line electrified
1930	Concrete road Hornsby-Hawkesbury opened – increased road traffic and runoff
1930	Regular operation of Peats Ferry starts
1931	Road sealed Peats Ferry-Mooney Mooney Creek
1931	Harbour Bridge opened – increased development of North Shore
1933	NSW population 2,600,847
1938	Warragamba weir constructed 1938-1940
1945	Bridge at Peats Ferry opened
1946	New Hawkesbury rail bridge opened
1947	NSW population 2,984,838
1959	Rail line electrified to Hawkesbury River
1960	Rail line electrified to Gosford
1960	Warragamba Dam opened – start of impacts on freshwater flows
1961	NSW population 3,917,013
1965	Hawkesbury-Mt White F3 opened
1971	City water supply connected to Dangar Island
1972	Long Island and Spectacle Island Nature Reserves dedicated
1973	F3 freeway bridge opened
1973	Macarther Bridge over Nepean at Camden opened
1975	TBT antifouling 1970s to 1989 – impact on marine life
1981	NSW population 5,126,217
1982	Completion of Upper Mooney Mooney Dam with storage capacity of 4,500 ML replacing lower Mooney Dam that had capacity of 1,000 ML – affect on freshwater flow
1988	Estimated Hawkesbury-Nepean catchment population 500,000
2000	Estimated Hawkesbury-Nepean catchment population 800,000

7.3.2 Effects of Human Activities on Estuarine Processes

Human activities that have affected the functioning of estuarine processes in the study area relate primarily to construction/development and waterway activities. These impacts include changes to the hydrodynamics of the estuary, degraded water quality and increased catchment erosion.

One of the earliest and possibly most significant local impacts was caused by the construction of the railway causeway between Brooklyn and Long Island in the mid-1880s. While Sandbrook Inlet was naturally shallow, this blocked off the inlet at its eastern end reducing its linkage with the main Hawkesbury River and decreasing tidal flushing in the inlet (see Sections 4.4.1 and 4.4.4). In terms of water quality this change in hydrodynamics has increased the residence time of pollutants in the system with flow on effects to aquatic biota.

Changes to freshwater flows in the area have been caused by construction of dams in the upper catchments, both in Mooney Mooney Creek for the Gosford-Wyong water supply (see Section 3.3) and further upstream the Hawkesbury-Nepean for the Sydney water supply. Dams act to moderate water flows, reducing the large natural variability that can occur with flood and drought events.

Development in the Hawkesbury-Nepean catchment has altered water quality in the mainstream Hawkesbury River. Areas of bushland have been cleared for agricultural use since early in the history of settlement, resulting in increased nutrient loads via runoff and faecal coliform contamination from animal waste. The development of urban areas in the catchment has been accompanied by the construction of more than 40 sewage treatment plants which discharge treated sewage to the Hawkesbury River and its tributaries. This has had a large impact on nitrogen and phosphorus concentrations in the river, which are ubiquitously high and above guideline levels.

Urban development and agricultural activities in the study catchment, although relatively restricted by topography, have increased runoff and pollutant inputs to the estuary (see Section 3.4.1). Construction activities increased sediment inputs and impervious surfaces such as roofs, roads and carparks increased the amount of rainfall that runs straight off the land or enters the estuary via stormwater drains. This runoff carries with it substances such as nutrients, litter, pesticides and herbicides, trace metals and oils, and faecal coliforms. Faecal coliform and nutrient inputs are of particular concern in the majority of the urban areas in the study area as they are currently unsewered. Water quality is degraded in receiving waters downstream of residential areas in Brooklyn and Dangar Island due to failing on-site wastewater treatment systems (AWT, 1998a). Faecal contamination from dogs and other animals may also affect water quality, but it is not possible to quantify this source.

Road and rail corridors are significant features of the Brooklyn study area and their construction, including road and rail cuttings and filling, railway tunnels, the three existing bridges and the causeway, will have generated large sediment loads to the estuary over a short time period (see Section 3.5). In their completed state the Sydney-Newcastle Freeway, Pacific Highway and Main Northern Railway affect the estuary by increasing runoff, affecting natural drainage paths and by being a source of pollutants from vehicles and human activities (see Section 3.4.2).

Waterway activities in the Brooklyn Estuary and their effects on the estuary are discussed in detail in Section 7.2.6. In summary, these include possible perceived changes to the scenic amenity of the area due to the presence of development and vessels on the water, direct water pollution such as sewage discharge from vessels, disposal of waste produced by marinas and the oyster industry, potential need for dredging to maintain and/or improve vessel navigation, and issues regarding the sustainability of the fishing and oyster industries.

7.3.3 Key Issues

The impacts of human activity within the Brooklyn Estuary catchment have created a number of key issues that should be specifically addressed in the Management Study Plan to ensure the integrity of environmental, social and economic values in the area.

- *Sewage management*
  Currently the majority of urban areas are unsewered and existing on-site wastewater treatment systems are contributing to water pollution issues. The proposed Brooklyn and Dangar Island Priority Sewerage Program (SMEC, 2000) has the potential to greatly reduce sewage contamination in the southern part of the study area and work is in progress to determine the most effective option for doing so (see Section 3.5.1). A similar scheme involving the settlements of Mooney Mooney, Cheero Point and Little Wobby Beach, as well as a possible upgrade of the Peat Island STP (Ellis, Karm & Associates, 2002), also has the potential to reduce waterway contamination from sewage inputs on the northern shore of the estuary (see Section 3.5.2). It is critical that both of these schemes involve the highest possible level of sewage treatment so that effluent discharged (to the Brooklyn Estuary or elsewhere) does not further increase nutrient concentrations in the study area and the Hawkesbury River in general.

- *Vessel discharges*
  There has been a lack of facilities available for vessels to dispose of sewage from holding tanks and portable toilets and despite the designation of voluntary no discharge zones unknown quantities of sewage may have been released into the estuary from boats (see Section 3.5.3). The development a sewage pumpout facility at Brooklyn should improve this situation but stricter legislation along with education of waterway users may also be required to ensure that environmentally safe methods of sewage disposal are followed. Additional studies that determine the expected volume of vessel discharges (i.e. the number of boats per weekend) and the actual volumes received may be undertaken by Waterways to determine the usage rates of the pumpout facilities.

- *Freeway and railway runoff*
  The Sydney-Newcastle Freeway, Pacific Highway and Main Northern Railway are major features in the study area and contribute a significant amount of runoff, sediment and pollutants to the estuary (see Section 3.4.2). The impact of these and other minor transport routes may be minimised by effective stormwater management, such as that being initiated by Hornsby Shire Council's Catchment Remediation Program (HSC, 2001) (see Section 3.7).

- *Urban development*
  The potential for further urban development within the study area is largely restricted by land zoning and environmental constraints, but it is important that intensification of current urban areas is managed to reduce the visual and environmental impact. Areas in the upper Mooney Mooney Creek catchment, such as Somersby and Kariong, are being developed more intensively than

riverside settlements and have the potential to cause significant downstream impacts on Mooney Mooney Creek and the Brooklyn Estuary if not appropriately managed.

- *Railway causeway*
  The railway causeway is a longstanding feature of the Brooklyn environment that has reduced tidal flushing in Sandbrook Inlet (see Section 4.4.1), creating water quality and sedimentation problems. A possible suggestion has been that the causeway be breached (possibly by constructing culverts beneath the railway tracks), in order to improve flushing in the inlet.

- *Sedimentation*
  Sedimentation is currently requiring routine dredging in Sandbrook Inlet and Brooklyn Channel and has reduced vessel navigability in these areas. There are a number of issues involved when considering the option of sediment dredging and any applications for dredging should be fully researched to minimise detrimental consequences.

- *Fishing and oyster industries*
  The commercial fishing and oyster industries are important to the Brooklyn study area both socially and economically. Current threats include poor water quality and overexploitation and these must be managed to ensure the sustainability of these industries.

7.4 Cultural and Heritage Values

7.4.1 Aboriginal Heritage

Aboriginal settlement of the Hawkesbury-Nepean catchment may have commenced over 30,000 years ago (Recher *et al.*, 1993) but the most intensive Aboriginal occupation of the catchment is believed to have commenced 4000 years ago (Rosen, 1995). Hawkesbury Sandstone soils are nutrient-poor, shallow and have rapid drainage and evaporation rates, and, as a consequence, the major rivers and estuaries were important for the physical survival of the Aboriginal people (Recher *et al.*, 1993; Rosen, 1995). The Hawkesbury River served as a social nexus for various tribal groups (Rosen, 1995).

