BEROWRA CREEK ESTUARY PROCESSES STUDY
REVIEW AND INTERPRETATION OF EXISTING DATA

NSW Department of Public Works and Services
Manly Hydraulics Laboratory

in conjunction with

The Ecology Lab
Coastal and Marine Geosciences
Nelson Consulting
Water Research Laboratory
AWT EnSight

Foreword

The Berowra Creek Estuary Processes Study - Review and Interpretation of Data was carried out by Manly Hydraulics Laboratory (MHL), in conjunction with The Ecology Lab (TEL), Coastal and Marine Geosciences (CMG), Nelson Consulting, the Water Research Laboratory (WRL) and Australian Water Technologies EnSight (AWT) for the Berowra Creek Estuary Management Committee. The MHL component of the report was written by Dr David van Senden and Louise Howells.

This report was prepared with assistance in providing information from a number of sources including Ross M^cPherson, George Antonijevich, Kara Bateman-Malass (Hornsby Shire Council), Bob Clout, Bruce Coates (Department of Land and Water Conservation), Tony Church and Sean Hardiman (Environment Protection Authority) and Peta Senogles.

This study was jointly funded by Hornsby Shire Council and the Department of Land and Water Conservation (DLWC) under the Estuary Management Program.

Summary

The New South Wales Estuary Management Policy was developed to encourage the integrated, balanced, responsible and ecologically sustainable use of the State's estuaries. The policy is designed to reflect and promote cooperation between the State Government, local government, catchment management committees, landholders and estuary users in the development and implementation of estuary management plans for each estuary.

To assist in the development of estuary management plans, an Estuary Management Manual (NSW Government 1992) was published to outline the processes of implementation. Essentially, the process consists of eight steps. These steps are:

(1) form an estuary management committee;
(2) assess existing data;
(3) carry out estuary processes study;
(4) carry out estuary management study;
(5) draft estuary management plan;
(6) review estuary management plan;
(7) adopt and implement estuary management plan; and
(8) monitor and review management process.

The Estuary Management Committee for Berowra Creek was formed in 1994 and has adopted the following vision for the estuary:

> *'The establishment of a Berowra Creek Estuary which can be used sustainably by the people and businesses of the Hornsby Shire.'*

Manly Hydraulics Laboratory, in conjunction with Coastal and Marine Geosciences, The Ecology Lab, the Water Research Laboratory and Australian Water Technologies was commissioned by Hornsby Shire Council to undertake the second and third stages of the estuary management process for Berowra Creek.

Table of Contents

Appendices

List of Tables

List of Figures

1. Introduction

1.1 Background

Berowra Creek is an estuarine tributary of the Hawkesbury River, located north of Sydney, New South Wales. A location plan is shown in Figure 1.1. The creek is 24 km long with the tidal limit at Rocky Fall Rapids. It is fed by a number of creeks and is characterised by a number of bays which are popular for recreational boating.

In 1994 a Statement of Joint Intent (SOJI) was signed by a number of stakeholders in the Creek including Hornsby Shire Council (HSC), Department or Urban Affairs and Planning (DUAP), Environment Protection Authority (EPA), Hawkesbury-Nepean Catchment Management Trust (HNCMT) and Sydney Water. The aims of the SOJI are to achieve ecologically sustainable development and recover the environmental health of the Creek. In conjunction with the SOJI, Hornsby Shire Council and the Department of Land and Water Conservation have embarked on the estuary management process which requires the preparation of an estuary processes study. An improved understanding of the processes that determine the ecological structure and function of the estuary is essential if the objectives of the SOJI are to be realised.

This processes study is broken into five stages:

- review and interpretation of existing data
- hydrodynamics
- water quality
- geology and geomorphology, and
- ecology.

At the end of each of the five stages a report will be produced and a summary report of the five stages is to be produced at the end of the study.

This report, the Review and Interpretation of Available Data, is the first of five reports to form the basis of the Berowra Creek Estuary Processes Study.

For the purposes of this investigation, the study area comprises the estuarine areas of Berowra Creek including the tidal waterway, wetlands, foreshores and adjacent lands. Although termed an estuary processes study it is recognised that the status of the estuary is closely linked to processes operating in the catchment. These processes determine the material loads to the estuary and hence are also given consideration here.

1.2 Management Considerations

Berowra Creek is a complex environment which has showed signs of environmental stress in recent years. Significant visible indicators include the occurrence of algal blooms and reduction in oyster populations in the upper reaches of the creek. These indicators suggest that change has occurred in the creek that is beyond the natural variability of the system.

Detecting this change in the environment and establishing the cause confounds scientists and managers. The different levels of an ecosystem respond to a broad variety of stimuli and while causality may be established at lower levels (e.g. excess nutrients stimulating primary production), the consequences for higher trophic levels (the population/community/ecosystem levels of biological organisation) are not readily detected and often occur over long periods.

These higher level responses are generally complex and far removed from causative events and are manifestations of damage rather than predictive indices (Andersen 1997). Appropriate monitoring must continue at a range of levels and over temporal and spatial scales such that change may be detected and the effectiveness of management actions assessed.

Recent attempts to characterise ecological significance, environmental distress signals, the variables used to monitor change and their difficulty of measurement have been discussed by Andersen (1997) who derived a generalised system for use by managers, reproduced here in Figures 1.2 and 1.3.

Figure 1.2 indicates that incidences such as algal blooms (altered abundance and distributional change) are a later distress signal of damage and are of high ecological significance. This implies that some remedial action is required to reduce these incidences.

Figure 1.3 indicates how the range of commonly measured variables in ecology may assist in the prioritisation of the constituents and processes to be targeted for action. It also provides assistance in determining the direction for future monitoring for Berowra Creek.

Hornsby Council and the other signatories to the Statement of Joint Intent (1994) have begun to redress this damage through practical catchment and waterway measures such as targeting reduction of nutrients from sewage treatment plants, catchment remediation measures and monitoring. In conjunction with this, further investigation into the behaviour of the estuary is being undertaken through the estuary processes study.

1.3 Study Objectives

The main objective of the study is to identify and describe the cause and effect relationships that determine the ecological structure and function of the system. These relationships define the key processes operating within the system and through development of an understanding of these interactions will provide a rational basis for management decisions.

The objectives of the review are to:

- collate existing data;
- review publications associated with studies of Berowra Creek and similar systems;
- develop conceptual models of the overall system and sub-systems;

- apply data analysis and interpretation techniques to identify, describe and quantify the relative importance of the individual processes;
- identify major data and information gaps; and
- provide input to the workshop phase of the study.