A search of the NPWS Aboriginal Heritage Information Management System (P. Houston, NPWS, pers. comm.., 25/02/03) found 1076 identified Aboriginal sites within the Brooklyn Estuary study area with a total of 1371 site features. The Brooklyn Estuary catchment area covers two Local Aboriginal Land Councils (LALCs), the Darkinjung LALC to the north of the Hawkesbury River and the Metropolitan LALC to the south. Table 7.5 presents the type and number of Aboriginal site features within each of these LALCs.

Table 7.5
Aboriginal Heritage Sites and Features in the Brooklyn Estuary Study Area

Site Feature	Metropolitan LALC		Darkinjung LALC	
	Number	%	Number	%
Art	38	28.6	566	45.7
Artefacts	30	22.6	136	11.0
Burials			1	0.08
Earth mound	29	21.8	83	6.7
Grinding grooves	5	3.8	293	23.7
Modified tree	1	0.8	34	2.7
Shell	29	21.8	83	6.7
Stone arrangement			37	3.0
Waterhole	1	0.8	5	0.4
Total	*133*		*1238*	

Source: NPWS Aboriginal Heritage Information Management System (P. Houston, NPWS, pers. comm.)

As part of the EIS for the Brooklyn and Dangar Island Sewerage Scheme (SMEC, 2000) a field survey was conducted by Bobbie Oakley & Associates to assess Aboriginal archaeological potential in the Brooklyn and Dangar Island area. Two Aboriginal archaeological sensitive areas were identified in Brooklyn, at McKell Park and Kangaroo Point. The McKell Park area is located adjacent to a rich estuarine resource zone surrounded by recorded Aboriginal sites including occupation and art sites and was assessed to have a high Aboriginal archaeological potential. The Kangaroo Point area contains two recorded sites, a shelter with deposit and a rock engraving. The Aboriginal heritage sites that lie within the Sewerage Scheme study area are shown in Figure 7.5.

7.4.2 European Heritage

The towns of Brooklyn and Dangar Island have non-indigenous heritage significance derived from a history which dates back to the early days of settlement when the area was an important base for trading, recreation and access to other remote areas. In the late-18th and 19th centuries both towns were used as a base for expeditions up the Hawkesbury River and Australia's first steamer carried passengers between Brooklyn and Windsor until 1909. The area continued to develop and serve as a base for oyster farming, and bridge and railway construction. Expansion of Brooklyn occurred in the 1880s as a result of the completion of the Newcastle to Sydney railway and the settlement of workers for the construction of the railway tracks, station and Rail Bridge. The Hawkesbury River Rail Bridge was opened in 1889 and the Peats Ferry Road Bridge was opened in 1945. Much industrial and residential fabric from the Federation period has been retained in Brooklyn's civic centre.

There are many individual heritage items in Brooklyn and on Dangar Island. Hornsby Council has recently undertaken a Heritage Review, including a review of all items currently on its heritage register. It is also considering proposals to class the whole of Brooklyn as a heritage area, under a Context listing, or to list the Hawkesbury Estuary as a heritage item. Should Council adopt either or both of these alternatives, the result will be more detailed development controls over the area, aiming for conservation of identified heritage items and of the general character of the area (SMEC, 2000). Tables 7.6 and 7.7 list heritage items identified in the Brooklyn and Dangar Island areas.

Schedule 8 of the Gosford Planning Scheme Ordinance (GCC, 2002b) lists items of environmental heritage within the Gosford City LGA. It states that “items of environmental heritage” mean a building, work, relic or place of historic, scientific, cultural, social, archaeological, architectural, natural or aesthetic significance. Listed heritage items within the Brooklyn Estuary study area are the 3 pylons of the old Hawkesbury River Railway Bridge and the site of George Peats Inn, Mooney Mooney Point, Hawkesbury River (GCC, 2002b). A search of the online State Heritage Inventory (NSW Heritage Office, 2002) found two additional heritage items both located in Somersby. These are Belltrees and the homesteads, and outbuildings of Belbourie.

Table 7.6
European Heritage Items in the Brooklyn area

Item	Location	Significance
Shop	1-3 Bridge Street	Local
Shop	5 Bridge Street	Local
Shop	7 Bridge Street	Local
Brooklyn Police Station	11 Bridge Street	Local
Brooklyn Post Office and Residence	13 Bridge Street	Local
House	15-17 Bridge Street	Local
Brooklyn cemetery	Brooklyn Road	Local
Seymours Creek Mangrove wetland	Brooklyn Road	Local
House	51 Brooklyn Road	Local
House	52 Brooklyn Road	Local
Brooklyn Park	87 Brooklyn Road	Regional
“Rossmore”	89-91 Brooklyn Road	Local
House	95-97 Brooklyn Road	Local
“Ross Homestead” and garden	96 Brooklyn Road	Local
Brooklyn Public School (excluding grounds)	106 Brooklyn Road	Local
House	117 Brooklyn Road	Local
War Memorial Hall	120 Brooklyn Road	Local
House	121 Brooklyn Road	Local
House	129 Brooklyn Road	Local
House	131 Brooklyn Road	Local
“Melville”	140 Brooklyn Road	Local
Old St Mary’s Church	156A Brooklyn Road	Local
House	176 Brooklyn Road	Local
House	180 Brooklyn Road	Local
“Blinkbonnie”	206 Brooklyn Road	Local
House	208 Brooklyn Road	Local
House	212-214 Brooklyn Road	Local
McKell Park – lower, upper, cabbage palms and World War II gun and emplacements	Dangar Road	Regional
Governor Phillip Memorial	Dangar Road	Local
Hawkesbury River Railway Station	Dangar Road	Regional
House	10 Dangar Road	Local
House	5 George Street	Local
House	7 George Street	Local
Brown’s boatshed	10-16 James Road	Regional
Footpath	Karoola Street	Local
House	1 Karoola Street	Not stated
House	2 Karoola Street	Local
House	3 Karoola Street	Local
House	5 Karoola Street	Local
House	8 Karoola Street	Local
House	12 Karoola Street	Local
House	23 Karoola Street	Local
Old railway dams	Kuring-gai Chase National Park	Regional
Railway tunnels	Long Island	State
1889 railway bridge piers, pylon and plaque	Long Island	State
1946 railway bridge, memorial and construction docks	Long Island	Regional
Nature Reserve - bushland	Long Island	Regional
Road remains	Disused Old Peats Ferry Road	State
Peats Ferry road bridge	Pacific Highway	Regional
Rest Park	Pacific Highway	Local
Station Master cottage	1 William Street	Local

(from HSC, 1996; SMEC, 2000)

Table 7.7
European Heritage Items in the Dangar Island area

Item	Location	Significance
Baroona Street Pedestrian Street	Baroona Street	Local
Recreation Reserve	Baroona Street	Not stated
Tyneside house	8 Baroona Street	Local
Grantham Crescent Pedestrian Street	Grantham Crescent	Regional
Grantham Crescent Blackbutt trees	Grantham Crescent	Regional
Bradleys Beach	43X Grantham Crescent	Local
House	67 Grantham Crescent	Not stated
Neotsfield Avenue Pedestrian Street	Neotsfield Avenue	Regional
Waterfront, seawall, wharf, trees and 1889 Railway Bridge construction site	Northern foreshore	Local
Sandstone tower	9 Neotsfield Avenue	Not stated
Riverview Avenue roadworks	Riverview Avenue	Local
Kiparra Park bushland	91X Riverview Avenue	Regional
Former billiard room	9 Yallaroi Parade	Not stated

(from HSC, 1994; SMEC, 2000)

7.4.3 Key Heritage Sites

All of the sites contained within the NPWS Aboriginal Site Register are of significant cultural and heritage importance. The McKell Park and Kangaroo Point areas were identified by SMEC (2000) as being of particular significance.

The NPWS has a statutory responsibility for the care and protection of sites of Aboriginal heritage throughout NSW. Under the National Parks and Wildlife Act (1974) it is an offence to:

- disturb or excavate land to discover a relic,
- remove a relic from a national park or Aboriginal area,
- knowingly destroy, deface or damage a relic or Aboriginal place without the permission of the Director-General of the National Parks and Wildlife Service,
- erect or maintain a building or structure for the storage or exhibition of any relic in a national park or Aboriginal area without a permit issued by the Director-General, or
- fail to comply with the conditions of a permit relating to a relic.

Under these conditions the Aboriginal heritage sites within the study area, including those on the northern side of the river that have not been identified, are currently in a state of conservation.