1.4 Study Methodology

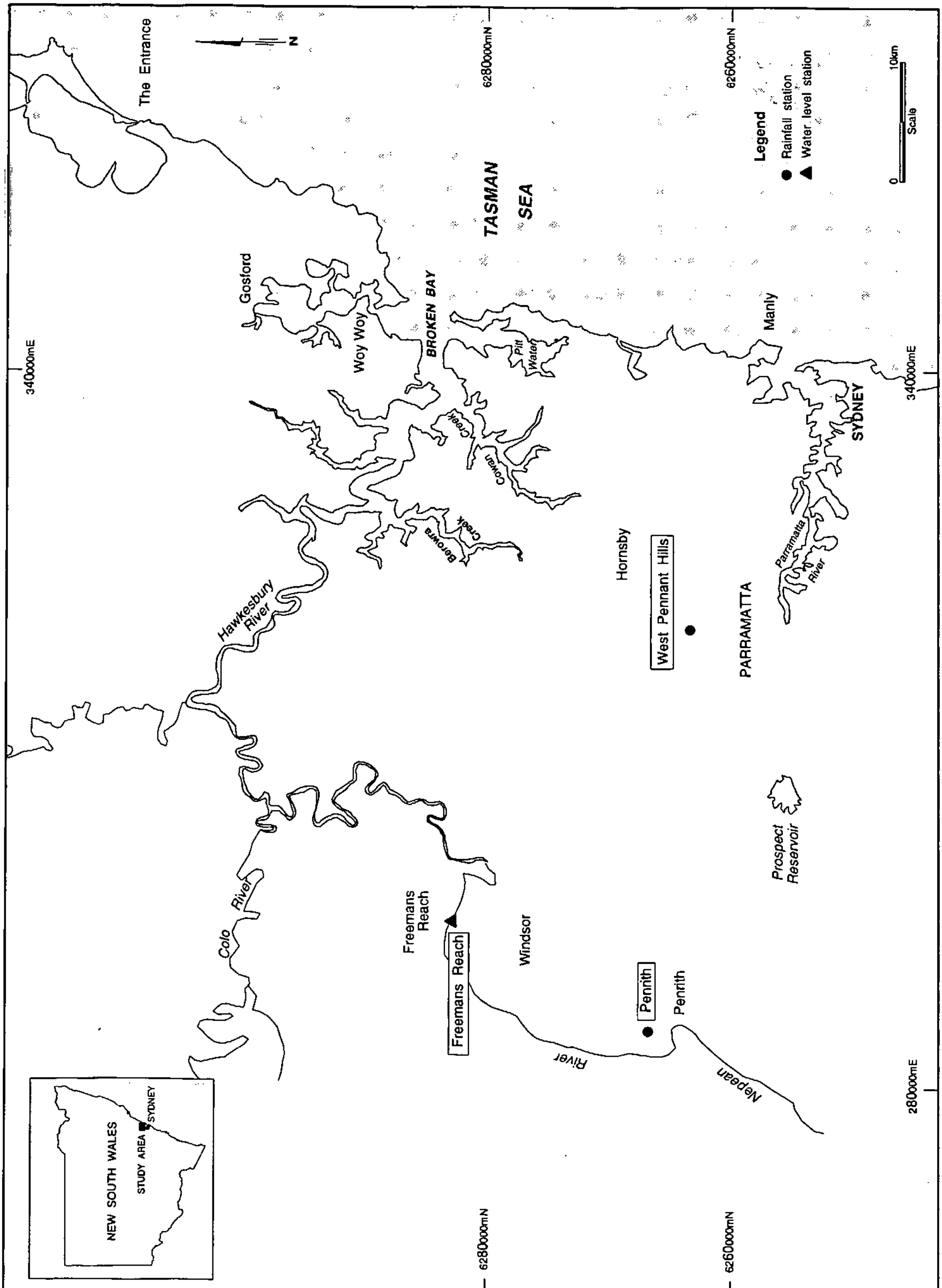
This study, the Review and Interpretation of Available Data, was undertaken by collating information from HSC, DLWC, EPA and a number of other sources and reviewing this information to gain a preliminary understanding of the processes occurring in the creek. This preliminary assessment was also designed to provide a focus for the later, more detailed stages of the study.

1.5 Report Outline

This report has been divided into a number of sections, including a summary of processes, interactions and data gaps (Section 2) which summarises the findings of each chapter of the report and integrates the information into one location to provide an overview of the Berowra Creek estuary.

The report is divided into sections based on the processes occurring in the creek, including:

- catchment and estuary characteristics (Section 3);
- land use, recreation and cultural heritage (Section 4);
- weather and climate (Section 5);
- geology and geomorphology (Section 6);
- hydrodynamics (Section 7);
- water quality (Section 8); and
- ecology (Section 9).



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LOCALITY PLAN

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Figure 1.1

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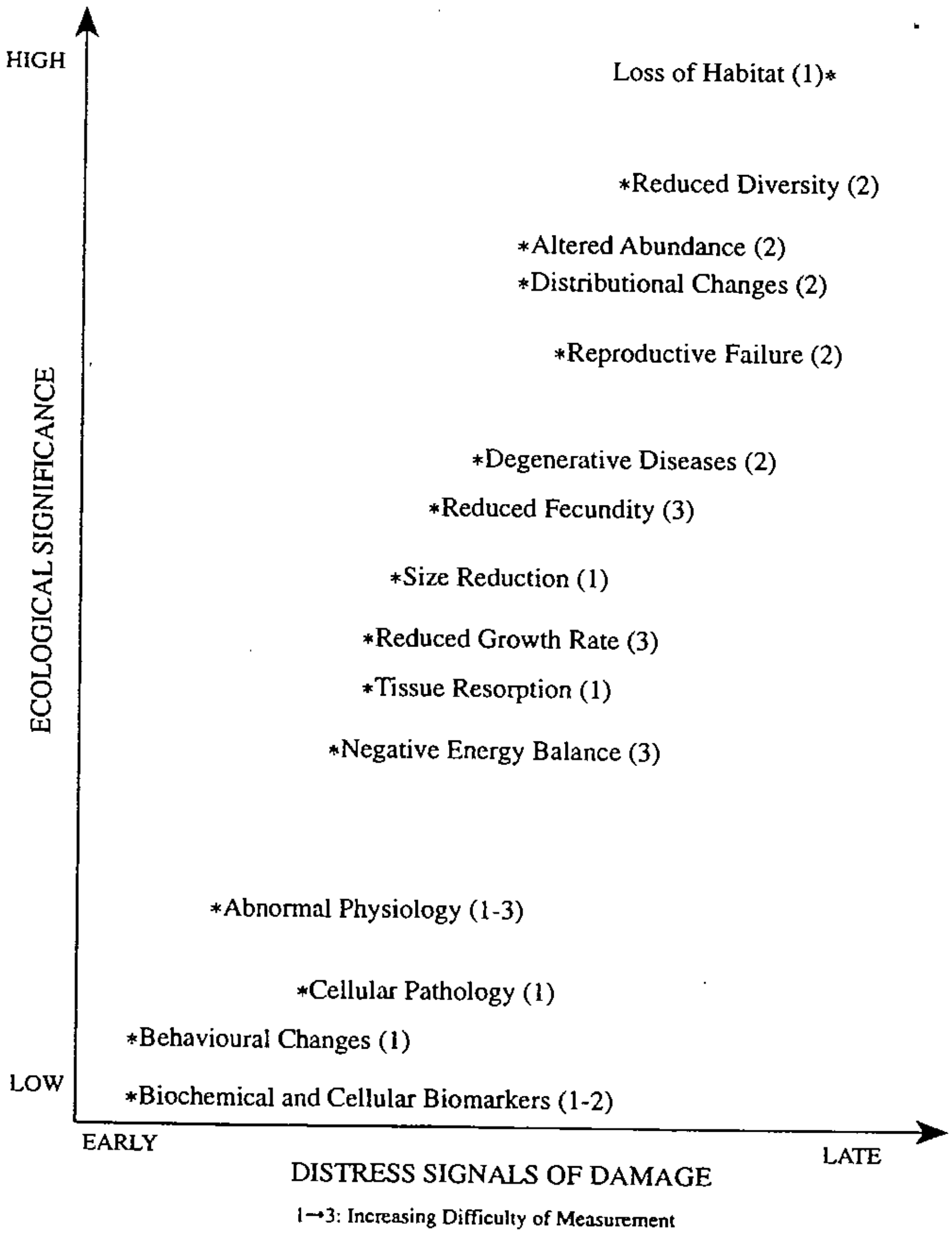

Note: After Anderson (1997)