A number of the European heritage sites identified in Tables 7.6 and 7.7 are seen to have Regional or State significance. Sites of State significance include the railway tunnels and the 1889 railway bridge piers, pylon and plaque on Long Island, as well as the road remains from the disused Old Peats Ferry Road. Sites of Regional significance relate largely to aspects of early settlement, such as the Peats Ferry Road Bridge and the “Rossmore” homestead, or preserved nature areas, such as the Long Island Nature Reserve, McKell Park, and Kiparra Park bushland. The locations of the European heritage sites of State and Regional significance are shown in Figure 7.6.

All European relics are protected under the Heritage Act, 1977. The consent of the Heritage Council is required prior to the disturbance of any relic (HSC, 1996).

7.5 Visual Amenity

The lower Hawkesbury River is one of the most visually spectacular waterways in New South Wales. Views of the scenery are best appreciated from the waterway and high quality vistas are also available from the bridges and certain vantage points, such as McKell Park, the eastern end of Long Island, Kangaroo Point and Mooney Mooney Point (PWD, 1988).

The conservation of this scenic value is critical in consideration of any development. Existing developments in Brooklyn, Dangar Island and Mooney Mooney are generally sympathetic to their environment. Controls outlined in the Brooklyn and Dangar Island Development Control Plans (HSC, 1994; 1996) consider the provision of scenic amenity by loosely restricting aspects of design such as height, density and setback distances. Within Gosford City Council’s DCP No. 89 – Scenic Quality, the Brooklyn Estuary landscape unit is categorised as having state significance, meaning that the protection of its scenic quality should be a matter of priority because its significance extends beyond the Gosford region. Some recent developments when viewed from the river, however, do appear to visually degrade the local area due to their size and building materials (as shown in Figure 7.4).

In 1996 the Department of Urban Affairs and Planning published a report describing results of a study of scenic quality in the Hawkesbury-Nepean (DUAP, 1996). The study formed part of a comprehensive review of Sydney Regional Environmental Plan No. 20 – Hawkesbury-Nepean River (REP 20), and was based on a landscape approach and descriptive inventory. Landscape units contained within the study area were Brooklyn Estuary, Mooney Mooney Creek and Mullet Creek. Table 7.8 summarises the information provided in DUAP (1996) in relation to these areas. The table also highlights the sensitive visual issues and summarises a suggested future strategy for preserving the visual amenity of the area.

Table 7.8
Scenic quality, values and significance of the Brooklyn Estuary, Mooney Mooney Creek and Mullet Creek

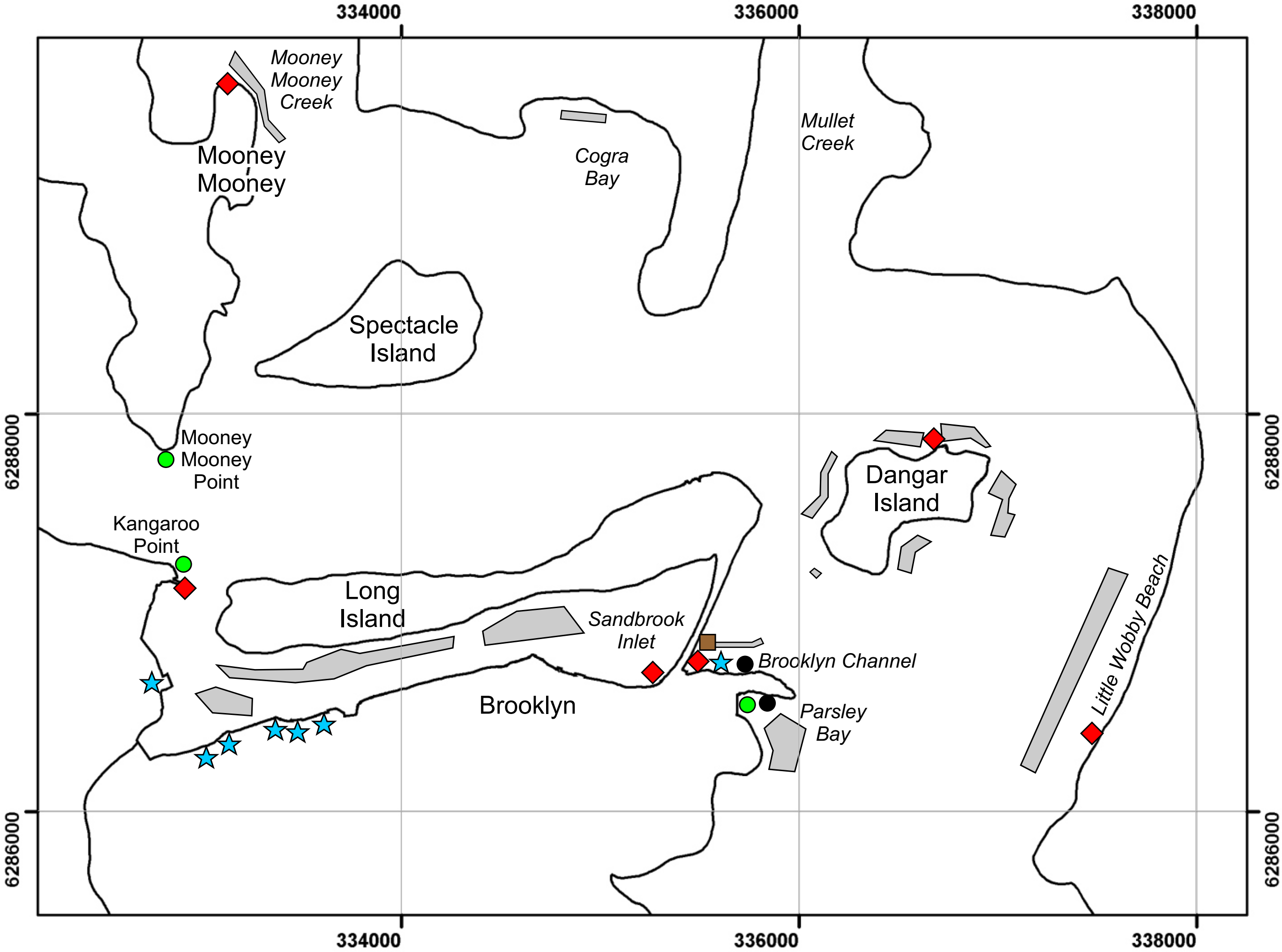
Landform	**Brooklyn:** Wide drowned river valley estuary cut into dissected sandstone plateau, with remnant hilltops as islands and alluvial silt banks in creeks. **Mooney Mooney:** Drowned creek valley estuary cut into dissected sandstone plateau with alluvial tidal flats. **Mullet:** Drowned creek valley estuary cut into dissected sandstone plateau with alluvial tidal flats.
Plant communities	**Brooklyn:** Largely natural sclerophyll woodlands and forests on hills, with mangrove forests on silt banks. **Mooney Mooney:** Largely natural sclerophyll woodlands and forests on hills, with mangrove forests on silt banks. **Mullet:** Largely natural sclerophyll woodlands and forests on hills,

	with mangrove forests on silt banks.
Plantings/crops	**Brooklyn:** Plantings restricted to settlements and previously occupied sites, especially conspicuous at Brooklyn and institutional sites (Peat and Milson Islands). Norfolk Island pines, pines, cypress, coral trees, plane trees common.
Development density and scale	**Brooklyn:** Generally low density and of residential scale, large scale elements associated with road and rail transport. Density varies with transport availability from individual dwellings with no road access to the urban density of Brooklyn. **Mooney Mooney:** Very low density and of residential scale. **Mullet:** Low density and of residential scale.
Designed environments	**Brooklyn:** Peat and Milson Islands, freeway corridor, parks and many other sites in the Brooklyn area. **Mooney Mooney:** Not conspicuous. **Mullet:** Not conspicuous.
Cultural elements	**Brooklyn:** Road and rail bridges and other works, river settlements, institutional and residential islands, oyster leases, boat sheds and marinas, moored boats. **Mooney Mooney:** Settlement, isolated houses, freeway and highway cuttings, oyster leases. **Mullet:** Isolated houses, oyster leases, railway line and works.
Building forms/types	**Brooklyn:** Varies, but generally of residential and traditional form. Commercial buildings of modest scale. **Mooney Mooney:** Residential and traditional forms. **Mullet:** Residential and traditional forms.
River landmarks and important places	**Brooklyn:** Bar Point, Milson Island and Passage, wreck of HMAS *Parramata*, Peat Island, Kangaroo Point, road and rail bridges, Spectacle Island, Long Island, Dangar Island, Little Wobby, Juno Point, Brooklyn village, Porto Ridge. **Mooney Mooney:** Road bridges, Mooney Mooney settlement. **Mullet:** Rail bridge.
Land-water edges	**Brooklyn:** Mostly steep wooded slopes falling into deep water with little foot slope development. **Mooney Mooney:** Mostly steep wooded slopes falling into deep water with little foot slope development. **Mullet:** Mostly steep wooded slopes falling into deep water with little foot slope development..
Recreation sites	**Brooklyn:** Many, associated with the river itself as a passive and active recreation resource. **Mooney Mooney:** Restricted to water.
View points, vistas	**Brooklyn:** Freeway and highway, especially north of the river, railway line at Hawkesbury River station and especially north of the river along Mullet Creek, Kangaroo Point, The Wrecks, Brooklyn Park, Brooklyn wharves, Long Island point, Mooney Mooney village, Dangar Island,