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BIOLOGICAL DISTRESS SIGNALS

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Figure 1.2

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Levels of Biological Organization: Molecular (Membrane Alterations – Neurotoxicity) | Cell/Tissue (Cellular Granules – General Toxicity) | Organism (Abnormal Physiological Behavior – Pathology)

VARIABLES	Membrane Alterations	Genotoxicity	Photosensitization	Stress Proteins	Metal-Binding Proteins	Compound-Specific Biomarkers	Neurotoxicity	Cellular Granules	Cell Injury	Tissue Hypoxia	General Toxicity	Abnormal Physiological Behavior	Pathology
Synthetic Organics	●	●	●			●	●		●		●	●	●
PAHs	●	●	●	●		●			●			●	●
Trace Metals	●	●		●	●		●	●	●		●	●	●
Petroleum (Oil)	●	●	●			●	●		●		●	●	●
Herbicides/Pesticides		●				●	●		●		●	●	●
Dissolved Oxygen													
Artificial Radionuclides		●							●			●	●
Pharmaceuticals											●		
Phytoplankton Pigments							●		●	●	●	●	●
Human Pathogens													
Nutrients									●	●		●	●
Algal Toxins							●		●		●	●	●
Litter/Plastic										●		●	
Suspended Particulate Matter										●			

Contaminant/Analyte	Seawater	Fresh Water	Suspended Material	Tissues	Sediments	Beaches	Atmospheric Precipitation
Algal Toxins	3			3			
Artificial Radionuclides	3		3	3	2		3
Herbicides/Pesticides	3	3	2	2	2		3
Litter/Plastics			*			1	
Human Pathogens	2	2	1	1		1	
Nutrients	1	1					2
Dissolved Oxygen	1	1					
Synthetic Organics	3	3	2	2	2		3
Petroleum (Oil)	1	1	1	2	2	1	3
PAHs		2	2	2	2		3
Suspended Particulate Matter	1	1	*				
Trace Metals	2	2	2	2	2		3
Phytoplankton Pigments	1		1		3		
Pharmaceuticals	3	3		3	3		

The numerical entries in this table represent the relative simplicity of the measurement of the relevant analyte/matrix combination. An assignment of 1 signifies that the measurement is routinely made and there is widespread competence. An assignment of 2 signifies a somewhat more difficult measurement but one that can be made by marine or public health laboratories in essentially all regions of the world. An assignment of 3 signifies a relatively difficult and complex measurement for which there are a limited number of laboratories worldwide able to make it. A * denotes that the analyte and the matrix are synonymous.

Note: After Anderson (1997)

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MANAGEMENT SYSTEMS TO MONITOR CHANGE

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Figure 1.3

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2. Summary of Processes, Interactions and Data Gaps

2.1 Introduction

The issues facing the Berowra Creek Estuary Management Committee (BCEMC) in the development of a management plan need to be considered during the present processes study so the limited resources available can be focused on resolving key processes most likely to affect management direction in the near future.

Management of the system needs to consider:

- the very diverse interests of estuarine and foreshore users, both recreational and commercial;
- development pressures and water quality in the estuary; and
- increasing demand for access to the system and the associated infrastructure placing pressure on the ecosystem.

The estuary may currently be classified as eutrophic as typified by the high levels of nutrients and chlorophyll-a. Water quality has deteriorated and over the last few decades programs have been put in place within the catchment by Hornsby Shire Council to reduce the nutrient and sediment sources. Further improvements in water quality are deemed a high priority for the BCEMC. Another important issue is the development of appropriate local guidelines and monitoring to assess the health of the system and impact of management actions.

Given these issues the focus for the study has been to define the processes affecting water quality, sediments and the potential shift in the relative importance of key processes over the past 50 years (when urbanisation pressures have accelerated).

2.2 Interactions

Processes can be summarised as shown in Figure 2.1. Processes occur on a number of time scales (Figure 2.2) and can have 'downstream' effects at similar or longer temporal scales.

For example, rainfall events occur over hours or days and the resultant runoff and its loads is delivered to the estuary at a similar timescale but an increase in biota due to nutrient enrichment may not occur for several years and decades. The interaction between the catchment and estuary is particularly important for estuarine water quality.

Through the development of an understanding of the interactions and definition of the cause and effect relationships, a model of the system will be compiled. This model will provide input to the process of assessing potential management options.

The design and implementation of experiments that can resolve the interactions is a component of the environmental monitoring program that will evolve during the study.

2.3 Catchment and Estuary Characteristics

The catchment area for Berowra Creek and its main tributary, Marramarra Creek, is approximately 310 square kilometres (MHL 1996). The catchment is generally steep with ridges close to the edge of the waterway characteristic of drowned river valleys. The top of the catchment has an elevation of approximately 200 m AHD (Australian Height Datum).

The Berowra Creek estuary is a drowned river valley which joins the Hawkesbury River 11 km upstream of Brooklyn, approximately 24 km from the ocean. Marramarra Creek joins Berowra Creek near its confluence with the Hawkesbury River and is the main tributary creek. The tidal limit is at Rocky Fall Rapids approximately 25 km upstream of the confluence of Berowra Creek and the Hawkesbury River.

2.4 Cultural Aspects

Most of the Berowra Creek catchment is bushland, with urban development (primarily detached dwellings) located to the east, and rural and rural-residential development to the west of the creek. Small river settlements are dotted along the creek. The main activities within the rural and rural-residential areas include orcharding, market gardens, nurseries, poultry production and agistment. Commercial fishing is carried out in Berowra Creek as well as oyster farming.

Recent changes to land uses in the catchment include a shift from traditional agricultural activities to rural-residential development and hobby farms and the development of the Cherrybrook urban release area (Price Waterhouse Urwick 1993, HSC 1995a).

Factors which could alter land use in the future include:

- any extensions of Marramarra National Park, Muogamarra Nature Reserve or Berowra Valley Bushland Park;
- a continuation in the shift from rural to rural-residential development;
- a shift from rural to tourism uses; and
- changes in agricultural production techniques (e.g. hydroponics) allowing less suitable land to be farmed.

Other factors which could influence development levels and population growth are:

- increased densities in urban areas (multi-unit housing is permitted in residential zones);
- any release of Crown land areas in the northern part of the study area for rural-residential uses;
- any residential development of privately owned rural land in the south-west of the catchment;
- any extension of the water and sewerage reticulation systems;
- a continuation in the shift from rural to rural-residential development; and
- development of the tourism industry.

Further development in the catchment is constrained by the costs and difficulties in providing water and sewerage services and the capability of the land to support development (e.g. steep slopes). Accordingly, population growth will most likely occur through urban consolidation and infill housing. It is noted that there is little opportunity for a significant population increase in the rural area.

Concerns relating to the expansion of urban development, and in particular the river settlements, are primarily associated with water quality. The steep slopes and shallow soils in the catchment mean that absorption capacity is poor and therefore in unsewered areas, which rely on septic tanks etc., effluent may find its way into watercourses.

Impacts associated with horticultural activities in the catchment may include:

- the erosion of bare soil between crops;
- deterioration of water quality in nearby water courses through nutrient runoff and erosion; and
- soil contamination through the use of chemicals such as pesticides, herbicides or weedicides, a residual component of which can remain in the soil.

Impacts which may be associated with animal production include:

- erosion of bare soil caused by overgrazing; and
- deterioration of water quality in nearby watercourses through nutrient runoff containing animal wastes (HSC 1995a).

Recreational opportunities in the Berowra Creek area include picnicking, camping, bushwalking, boating, canoeing, swimming and fishing. There are a number of European and Aboriginal sites located along the waterway which are of cultural significance.

Berowra Waters is an important tourist attraction for Hornsby Shire but is subject to congestion during peak periods (queuing for the ferry, car parking at capacity). The environmental concerns of residents regarding growth in tourism and its impacts on Berowra Creek include:

- increased use of, and pressure on waterways, particularly from increased boating activity;
- pressure to dredge the waterways to accommodate boating, resulting in damage to the seagrass beds and mangrove communities;
- pollution associated with vehicle emissions, garbage and sewage; and
- further congestion.

2.5 Weather and Climate

Climatic changes and weather-driven processes contribute greatly to the nature of the Berowra Creek ecosystem and hence weather and climate variability is important to the interpretation of natural versus anthropogenic changes in ecosystem variables.

Weather and climate impact upon hydrodynamic processes, geological and geomorphological processes and ecological processes occurring in the estuary and are important forcing factors driving much of the estuarine processes.

General trends are summarised below.

Rainfall

- mean annual rainfall ranges from 900 mm in the west of the catchment to 1,400 mm on the higher slopes;
- the duration between rainfall events is seasonal with autumn typically the season with the longest dry periods;
- long-term indicators such as the Southern Oscillation Index (SOI) show that the drought/wet year cycle is erratic, however recent years are characterised by negative SOI values and therefore a drought period.

Temperature and Humidity

- average temperature ranges from 7.6-26.7°C;
- average relative humidity ranges from 50-74%.

Wind Speed and Direction

- 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.

Solar Radiation and Evaporation

- solar radiation and evaporation are typical of temperate climate areas (high values in summer and lower values in winter, 0-1,000 W/m^2 and 85-252 mm respectively), however the steep nature of the catchment means that the water surfaces may only be partially exposed to the intensities recorded at meteorological stations.

2.6 Geology and Geomorphology

Berowra Creek is a typical drowned river valley estuary formed some 6,500 years ago at the end of the postglacial marine transgression. From this time up until the present the estuary has partially infilled with coarse and fine grained fluvial sediments.

Details of creek sediments include:

- coarse grained sediments (gravelly quartz sands) have accumulated in fluvial deltaic deposits in the main Berowra and Marramarra Creek channels and a number of their smaller tributaries. Water depths in the vicinity of these deltaic deposits are commonly less than 1 m;
- fine grained sediments (muds) have accumulated in the deeper (underfilled) sections of the estuary where water depths reach a maximum of 18 m; and

- there is some evidence (sediment mineralogy, bathymetric features, historical changes in mangrove areas) to suggest that fine grained fluvial sediments from the Hawkesbury River are deposited in the lower reaches of Berowra Creek, particularly during floods.

Considerable baseline data is available to characterise the natural variability of catchments within the study area.

Calculations and data collection required include:

- calculations of long-term sedimentation rates based on estimates of late Quaternary sediment volumes and historic bathymetric changes provide an opportunity to assess the impact catchment modifications have had on rates of sediment supply to the estuary;
- quantification of sedimentation rates based on indirect methods requires the collection of undisturbed core samples for the purpose of characterising subsurface sediments and obtaining material for radiometric dating; and
- no radiometric dates are available for sedimentary deposits in the study area – this type of data is fundamental to establishing rates and volumes of estuarine sedimentation. This data is to be collected as part of latter stages of the study.

Ongoing geological investigations aimed at developing a conceptual model of estuarine sedimentation for the study area will rely on the integration of the available data and collection of new information on the estuarine deposits (surface and subsurface samples, radiometric dates). The results of these investigations will become available to the rest of the project team and will have particular significance for issues of contaminated sediment dispersal, potential sediment-water interactions, and the implications for dredging.

Results of geological investigations within Berowra Creek will be relevant to other drowned river valley estuarine systems within the Hornsby Shire and adjacent local government areas.

2.7 Hydrodynamics

The hydrodynamics of Berowra Creek have been the subject of an intensive field data acquisition investigation conducted by DLWC in 1995 (MHL 1996). The analyses of these data will form the basis of a review of processes during the present program. A water quality model of the creek was also developed for the environmental impact assessment of the sewage treatment plants.

Berowra Creek may be classified as a partially mixed tidal estuary. The dominant currents are caused by tidal flows but the exchange of water between the creek and the Hawkesbury River is also affected by baroclinic (or density driven) flows. A number of mechanisms influence water exchange and the relative importance of each mechanism changes with time, depending upon wet/dry periods, solar heating and cooling.

The topography of the creek also influences the hydrodynamics and flushing characteristics. The relatively wide and deep section near Calabash causes a reduction in the tidal flow velocities and hence less advection and mixing of waters in this region compared with areas further up and downstream. This reduced mixing or longer residence tine appears to influence the algal blooms that occur in the area.

Further investigation of the mixing characteristics, both vertical and horizontal, is planned for this program. A knowledge of vertical mixing is deemed an important priority for assessing the role of sediment nutrient release.

2.8 Water Quality

Catchment

Water quality in the Berowra Creek catchment watercourses varies according to the nature of the local catchment and sources of material located within those catchments.

Major issues in the streams include:

- sediment loads from developing urban areas;
- nutrients from urban runoff and sewage treatment plants;
- inputs of heavy metals and organic pesticides; and
- inputs of high faecal coliforms during large rainfall events and overflows.

Hornsby Shire Council has implemented a number of programs aimed at reducing sediment and nutrient loads from the catchment. Sydney Water is continually upgrading their sewage treatment plants to reduce the nutrient inputs to the creek. The industrial area outlets are monitored to check levels of contaminants.

These programs have led to a substantial body of information on the catchment waterways that will be reviewed in the present program. At this stage, no further monitoring beyond the HSC program is recommended for water quality in the catchment streams.

Estuarine Waters

Water Clarity

- turbidity exceeds guidelines;
- non-filterable residue exceeds guidelines at some sites.

Phytoplankton

In situ measurements are necessary to properly understand the role that light extinction plays in phytoplankton dynamics. This includes:

- at very least the sampling should be extended to include Secchi disk depths. The Secchi disk is simply a circular metal disk (ranging in size between 20 and 30 cm but more often 30 cm), painted all white or in white and black quadrants. The Secchi disk is lowered over the side of the boat and the distance at which it just disappears from site recorded. These depths can be used to estimate the light extinction coefficient with reasonable reliability (Holmes 1970);
- a more comprehensive approach would be to measure photosynthetically active radiance (PAR) directly with one of the commercially available light meters. A suitable unit would be the Licor or Biospherical meter and 4 π sensor, costing approximately $2,000-3,000 depending upon model specifications; and

- to clarify the role of stratification in the production of phytoplankton blooms, nutrient concentrations in the bottom layer should be measured during stratified conditions.

Nutrients

Nutrients have an important role in Berowra Creek. The present monthly monitoring conducted by HSC should be enhanced to resolve the processes affecting nutrient transfer between catchment, water column and biota including phytoplankton and larger plants.

Metals and Pesticides

Metals and pesticides have been monitored previously by the EPA and few species were found in high concentrations. Given the analytical costs and difficulties in assessing their impacts, the present program will not focus on these pollutants.

Pathogens

Faecal contamination of the estuary is known to occur during rainfall events, lasts for relatively short periods and appears to be problematic in the upper reaches where most of the urban runoff enters the creek. Overflows from the sewage infrastructure have also been implicated as a possible source, but it is difficult to assess this contribution. This present study will not aim to monitor these events.

Estuarine Sediments

Nutrients

Previous studies have shown high levels of nutrients in sediments of the deep basin areas near Calabash Bay. It is not clear whether these levels are problematic in that their rates of transfer from sediment to water is not known.