	innumerable from the water. **Mooney Mooney:** Freeway sections to north of river, freeway bridge over Mooney Mooney Creek, Pacific Highway, road bridges looking north. **Mullet:** Railway line along Mullet Creek.
Visibility	**Brooklyn:** Visible from the main road and rail transport routes north of Sydney. Roads have no made viewing points. Visible from parts of surrounding national parks and reserves, mainly with difficult access. Sightseeing on the river is a popular pastime. **Mooney Mooney:** Creek experienced as glimpses on road travel. One made lookout point (Mooney Mooney freeway bridge, designed for viewing bridge, not river landscape). Settlement not conspicuous from main river channels and roads. **Mullet:** Visible from the rail line which follows the creek for some distance.
Landscape character (summary)	**Brooklyn:** An environment featuring waterside retreats and settlements of generally modest and traditional kind, boating, bridges and recreation, in a natural setting. A landscape of great diversity, with wide river channels and islands, scattered dwellings and settlements, wide creeks, tidal flats, cliffs and rounded hills. **Mooney Mooney:** A largely natural creek environment dominated by steep wooded hills and open water, with the settlement of Mooney Mooney clinging to the northern shore of the mouth. At low tide the creek has extensive exposed mud flats and oyster farms. **Mullet:** A largely natural creek environment dominated by steep wooded hills and open water. The northern railway line runs along the foot of the northern shore. At low tide the creek has extensive exposed mud flats and oyster farms.
Scenic conservation issues	**Brooklyn:** Lack of lookout sites on roads. Residential and informal scale of settlements should be retained. Ridge tops, cliff lines and conspicuous slopes should be exempted from development. Development occurring on upper slopes would be inappropriate and out of character. **Mooney Mooney:** Further development should be confined to the settled areas. Settlement visibility is generally low to travellers. Development is becoming more urban in character. **Mullet:** The area should be exempted from development. Railway works are unsympathetic.
Absorption capacity	**Brooklyn:** Some settlements are at maximum capacity (Wobby, Milson Passage, Bar Point). Capacity higher at Brooklyn, where some further sympathetic development could occur on lower slopes. **Mooney Mooney:** The area of the settlement has some capacity for further development in less conspicuous sites. The creek upstream has low capacity.
Visual sensitivity	**Brooklyn:** Visual sensitivity is high because of the visual access to the area and high community esteem. **Mooney Mooney:** Visual sensitivity is high overall because of the

	visual access to large numbers of distance travellers.
Detracting elements	**Brooklyn:** Obtrusive, overscale and inappropriately coloured buildings in prominent positions (e.g. Mooney Mooney, Wobby, Brooklyn), overdevelopment of waterfront (Wobby, Brooklyn 'Gut'), areas approaching maximum carrying capacity (Dangar Island, Brooklyn near Kangaroo Point). Ugly public utility works (Long Island, Mullet Creek, Brooklyn causeway). **Mooney Mooney:** Conspicuous ridge top and water level dwellings, buildings of excessive bulk and size in elevation, areas reaching urban densities, inappropriate building forms.
Statement of significance	**Brooklyn:** The area is of high scenic quality and acknowledged heritage significance. It has the perceptual and formal attributes of high quality scenery, is an outstanding regional example of a ria coast estuary, is esteemed by the community for its scenic qualities, has been the stimulus for artistic endeavour, is a traditional recreational and water sport destination for Sydney and has a long history related to land transport routes to the north and river transport to Sydney. **Mooney Mooney:** The area is of high scenic quality and acknowledged heritage significance. It has the perceptual and formal attributes of high quality scenery, is an integral part of an outstanding regional example of a ria coast estuary.
Suggested response	**Brooklyn:** Develop a visual management strategy plan for the entire area. Prevent large scale and high density developments, particularly on waterfront lands. Prevent building on ridge topes and conspicuous slopes. Assess the visibility and impact of all proposals from water and land view points. Require landscape management and landscape design plans to accompany new proposals. Limit new buildings on waterfront sites to existing settlements. Encourage new buildings on conspicuous sites to be of forms broken up into smaller elements, rather than simple prismatic shapes. **Mooney Mooney**: Prevent large scale and high density developments. Prevent building on ridge tops and conspicuous slopes. Limit new buildings on waterfront sites to existing settlements and to sites with wide frontages.

(from DUAP, 1996)



- Public wharf
- Marina
- Public launching ramp
- Commercial fishing boat jetty
- Mooring area
- Public disabled access

WRL	WATERWAY FACILITIES IN THE BROOKLYN ESTUARY STUDY AREA	Figure 7.1
Report No. 2002/20		00758-07-01.cdr