Estimates of the sediment nutrient release rates can be inferred from other locations but it is known that these rates vary considerably between sites. Measurement of these fluxes is very difficult and requires extensive resources that would be beyond the scope of this study.

Metals and Pesticides

Metals and pesticides have been monitored at a few sites within the system and results show high variability with a few high concentrations measured.

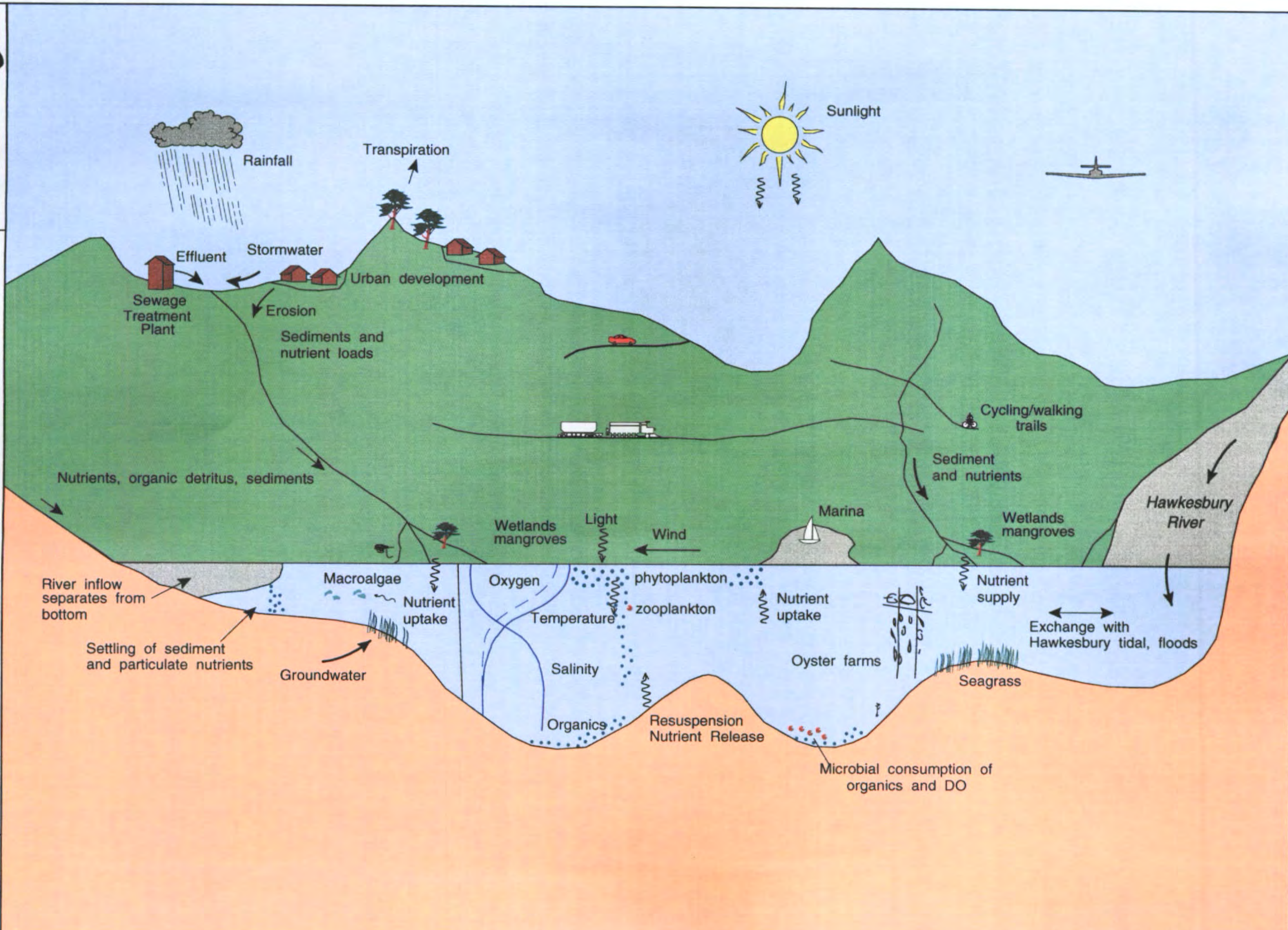
2.9 Ecology

Ecological processes in Berowra Creek appear to be fundamentally similar to those in other estuaries along the NSW coast. The system has several unique attributes that contribute to making certain of these processes a concern to the community at large and the managers responsible. One important feature, that Berowra Creek flows not directly into the ocean, but into the Hawkesbury River, has important implications for the movement of water (and, in particular, the retention of water in the creek) and the ecological processes mediated by water movement, such as the recruitment of fish and invertebrates. Another important feature of Berowra Creek is the presence of deep holes, mainly in the middle section of the creek, that are sinks for fine sediments and have unique water quality characteristics. In the absence of anthropogenic inputs, such a system would be expected to be dynamic, as these physical features interact with ecological processes. It would be expected that, periodically, natural phytoplankton blooms would be 'trapped' in the mid section of the creek due to the nature of water flushing in the system. It also might be expected that fish kills would occur naturally, although at some unknown frequency, due to the possibility that oxygen-depleted water from the deep holes would rise to the surface due to mixing events. Thus, while phytoplankton blooms and fish kills have directly observable and catastrophic effects on fish and plankton, they can be viewed as natural phenomenon probably exacerbated by anthropogenic causes. Human inputs into the system such as nutrients from sewage treatment plants and runoff from farms may increase the occurrences or duration of both phytoplankton blooms and fish kills. Anecdotal accounts hold that these events are more frequent now than in the past, but quantitative data is lacking to confirm that view.

Adequate information is available to indicate that, in general, water quality in the creek system is poor, and frequently fails to meet standards considered to be minimal to ensure ecological health.

For other elements of the ecological system in the creek, a lack of data linking water quality and fauna hampers the identification of the ecological effects of poor water quality. For groups such as zooplankton and estuarine benthos, observations of reduced abundance and diversity are difficult to attribute directly to poor water quality in the absence of longer-term quantitative data on the natural variations in these parameters. The expected pattern for benthic fauna, for instance, is for small estuarine systems to have smaller abundances and less diversity of aquatic plants and animals compared to larger, fully marine systems. Ecological processes controlling the abundance and diversity of the benthos such as the pattern of replenishment of benthic fauna after a significant flood event have been documented for the adjacent Hawkesbury River (Jones et al. 1986, Jones 1987). The controlling factor in such replenishment is water exchange with the ocean, the major source of benthic larval propagules. Because the Berowra Creek system has restricted flushing and is not directly linked with the ocean, a pattern of slower replenishment after a significant event would be expected, resulting in fewer species present than in the adjacent Hawkesbury River. But the data are not available to distinguish this natural process from the hypothesis that the benthos in Berowra Creek are impoverished due to the effects of sewage or other human influence.

Thus, within the restrictions attending such studies, the ecological investigations will focus on a few important links in the ecology of the aquatic flora and fauna in Berowra Creek. The distribution and abundance of fish and benthos on a habitat-by-habitat basis will be examined in an attempt to link pattern with process. Because the increase in the extent of mangroves in the system has been substantial since the 1940s, and because these plants have the capacity to change the very nature of the aquatic habitat, the role mangroves currently play in the system will also be examined.