WRL Report No. 2002/20	OYSTER LEASES IN THE BROOKLYN ESTUARY STUDY AREA	Figure 7.2

00758-07-02.cdr

WRL

Report No. 2002/20

INDICATIVE SEASONAL TRENDS IN ACTIVITY

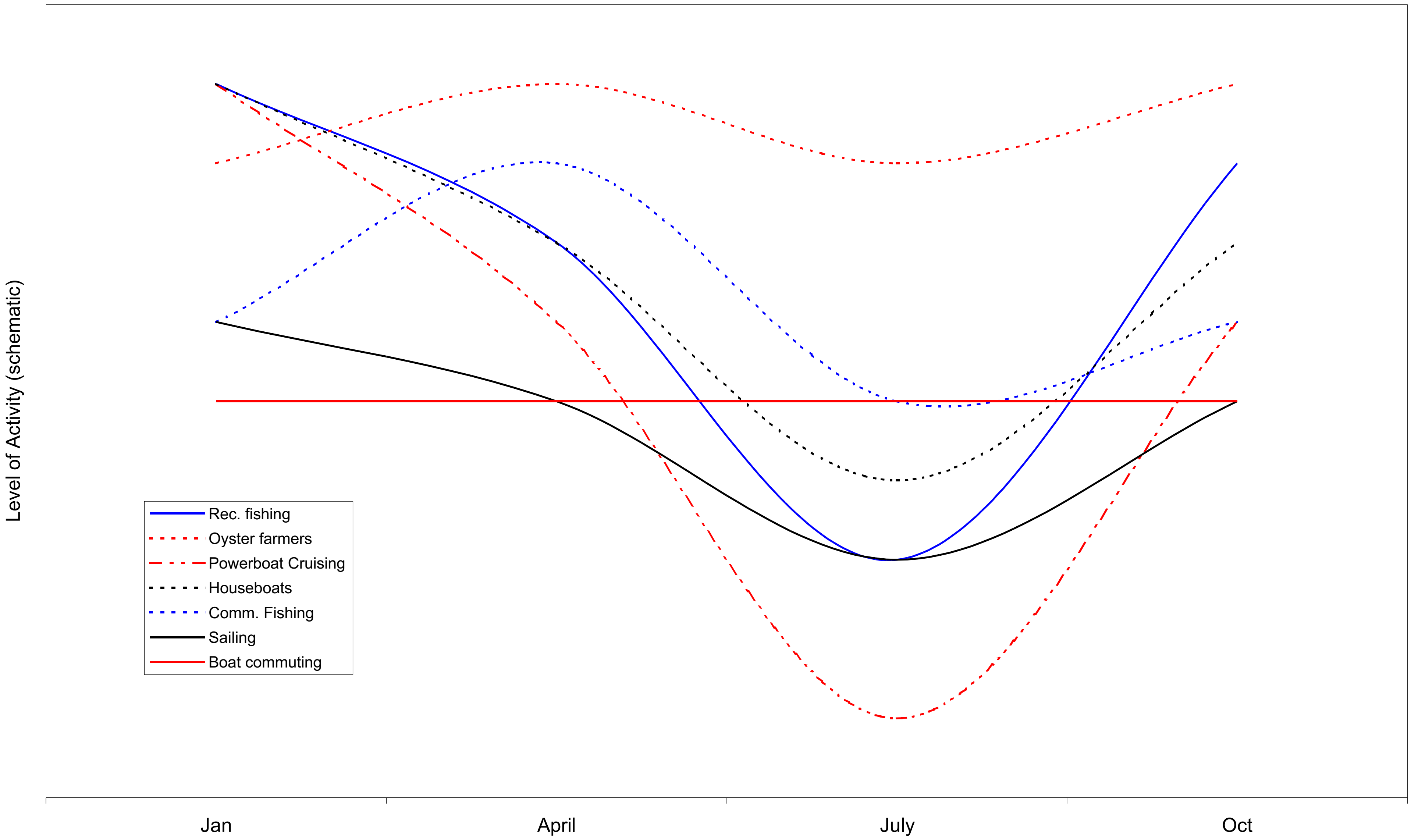
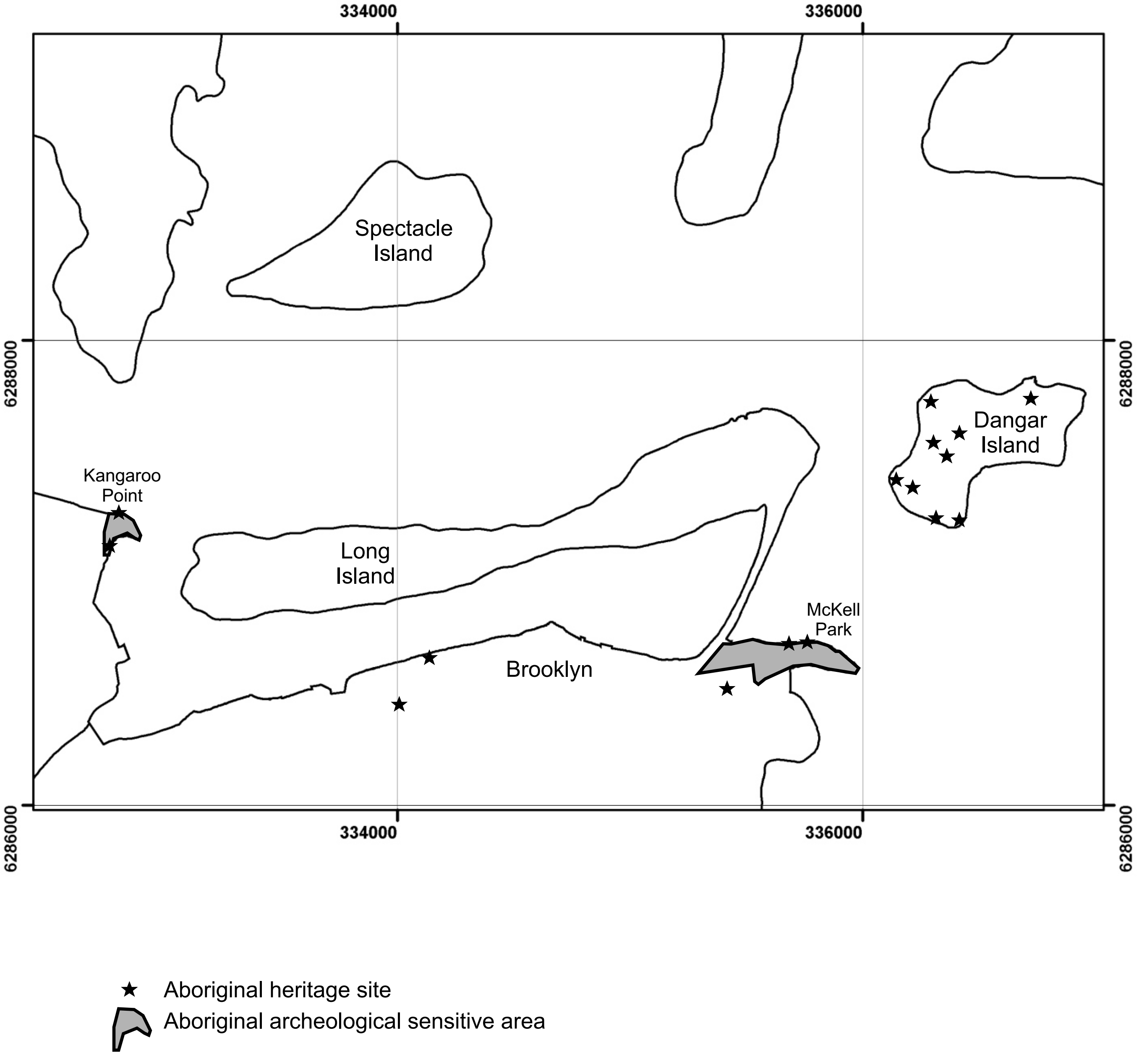


Figure 7.3

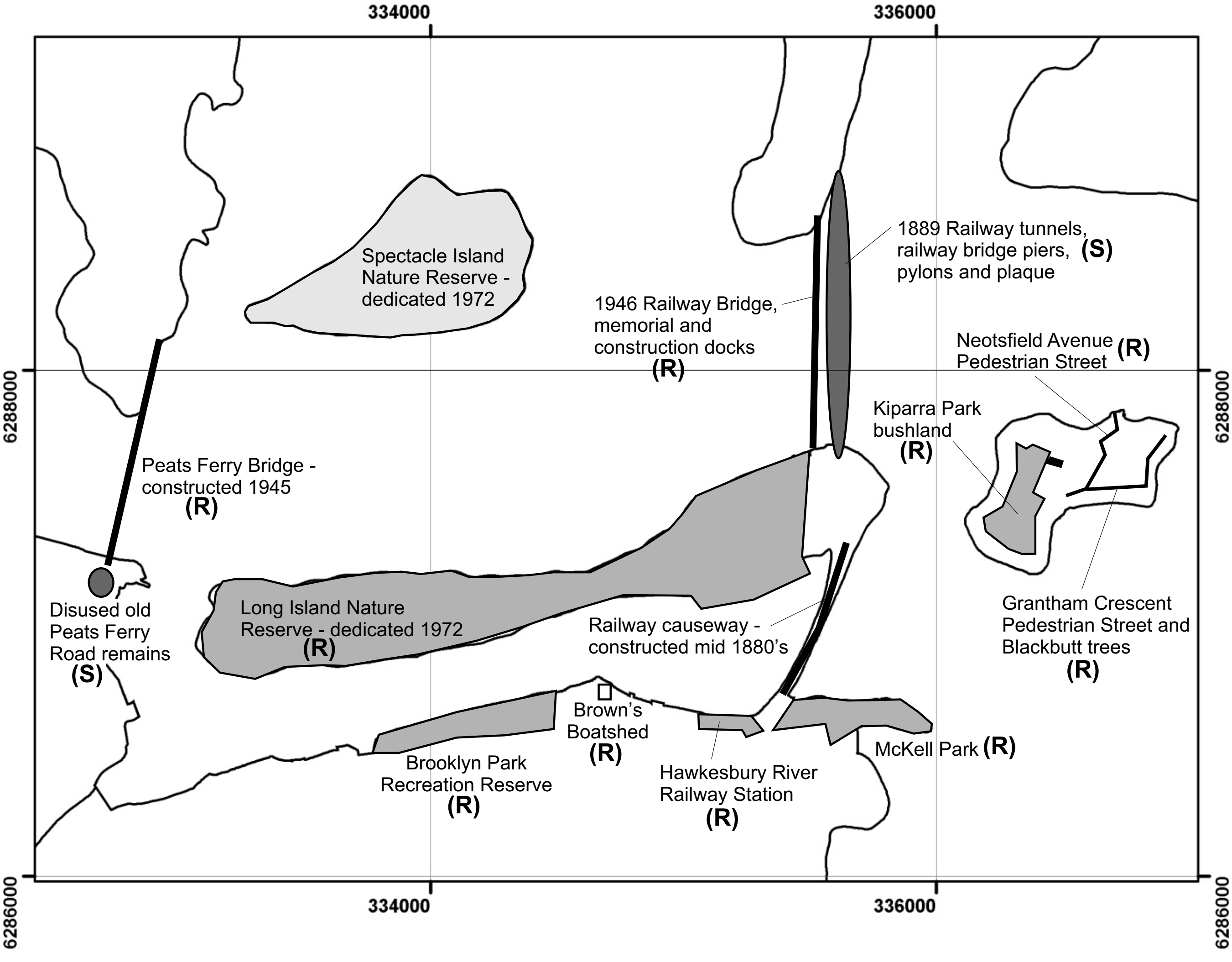
00758-07-03.cdr

WRL Report No. 2002/20	RECENT CONSTRUCTION - EXAMPLES OF OVERDEVELOPMENT	Figure 7.4 00758-07-04.cdr



Source: SMEC (2000)

WRL Report No. 2002/20	IDENTIFIED ABORIGINAL HERITAGE SITES	Figure 7.5 00758-07-05.cdr



(S) State significance

(R) Regional significance

WRL Report No. 2002/20	IDENTIFIED EUROPEAN HERITAGE SITES OF STATE AND REGIONAL SIGNIFICANCE	Figure 7.6 00758-07-06.cdr

8. ISSUES PERTAINING TO MANAGEMENT

The Brooklyn Estuary Management Committee has identified a range of environmental, social and economic concerns regarding the Brooklyn estuary study area. These issues have been addressed throughout the processes study and, based on these findings, have been incorporated into the headings outlined below.