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SCHEMATIC DIAGRAM OF BEROWRA CREEK ESTUARY PROCESSES

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Figure 2.1

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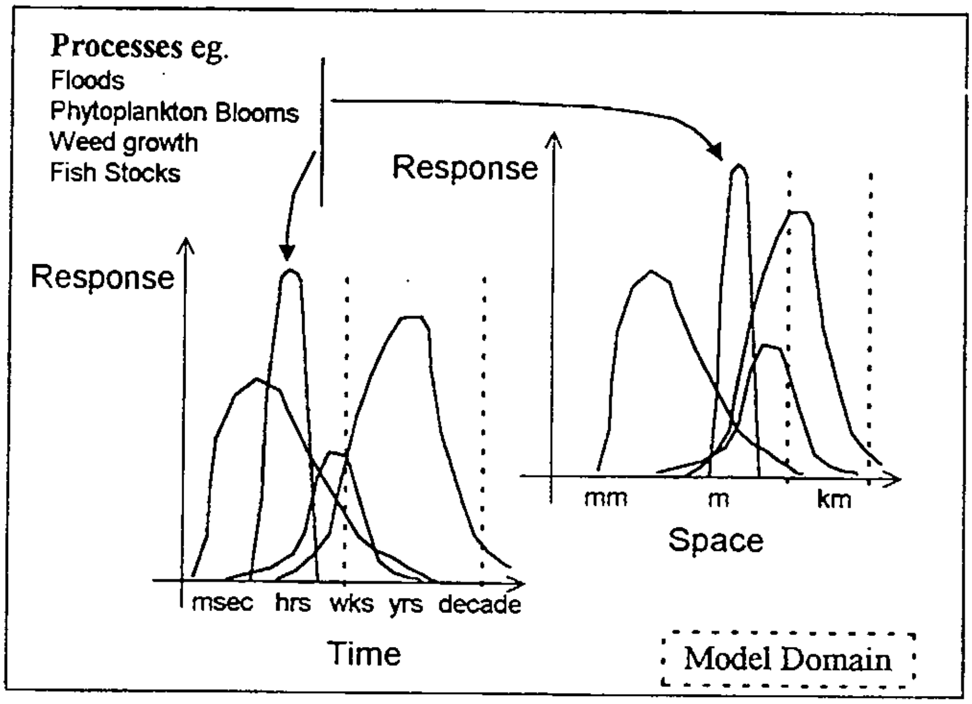

Note: After Van Senden (1996)

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TIME SCALE FOR ESTUARY PROCESSES

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Figure 2.2

3. Catchment and Estuary Physical Characteristics

3.1 Catchment

The catchment area for Berowra Creek and its main tributary, Marramarra Creek, is approximately 310 square kilometres (MHL 1996) and is shown in Figure 3.1. The catchment is generally steep with ridges close to the edge of the waterway characteristic of drowned river valleys. The top of the catchment has an elevation of approximately 200 m AHD.

The catchment exists entirely within the Hornsby Council local government area.

3.2 Estuary

The Berowra Creek estuary is a drowned river valley which joins the Hawkesbury River 11 km upstream of Brooklyn, approximately 24 km from the ocean. Marramarra Creek joins Berowra Creek near its confluence with the Hawkesbury River and is the main tributary creek. The estuary has an approximate waterway area of 11.5 square kilometres (Bruce Coates/Bob Clout, DLWC pers. comm.) and is shown in Figure 3.1. The tidal limit is at Rocky Fall Rapids some 25 km upstream of Bar Island at the confluence of Berowra Creek and the Hawkesbury River.

Tributary creeks to Berowra Creek include (upstream to downstream):

- Pyes Creek
- Waitara Creek
- Tunks Creek
- Galston Creek
- Still Creek (Charlton Creek and Halls Creek are tributaries)
- Calna Creek
- Sams Creek
- Crosslands Creek
- Fosters Creek (into Calabash Bay)
- Banks Creek (into Calabash Bay)
- Calabash Creek (into Calabash Bay)
- Joe Crafts Creek
- Bujwa Creek
- Kimmerikong Creek
- Denny Creek (into Donnybrook Bay)
- Coba Creek (into Coba Bay)
- Muogamarra Creek, and
- Marramarra Creek.

Tributaries to Marramarra Creek include:

- Fiddletown Creek and
- Colah Creek.

Bays of the creek include (upstream to downstream):

- Dusthole Bay (Ferry and Marina)
- Calabash Bay
- Deep Bay
- Joe Crafts Bay
- Half Moon Bay
- Bujwa Bay
- Square Bay
- Bennets Bay
- Kimmerikong Bay
- Coba Bay (including Donnybrook Bay), and
- Peats Bight.

Bays of Marramarra Creek include (upstream to downstream):

- Big Bay
- Friendly Bay
- Kulkah Bay, and
- Back Bay.

Common sampling locations on the creek referred to in this report include (upstream to downstream):

- Rocky Fall Rapids
- Crosslands
- The Woolwash
- Calabash Point
- Cunio Point
- Oaky Point
- Ants Nest Point
- Coba Point, and
- Berowra Point.

Sampling locations in the Hawkesbury River referred to in this report include (upstream to downstream):

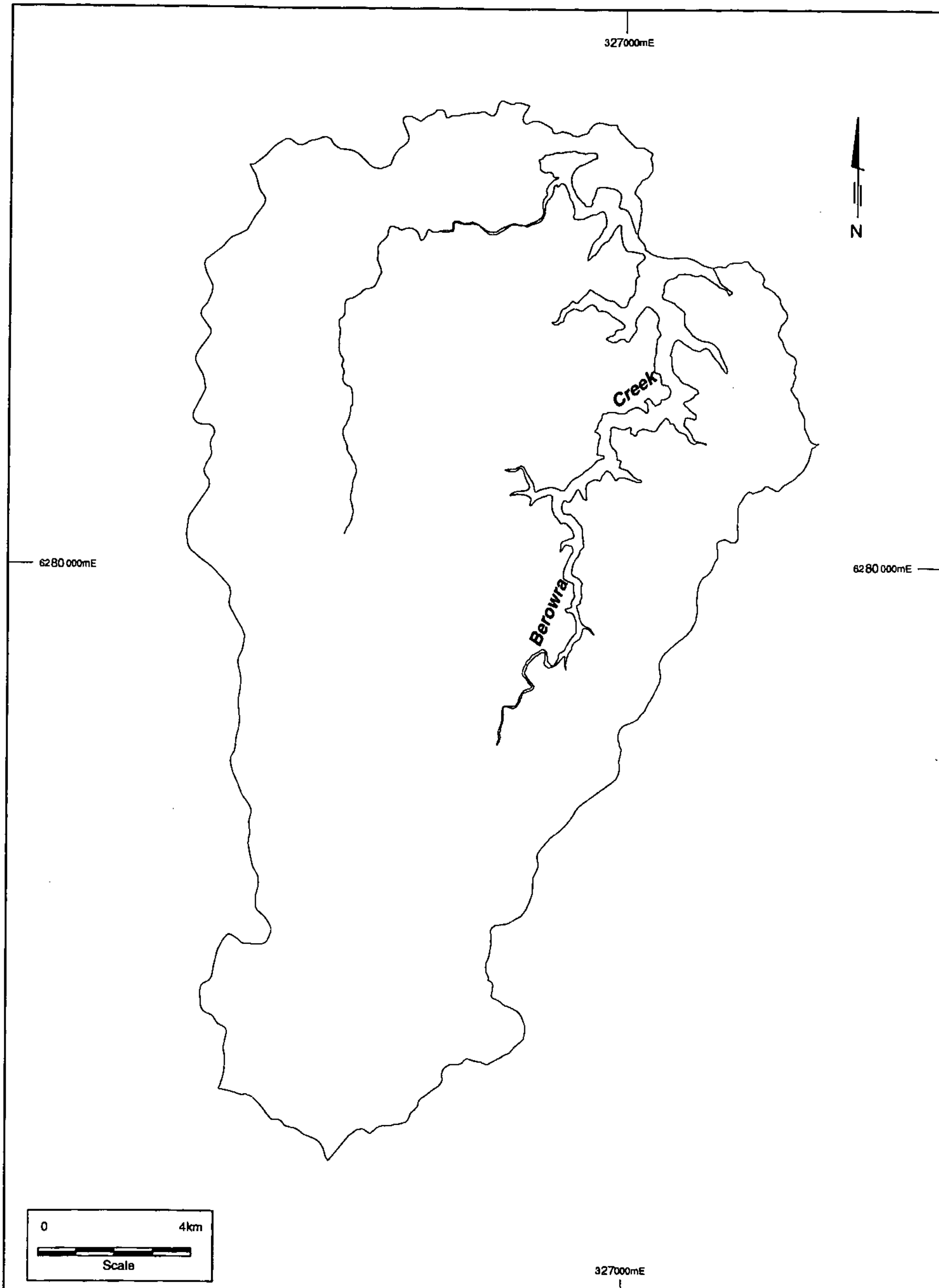
- Freemans Reach
- Sentry Box Reach
- Gentlemans Halt, and
- Peats Ferry Road Bridge.

The creek is generally 3-4 m deep with some deep holes (18 m). Tributaries of the creek are generally shallow. Bathymetry of the creek is further discussed in Section 6.5.

Creek surface areas and volumes have been estimated by DLWC (Bruce Coates/Bob Clout pers. comm.) and are presented in Table 3.1.

Table 3.1 Creek Surface Areas and Volumes

Location	Surface Area (km^2)	Volume (m^3)
Full system to Bar Island	11.53	31.43×10^6
Upstream of Berowra Point	7.37	24.2×10^6
Upstream of Oaky Point	2.07	10.88×10^6
Upstream of Berowra Ferry	0.88	1.43×10^6
Upstream of Crosslands	0.12	0.10×10^6



NSW DEPARTMENT OF PUBLIC WORKS AND SERVICES
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CATCHMENT AREA AND WATERWAY

MHL Report 855

Figure 3.1

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4. Land Use, Recreation and Cultural Heritage

4.1 Land Use and Zoning

4.1.1 Land Use and Planning History

Table 4.1 provides an overview of land use and planning history in Hornsby Shire and the Berowra Creek catchment.

Table 4.1 Overview of Land Use and Planning History

Date	Event
early 1800s	• harvest of Blue Gums and Grey Ironbarks from the ridge tops
c.1816	• Government sawmill established at Pennant Hills
1817	• construction of Old Northern Road • first parcels of land granted north of Dural, following the Glenorie and Marramarra ridges
1819	• land granted at Galston and Arcadia
1826-1831	• construction of Great North Road to Wisemans Ferry providing access to previously inaccessible lands
late 1820s	• land grants along the course of the Great North Road
1829	• 'New North Road' opened from Five Dock to Dural • oranges in full production at Pennant Hills
1831	• Government saw mill at Pennant Hills closed
1836-1910	• land grants along Berowra Creek
1850	• construction of what was to be the Pacific Highway marked the beginning of urban development replacing orchards
1860s	• orchards spread from Pennant Hills to Dural, Galston, Arcadia and Glenorie.
1886	• Homebush to Waratah (Newcastle) railway line opened
late 1800s-early 1900s	• residential subdivision of land along the railway line
1895	• water tanks built at Wahroonga providing local water supply
1901	• National brickworks at Thornleigh commenced operation
1906	• Incorporation of Hornsby Shire
early 1900s	• Opening of quarry at Dural
1910s	• suburban settlement reached beyond the confines of the main ridges • beginning of subdivision of land along creeks
1913	• maltworks at Thornleigh commenced operation
1915	• sewerage system operational and servicing Hornsby and Waitara

Table 4.1 Overview of Land Use and Planning History (cont'd)

Date	Event
1926	• Silverwater Estate at Crosslands on Berowra Creek auctioned • first residential district proclaimed at Hornsby
1928	• electrification of North Shore railway line
1933	• Elouera Bushland Reserve (later incorporated into Berowra Valley Bushland Park) gazetted
1934	• Muogamarra Sanctuary established
1930s	• downturn in citrus industry • 19 residential districts proclaimed followed by a brief period of growth and building in the late 1930s
1930s-60s	• nurseries established at Dural, Galston, Arcadia and Glenorie
1936-37	• sewerage system amplified
1938	• service reservoirs built at Dural and South Dural
1939	• service reservoir built at Berowra
1945	• Hawkesbury River Road Bridge opened • a further two residential districts proclaimed • at this time land devoted to various uses was categorised as 'negligible' for industry, residential land took up 5%, recreational uses 10%, rural 20% and 65% of Hornsby Shire was 'unused' • further residential expansion began
late 1940s	• series of flats built
1951	• County of Cumberland Planning Scheme came into force
1960	• Sir Edward Hallstrom Faunal Reserve established
1960-61	• final four residential districts proclaimed
1962	• land use controlled by Interim Development Orders
1969	• Muogamarra Nature Reserve dedicated (included Hallstrom faunal reserve)
1975	• western extension of the Galston Village
1976-77	• subdivision of land on the eastern side of Glenorie
1977	• Hornsby Planning Scheme Ordinance gazetted
1978-79	• rezoning of first and second stages of Cherrybrook urban release area
1979	• Marramarra National Park dedicated
1981-1991	• residential development of South Dural
1984	• rezoning of third stage of Cherrybrook urban release area
1986	• rezoning of forth stage of Cherrybrook urban release area
1987	• Berowra Valley Bushland Park gazetted
1991	• completion of sewerage system to service the southern portion of the Dural service centre
1994	• Hornsby Shire Local Environmental Plan gazetted
1997	• Berowra Valley Bushland Park declared a regional park

Sources: Kass 1993, HSC 1993, NPWS 1997.

4.1.2 Land Use

The Berowra Creek line is surrounded by bushland, much of which is included in the Berowra Valley Bushland Park, Marramarra National Park and Muogamarra Nature Reserve. In addition to this, there are a number of parks adjoining Berowra Valley Bushland Park, especially in the southern section of the catchment, where various parks follow creek lines including Pyes and Waitara creeks and other smaller tributaries. A relatively large area of Crown land bushland adjoins the park at Turner Road, Berowra Heights. The tidal waters of Berowra Creek are not included in the Berowra Valley Bushland Park. They are also excluded from Marramarra National Park and Muogamarra Nature Reserve, with the exception of Joe Crafts Bay and Bujwa Bay which are adjacent to the nature reserve.

Urban development in the Berowra Creek catchment is located to the east, and rural and rural-residential development to the west of the creek. Urban development is concentrated in the central and southern sections of the catchment, and north from Hornsby along the Pacific Highway and main ridges. It consists primarily of detached dwellings on separate allotments, although there are medium density developments interspersed throughout the residential area. On the creek itself, Berowra Waters is the only village with small river settlements located both upstream and downstream. The settlements are generally only accessible by boat and include Calabash Point, Neverfail Bay, Coba Point, Marramarra Creek and Sunny Corner. They vary in shoreline length between 400 m and 1,000 m, with an average lot size of 700 m^2 to 1,000 m^2. Dwellings often include ancillary development such as boatsheds, seawalls, slipways, jetties and pontoons (HSC 1993). Industrial development is located at Thornleigh.

The main activities within the rural and rural-residential areas include orcharding, market gardens, nurseries, poultry production and agistment. Other uses include commercial activities, rural industries, commercial fishing, mining, education establishments, community uses and recreation. An overview of land use in the Berowra Creek catchment is shown in Figure 4.1 and Table 4.2.