<u>Water Quality</u>

- Degraded water quality from local sources is likely only near the source point or from external (upstream/downstream) inflows due to the hydrodynamics of the area.
- The Hawkesbury River is the main contributor and consequently, the biggest single issue for overall water quality.
- Railway and freeway runoffs estimates provide a good approximation of the anthropogenic pollution sources on water and sediment quality. The influence of these sources is limited within the entire catchment due to upstream/downstream inflows, however, further studies are necessary to determine their direct impact on localized areas.
- Water quality degradation from local sources shall be most apparent in less flushed regions of the estuary such as Sandbrook Inlet.
- Additional information regarding water quality is given in Chapters 3, 4, 5, 6, and 7.

<u>Boating, Houseboats and Pump Out Facilities</u>

- Pollution from house boats is not necessarily a major issue in the majority of the study domain, although their influence is proportional to seasonal trends discussed in Chapter 7, and shown in Figure 7.3.
- Pumpout facilities may reduce environmental risk to oyster leases and less flushed parts of the estuary. The installation of two pumpout facilities provides a large number of recreational and commercial vessels with an easily accessible means of legal and environmentally safe waste disposal.
- A boating management study could address the issues of restricted space, maximum numbers of boats and potential conflicts during busy periods.
- Additional information regarding boating, houseboat and pump out facilities is provided in Chapters 3 and 7.

<u>Management of Marinas</u>

- Concentrated shoreline activity, including marinas, may degrade adjacent water ways and reduce tidal flushing, but the impact of these activities is small compared with upstream and downstream inputs.
- To maintain acceptable water quality parameters and hydraulic integrity, marinas should wherever possible avoid constricting or blocking flow.
- Accident and emergency response plans should be in place for fast and effective action on any pollution or impact events.
- All commercial operators should operate within an Operational Plan of Management or Environmental Plan of Management
- The reader is directed to section 7.2 for information pertaining to mooring style, pollution reduction schemes (i.e., floating booms), or public access issues.
- Additional information pertaining to issues concerning marina management can be found in Chapters 4, 6, and 7.

Changes in Land Use

- Consideration should be made of additional pollutant sources from industrial or residential land uses and how contamination issues can be minimised.
- The region is surrounded by many protected areas that already have legislated against changes in land use including Aboriginal and European Heritage Sites. A list of heritage sites within the study area is given in Tables 7.5-7.7.
- Population pressures exist throughout the Sydney region. Population changes in the Hawkesbury Nepean catchment will have a direct influence on water quality and ecology in the study region. GIS mapping, such as in Figure 3.4, is an important component to understanding the associated land use changes.
- There are important distinctions between foreshore or bushland development, as well as commercial or residential development on ecological health.
- Issues relating to changes in land use and its impact on sediment and water quality are detailed in Chapters 3, 6, and 7.

Navigation, Dredging and Siltation

- Dredging programs already exist and shall be required into the future to maintain navigability in certain channels.
- When necessary dredging activities should apply techniques that minimise dredging plumes and control the destination of these plumes.
- There are possible issues with contaminated sediments if dredging into materials deposited over 20 years ago. Care should also be given to acid sulphate soils and PAH contamination.
- Additional information on dredging and siltation issues can be found within Chapters 3, 4, and 6.

Contaminants in Sediments

- Sandbrook Inlet has an issue with regard to long term accumulation of sediments and contaminants. The source of these sediments is not only from with the Inlet but from fine sediments entering from the main river and being deposited. Management consideration should be given to increased flushing of the inlet to reduce the sediment accumulation rates.

Flushing through Causeway

- Water quality, sedimentation and ecological calculations all concur that improvements would be made if there was improved flushing in Sandbrook Inlet. This could be achieved by providing flow paths through/under the causeway.
- Additional hydrodynamic and flushing concerns are given within Chapter 4.

Sewage Management

- Untreated or partially treated sewage will impact receiving waters. The extent and distribution of sewage depends on water body flushing times and the mass discharged. Sewage discharged to well mixed parts of the estuary has the potential to be transported to less flushed areas decreasing water quality.
- Unsewered land at Brooklyn and Dangar Island may increase the nutrient load within the groundwater and surface water environments.
- The installation of sewage management scheme that incorporates sewerage systems for each town and a local centralized sewage treatment plant would reduce the total nutrient load to the waterways.
- Sewage management issues are detailed within Chapters 3 and 7.

Land Management

- There should be an emphasis placed on upstream land management issues in any regional management plan as water quality in the Hawkesbury Nepean will have a significant effect on the Brooklyn Estuary.
- Land management plans are already in place for the protection of heritage and Aboriginal sites.
- Land management about Mooney Mooney Creek catchment should be concerned about runoff as it has a lower flushing time and higher assimilation capacity. A large portion of the Piles Creek catchment has been zoned for further industrial development in Somersby.
- Land management issues are further detailed in Chapters 3, 4, and 7.

Habitat

- Management consideration should take into account land and marine based habitats to maintain the total available variety of habitats.
- Additional information concerning estuarine habitats issues and ecological health can be found throughout Chapter 6.

Public Access

- Findings suggest that there is limited access to Sandbrook Inlet during peak use periods, but that usage is strongly seasonal.
- Several factors including topography, current infrastructure, and lack of roads limits public access to many areas of the study site.
- Additional development of the foreshore region should consider public access to the waterways including handicap access, sufficient parking space and access to public wharves.
- Mangrove stands that restrict access to the foreshore such as at Sandbrook Inlet should be preserved because of their ecological value to the region.
- Public areas such as Bradley's Beach on Dangar Island are highly valued and patronised by the community.
- Public access issues are discussed further in Chapters 3 and 7.

Fisheries

- Recreational fishing is increasing in the study area.
- Commercial fishing is decreasing in the study area.
- Oyster growing is a major industry in the study area and this is the second largest oyster production area in NSW.
- Oyster growers require clean water free from contaminants to produce commercial oysters.
- The impact from oyster growing on the environment appears minimal.
- All fishing is a significant economic significance to the area.
- Fishing appears to be compliant with current regulations.
- No major impacts on ecosystem health were noted from fisheries.
- Fisheries data must be based on more specific studies before any specific recommendation can be made on the impacts of fishing or changes to regulations.
- Fisheries issues are addressed in Sections 6.4 and 7.2

The reader is advised to consult the appropriate chapters sections for additional information regarding specific management issues.

8.1 Summary of Recommendations for Further Studies

The following list is a summary of all issues raised in this study with recommendations for further studies.

- Further studies with adequate spatial/temporal replication in Brooklyn harbour and Sandbrook Inlet are recommended to determine impacts of bioaccumulation in oysters (Section 6.6.3).
- It is recommended that long term concentrations of heavy metals in oysters are further investigated and monitored. (Section 6.6.4)
- A better understanding of the health of seagrass beds could be gained by studying the maximum depth of beds, shoot density, shoot morphology and epiphyte cover of each bed. (Section 6.7)
- Further studies are recommended to assess long-term trends in pollutants impacting on the shellfish industry (Section 6.7).
- The accumulation of PAH compounds over time in the eastern portion of Sandbrook Inlet may warrant further investigation. (Section 5.3.7)
- Further studies could focus on the following processes that might be affecting the distribution of organisms on rocky shores: current regimes influencing the availability of larvae and nutrients on either side of the causeway; differences in the substratum such as differences in complexity, texture and orientation; variations in sunlight and wind; anthropogenic pressures; and effects of competition and predation between organisms. (Section 6.3.2.3)
- Well-designed manipulative experiments are required to test hypotheses about how such factors, acting singly or in combination, cause and maintain the variations in fauna observed between Sandbrook Inlet and the reference locations. (Section 6.3.3.3)
- Additional long-term sampling sites are recommended to enhance the level of knowledge of water quality in the study area, particularly with respect to specific activities and land uses, such as marina operations in Sandbrook Inlet and Brooklyn Harbour and the impacts of industrial activity in the Somersby area. (Section 5.1.4)
- It is recommended that potential sources of heavy metal contamination be investigated and monitored. Further studies are recommended to assess long-term trends in pollutants and their effects on ecosystem health (Section 6.7).
- Additional long-term sampling sites are recommended to enhance the level of knowledge of water quality in the study area, particularly with respect to specific activities and land uses, such as marina operations in Sandbrook Inlet and Brooklyn Harbour and the impacts of industrial activity in the Somersby area.(Section 5.1.4)
- Further studies with adequate spatial/temporal replication in Brooklyn harbour and Sandbrook Inlet are recommended for bioaccumulation in oysters (Section 6.6.3)
- It is recommended that long term concentrations of heavy metals in oysters are further investigated and monitored. (Section 6.6.4).
- It is recommended that potential sources of heavy metal contamination be investigated and monitored. (Section 6.7)
- It is recommended that usage of pump out facilities be monitored and water quality measurements, particularly bacterial levels, be taken regularly in the area to determine whether the provision of this facility is adequate to service the study area and surrounds (Section 7.2.6)

- Further specific study would be required to determine where the sediment mass mobilised by opening the causeway at Sandbrook Inlet may be deposited or whether it would be transported out of the inlet. (Section 4.5)
- Elevated PAH values in Mooney Mooney Creek also warrant further investigation. (Section 5.3.7)
- It is recommended that a list of specific legislative or private bodies having responsibility over potentially polluting catchments be assembled. (Section 3.7)

9. RELIABILITY ASSESSMENT

This study has been based on a large amount of previously available data and various additional components collected during the study period. This section aims to summarise which data and assumptions have greater reliability than others. This section should allow for priorities to be placed on further works as issues arise.

Flushing Times
Since flushing times are based on the physical measurements of recurring processes this data is reasonably reliable..

Water Quality Constituents
Water quality constituents are reliable in the main parts of the study region but the lack of sampling in the upper reaches of Mooney Mooney Creek limits the reliability in this area.

Water Quality Processes
There is not a full understanding of all the water quality processes taking place. Key influencing factors have been identified, but a complete "cause and effect" relationship cannot be drawn without a far greater temporal and spatial data set of water quality sampling, environmental conditions and (most importantly) loads.

Catchment Loads
There is a very limited measured data set on catchment loads and current predictions are from numerical modelling simulations without site specific calibration. Therefore, catchment loads can be considered as reasonably uncertain.

Algal Blooms
There is limited evidence of the occurrence of algal blooms in the study area, hence there is uncertainty of whether the mechanism of blooms is catchment loads or sediment recycling. There is also uncertainty of the natural occurrence of algal blooms.

Sediment Quality
A reasonable spatial picture of sediment quality was presented. Further sediment reliability can be reached by assuring similar methodologies in future sampling programs.

Hawkesbury River Loads
The Hawkesbury River loads are large and numerical estimates have been made. However, total measured Hawkesbury River loads have poor estimates of changes in water quality.

Ecological Processes
Snapshots have been taken of ecological processes, therefore there is an uncertainty of any long term trends and/or natural variability

Oysters Bioaccumulation
Oysters are a somewhat more reliable indicator, due to the large volume of water being filtered and the long data record. Oysters can be thought of as "integrating" the short term temporal trends in water quality.

Improvements in Ecosystem Health

There is good confidence that increased flushing times would increase the assimilative capacity of receiving waters, which allows for greater catchment and water quality loads with lesser impacts.

10. KEY FINDINGS

The Brooklyn estuary is an important component of the lower Hawkesbury River currently facing developmental and environmental pressures. To ensure proper environmental, social and economic management of the region, this processes study was commissioned by the Hornsby Shire Council in accordance with the Estuary Management Manual (NSW Government, 1992). This report details the data compilation and estuary processes components including catchment characteristics, hydrodynamics, water quality, ecological processes, and human activities. This chapter attempts to outline some the key findings of the study from each section of the report. As such, it does not detail every finding within the processes study and the reader is advised to consult individual chapters for additional information.

<u>Catchment Characteristics (Chapter 3)</u>
The Brooklyn area covers approximately 185 square kilometres including the Mooney Mooney Creek, Mullet Creek and Sandbrook Inlet catchments which comprise 75%, 15%, and 10% of the total area respectively. The climate is characteristic of temperate regions, with warm to hot summers and cool to cold winters, and mainly reliable rainfall patterns. GIS mapping of land use indicates that over the past 42 years bushland has decreased 13.3%, while unsewered semi-urban developments, orchards and unfertilised grazing land uses increased by 7%, 1.7% and 1.6%, respectively. Catchment runoff pollutants are highly dependent on rainfall and are dominated by total nitrogen loads (47000 kg/yr versus 8200 kg/yr for total phosphorus). Runoff load estimates from major road and railway lines (Table 3.11) indicate that for the three major transport networks annual nitrogen loading is 864 kg, total phosphorous loading is 45 kg, and suspended solid loading is 10,368 kg.

The sediment within the main river channel is composed primarily of coarse sediments such as sands, whereas the tributaries of the lower Hawkesbury are characterised by muds and sandy muds. Sediment transport events were most likely dominated by large scale construction events such as the development of roads, railways and associated bridges infrastructure. Extensive analysis of bathymetric surveys of the study area indicate minor changes to the bathymetry between 1872 and 1952, and pronounced areas of accretion and erosion after the construction of the Sydney-Newcastle Freeway Bridge in 1973. Furthermore, significant accretion within Sandbrook Inlet (10 to 20 millimetres per year) is related to restricted tidal flows.

Previous reports identified that more than 50% of inspected sewage disposal units at Brooklyn and Danger Island experienced environmental problems such as leaking, odours, insects or weeds. Findings suggest that the proposed sewage management scheme, which incorporates a sewerage system for each town and a local centralised sewage treatment plant, would decrease the problems currently encountered during wet weather periods. It is critical that the proposed sewage schemes involve the pump out facilities which should also reduce nutrient and faecal coliform concentrations within the waterways and provide a means of legal and environmentally safe waste disposal for boats.

A significant finding of this report is that the Brooklyn estuary study area is strongly influenced by upstream processes and activities within the Hawkesbury-Nepean River catchment. In the future, particular interest should be addressed to upstream land use changes, flow regime modifications, effluent disposal and recreational pursuits within the entire Hawkesbury-Nepean catchment.

Hydrodynamics and Flushing (Chapter 4)

The study area for this Estuarine Processes Study covers a small fraction of the entire Hawkesbury-Nepean River catchment. Freshwater input to the study area includes flow from the Hawkesbury River, 286 ML/day in low flow conditions and greater than 1,000,000 ML/day in floods, and to a lesser extent from the local catchment, 1ML/day and 9000 ML/day for low flow and flood flow, respectively. Similarly about 25% of the tidal prism entering the study area at the downstream boundary is captured within the study area, while the remaining 75% passes through to the upper Hawkesbury. As such, much of the processes within the study area are influenced by the conditions of the greater Hawkesbury-Nepean River catchment.

The tidal range within the study area is very similar to oceanic tidal ranges with a slight tidal amplification towards the reaches of Mullet and Mooney Mooney Creeks. The tidal residuals within the study area show a good correlation with ocean residuals indicating that the non-tidal water level oscillations are associated with oceanic phenomena such as coastal trapped waves and storm surges. Hydrodynamic simulations illustrate that the removal of the causeway will not significantly affect flow even during 20% AEP peak flows.

Flushing times are relatively short, around 2 days for most of the study area, increasing to around 8-15 days in the Upper Mullet and Mooney Mooney Creeks. Low energy sections of the estuary away from the influence of strong tidal currents are blanketed with fine grained muds, indicating areas of sediment accumulation and, in some areas, a build-up of metallic and organic contaminants. Selected chemical analyses of sediments at a majority of sites were found to be generally within the ANZECC (2000) guidelines for nutrients, metals and PAHs, however certain metal concentrations were in excess of the low ANZECC (2000) trigger values and require further study.

Tidal flows within Sandbrook Inlet appear too low to remove fine grained sediments, leading to a build-up of contaminants from local sources. In view of this, future estuary management must consider enhanced tidal flushing to minimise the build-up of fine sediments. Contamination issues are not as pronounced in other regions of the estuary due to a combination of greater tidal flushing and/or the distance from anthropogenic pollution sources.

Water Quality (Chapter 5)

While conditions at the study site are largely determined by the Hawkesbury River, there are a range of local inputs and activities that are of concern at the smaller scale. Particularly, water quality within the study area can be divided into independent areas based on inflows and flushing characteristics. These sections include: (1) the main arm of the Hawkesbury River including Dangar Island; (2) Sandbrook Inlet; (3) the upper Mooney Mooney and Mullet Creeks; and (4) the lower Mooney Mooney and Mullet Creeks.

Water quality in the study site is generally good however there are impacts from the main Hawkesbury River where sections consistently fail to meet standards. There is some evidence of algal blooms in the upper Mooney Mooney Creek but elsewhere there is little evidence of algal issues. Faecal contamination by septic overflows and boat use may also cause localised elevated faecal counts but these are generally shortlived and confined to small areas at the discharge point.

Water sampling results were predominately in line with water quality guidelines. Seventy-five percent of dissolved oxygen samples were within aquaculture protection standards. pH readings were generally between 7.5 to 8.0 and did not depict acid sulphate soil leachate typical of other low-lying estuaries along the NSW coast. Salinity values fluctuated between 12-41 ppt indicating estuarine flushing and the inter mixing of freshwater and oceanic inputs. Suspended solid concentrations at all sites were well below the aquaculture protection guidelines except within Sandbrook Inlet due to tidal flushing over shallow mud flats. Secchi depth measurements also exceeded recreational guidelines indicating a potential problem from recreational users. Median turbidity, total phosphorous nutrient levels, and chlorophyll-a were all within the ANZECC (2000) criteria and indicate good water quality. Conversely, total nitrogen concentrations were often in excess of ANZECC (2000) criteria.

Within the study site a range of sediment textures were encountered, however, the majority of samples contained more than 50% mud (%<0.063mm). The energy regime of the estuary influences the sediment type with coarse grained sediments, typically muddy sands, occurring in strong tidal area and finer grained sediments occurring in lower energy parts of the estuary. Sediment metal content indicated that the railway causeway (i.e. the eastern portion of Sandbrook Inlet) may trap contaminants such as copper, lead and zinc. PAH compounds concentrations were also highest within Sandbrook Inlet but all sediment samples were below ISQG-Low guidelines. The accumulation of PAH compounds over time in the eastern portion of Sandbrook Inlet may warrant further investigation.

<u>Ecological Processes (Chapter 6)</u>
Ecological processes findings indicate that the general health of the entire estuary is stable and positive though individual areas may require attention. The medium level urban foreshore development at Brooklyn Harbour, Sandbrook Inlet and Dangar Island are likely to have a negative effect of the estuarine health of the local vicinity. In contrast, the undeveloped aspect of Mullet Creek and Mooney Mooney Creek would have a low negative impact on estuarine health.

Mangrove forests are abundant throughout the study area and have increased over the last 25 years since the construction of the freeway bridge near Mooney Mooney Creek and land reclamation. Mangrove stands near the west fringe of Spectacle Island and at Mooney Mooney Point have significantly increased in size. The leaf biomass for common grey mangroves in the Hawkesbury River (40 kg/m^2) is the highest recorded for temperate forest communities. The distribution of mangrove forest in the study area and their general state of health are stable and positive.

Seagrass beds are present in the study area at a number of locations including Sandbrook Inlet, Brooklyn Harbour, Dangar Island and the Head of Mullet Creek. The dominant seagrass was *Zostera capricorni* (eelgrass) and the cover of seagrasses has increased over the 16 years of available data. The seagrass bed in Brooklyn Harbour appeared healthy with a low epiphyte load (The Ecology Lab, 2002), while the beds in Mullet Creek have some epiphyte load.

Only recent information is available on the distribution of salt marsh habitats in the Brooklyn study area and hence, the stability of salt marsh areas could not be assessed. The largest stands of saltmarsh were located at the head of Mooney Mooney Creek, although small stands exist on both banks in Sandbrook Inlet. The saltmarsh species present were typical for the area.

Intertidal benthic assemblages from mangrove habitats were different between the eastern and western ends of Sandbrook Inlet (Lasiak & Underwood, 2002) and these locations were different to sites in Mooney Mooney Creek and Mullet Creek. This difference was due to variance in taxa, rather than lower abundances. This was also found by Jones *et al*. (1986), who found the benthos of Sandbrook Inlet to be depauperate compared to other locations in the Hawkesbury River. Generally, low species diversity is typical of highly disturbed environments. The intertidal rocky shore invertebrate communities were significantly different either side of the causeway. This could be the result of a number of natural factors as well as anthropogenic pressures.

The state of the Brooklyn region in terms of demersal fish species distributions and abundances is difficult to assess given the highly variable catch rates from beam trawling and beach seines studies. The Ecology Lab did find similar species of fish in this study and in 1988 which suggests some population stability. The assemblages of demersal fish and mobile invertebrates found in Sandbrook Inlet and Brooklyn Harbour in the present study were not different to other parts of the estuary. Therefore, factors other than proximity to urban developments (e.g. habitat cover or food availability) could be affecting the distribution of demersal fish and mobile invertebrates in the Brooklyn area. No information is available on the health of fish populations in the region.

Gobies were the most abundant group of fishes (Gehrke & Harris, 1996; The Ecology Lab 1988), while shrimps were the most abundant demersal invertebrate group (The Ecology Lab 1988; 2002). Fish of economic importance collected in the Brooklyn area included mullet, bream, whiting, tailor, flounder, leatherjackets, mulloway, sandy sprat (Booth & Schultz 1997; Gehrke & Harris, 1996; The Ecology Lab, 2002). Demersal invertebrates of economic importance included eastern king prawn, school prawn, greasyback prawns and king prawns (The Ecology Lab, 1988; 2002).

Recreational fishing occurs throughout the study area but tends to be concentrated around the main channel of the Hawkesbury River. The majority of recreational fishing occurs during the weekend and in summer with 90-95% of fishers complying with NSW fisheries regulations. The Hawkesbury River is also an important commercial fishing area and supplied 268 t of fish in 1998/1999. Over the past ten years the number of commercial fishers has decreased but it is difficult to assess the influence of commercial fishers numbers against stock management issues because of the considerable movement of fish species between Brooklyn and nearby waterways.

More than half of all the oyster farmers in the Hawkesbury operate within the Brooklyn area. In fact, the lower Hawkesbury River is the second largest oyster producing area in NSW. Oyster farming requires a consistent supply of high quality water and as part of their Quality Assurance Program farmers are required to conduct weekly water and meat sampling. Concentrations of metals, phenols and PAHs was not significantly elevated in wild oysters collected from the Hawkesbury than from other reference areas.

Human Usage and Activities (Chapter 7)

Public access is limited in many regions of the study area due to large areas of National Park and undeveloped land in the catchment, lack of road access in most areas, environmental features, and private ownership of the foreshore in developed areas. In several areas public and commercial wharves provide public access to the waterway, however, there is a lack of wheelchair access via these facilities. Field inspections of Brooklyn boat ramp facilities indicated that Parsley Bay Boat ramp experiences 62% more cars and trailers then the Mooney Mooney Boat ramp. The boat ramp at Kangaroo Point is less utilised than the other ramps but the high number of vehicle at this site may be due to pickup and drop off parking for the charter and cruise boat passengers.

Waterway usage is constrained within the study area by the inaccessibility of the foreshore due to existing developments and natural barriers, water depth and wave climate, environmental factors, social issues, and funding availability. Increased development may compromise water quality which is vital to the major industries of the area including oyster farming, commercial and recreational fishing and tourism. Mangrove areas should be maintained as they play a vital role in the estuarine ecosystem. Conflicts between waterway users are compounded by similarities among seasonal trends in activities (Figure 7.3).

Since settlement human activities have had an influence on estuarine processes. Major civil works have altered the flow regime and increased sediment transport and/or erosion. Reduced upstream flows such as dams moderate water flows and reduce the large natural variability. Agriculture increases nutrient loads and faecal coliform contamination through animal waste. Unsewered and sewered treatment facilities have increased nitrogen and phosphorous nutrient levels in the receiving waters from natural levels. Other indirect impacts include changes to the scenic amenity, disposal of waste from marinas, impact of dredging and fishing sustainability numbers.

The Hawkesbury River served as a social nexus for various tribal groups, and as such, the study area contains several Heritage protected sites. Furthermore, several European heritage sites which depict the history of European settlement have been listed within the study area. Tables 7.5-7.7 detail the number and location of all heritage sites within the Brooklyn estuary. The care and protection of these sites must be considered during any further developments. Additional consideration should also be given to the scenic amenities of the study area.

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