Table 4.2 Land Use in the Berowra Creek Catchment

Land Use	**Area (ha)**	**% of Total Area**
Bushland	13,819.5*	70.1
Established sewered urban	2,310.5	11.7
Established unsewered urban	39.5	0.2
Recent sewered urban	153.8	0.8
Unsewered semi-urban	2,202.0	11.2
Built-up (miscellaneous)	61.5	0.3
Industrial and commercial	100.0	0.5
Intensive vegetable/turf farming	1.8	0.0
Unfertilised grazing	161.5	0.8
Water	803.8[+]	4.1
Disturbed land	6.8	0.0
Undefined	42.3	0.2
Total	**19,700**	**99.9[#]**

Source: SMEC 1997

Notes: *excludes bushland in Marramarra National Park and Muogamarra Nature Reserve
+excludes tributary creek waterway areas
#does not add up to 100% due to rounding

Land use within the rural areas (including those outside the Berowra Creek catchment) is shown in Table 4.3 and the type of farming carried out in the different rural locations within the catchment is shown in Table 4.4.

Table 4.3 Rural Area Land Use

Land Use	Area (ha)	No. of properties
Agriculture - intensive horticulture	834.0	332
Agriculture - extensive horticulture	593.5	228
Agriculture - animal production	337.5	128
Agriculture - pasture	360.0	144
Residential - village	67.2	559
Residential - rural	2765.8	1,824
Commercial	169.5	66
Industrial	126.0	29
Community uses	354.5	60
Bushland	24,766.0	515*
Recreation	170.0	25
Utility installations and reservations	24.0	17
Total	**30,568**	**3,927**

Source: HSC 1995a

Notes: Marramarra National Park area included but not counted as a property
data includes all rural areas in Hornsby Shire, some of which are outside the Berowra Creek catchment

Farmland Returns were used as the basis for the data presented in Table 4.4. If an owner can demonstrate, through the Return, that land is used for farming in accordance with established criteria, a 50% discount applies to Council rates. A mixture of activities may occur on one property, therefore the number of activities or produce types exceeds the number of farms shown for each location.

Table 4.4 Farm Type

Farm produce or activity	Location								
	Arcadia	Berrilee	Canoe-lands	Dural	Forest Glen	Galston	Glen-haven	Glenorie	**Total**
no. farms per location	99	1	15	74	4	93	3	72	361
stone fruit	32	1	11	12	4	25	0	20	105
citrus	8	1	2	8	0	15	0	6	40
apples	3	0	0	0	0	0	0	0	3
other fruit	4	1	1	0	0	11	0	5	22
nursery	10	0	0	9		9	0	7	35
flowers	18	0	1	22	0	22	1	10	74
roses	3	0	0	3	0	3	0	2	11
trees	4	0	0	4	0	3	0	3	14
vegetables	21	0	0	23	0	18	0	22	84
horses	15	0	0	2	0	5	1	4	27

Table 4.4 **Farm Type** (cont'd)

Farm produce or activity	Location								
	Arcadia	Berrilee	Canoe-lands	Dural	Forest Glen	Galston	Glen-haven	Glenorie	Total
cattle	11	0	3	10	0	6	1	1	32
goats	2	0	0	1	0	0	0	1	4
deer	1	0	0	0	0	0	0	0	1
sheep	0	0	0	0	0	0	0	1	1
poultry	9	0	0	0	0	2	1	0	12
ducks & geese	0	0	0	0	0	1	0	0	1
bees	1	0	0	1	0	2	0	0	4

Source: HSC 1995a

Recent changes to land uses in the catchment include a shift from traditional agricultural activities to rural-residential development and hobby farms and the development of the Cherrybrook urban release area (Price Waterhouse Urwick 1993, HSC 1995a).

Factors which could alter land use in the future include:

- any extensions of Marramarra National Park, Muogamarra Nature Reserve or Berowra Valley Bushland Park;
- a continuation in the shift from rural to rural-residential development;
- a shift from rural to tourism uses; and
- changes in agricultural production techniques (e.g. hydroponics) allowing less suitable land to be farmed.

4.1.3 Land Use Zoning

Major land use zones are shown in Figure 4.2 and minimum lot sizes for rural, residential (single dwellings) and environmental protection zones are shown in Table 4.5.

Table 4.5 Minimum Lot Sizes

Zone	Minimum area per allotment
Rural A	10 ha
Rural B	2 ha
Residential A (Low Density)	500 m^2
Residential AA (Low Density - Aquaculture)	500 m^2
Residential AM (Low Density - Medical Support)	500 m^2
Residential AS (Low Density - Sensitive Lands)	600 m^2
Residential AT (Low Density - Tourist Village)	500 m^2
Environmental Protection A (Wetlands)	40 ha
Environmental Protection B (River Catchment)	40 ha
Environmental Protection C (Tourist)	1,000 m^2
Environmental Protection D (Recreation)	5 ha

Source: HSC 1994c

Land within the river settlements is zoned Environmental Protection B (River Catchment). The aim of this zone is to protect the visual and general environmental qualities of the Berowra Creek foreshores. Site coverage, which includes all buildings and structures such as terraces and swimming pools, is not permitted to exceed 30% and river settlement property owners are encouraged to share pontoon and wharf structures. Three sites at Berowra Waters are zoned Business D (Aquatic Service Centre), which recognises the function of these sites in providing waterway-related tourist and recreation facilities (HSC 1994d).

4.2 Development, Population Size and Growth

Changes to current levels of development will most likely occur through increased densities in residential areas, development of Landcom sites and development of some land identified as marginal for residential purposes.

Multi-unit housing is permitted in residential zones (see Table 4.5 for a description of zones):

- A, AA, AM or AT, if the density does not exceed one dwelling per 350 m^2; and
- AS if the density does not exceed one dwelling per 400 m^2 (HSC 1994c).

It is therefore possible over time that a general increase in densities in residential areas will occur, however, it is envisaged that most redevelopment will be around railway stations to assist in addressing the objectives of the State Government's urban consolidation initiatives (SMEC 1997).

Current Landcom development applications in the Berowra area total 369 lots (another 94 lots are proposed) covering an area of about 35 ha. At Hornsby Heights current applications total 76 lots covering about 12 ha (advice from HSC 7 April 1997).

The most suitable lands for housing (e.g. those with a slope up to 20%) have essentially been developed. Land with a slope between 20% and 25% may be capable of supporting urban development on suitable slopes, but development of land with slopes in excess of 25% may result in unacceptable environmental impacts with regard to site stability and soil erosion. Other factors taken into consideration in assessing the suitability of land for development are proximity to watercourses, soil dispersibility, soil landscapes, plant communities, bushland, fauna habitats and bushfire hazard. Accordingly some urban land in the catchment has remained undeveloped due to these environmental constraints, but as more suitable land for future development diminishes, these lands will come under increasing pressure (HSC 1996a). Figure 4.3 shows the capability of land to support development in the non-rural land areas in the vicinity of Berowra Creek.

Population projections by local government area are available from the Department of Urban Affairs and Planning to the year 2021 (DUAP 1995). Hornsby Shire's population as at 1991 was 127,699 (HSC 1995b). The estimated population increase between 1991 and 2021 under a low growth scenario is 20,850 and under high growth 37,350. HSC (1996b) notes that these estimates are based on past urban consolidation policies and more importantly on historical trends (i.e. times when major residential subdivisions and land releases occurred) and represent an overestimation of population growth. For example, increases in population growth between 1976 and 1981 coincided with the subdivision of Glenorie and Galston, rapid growth rates between 1981 and 1991 were mainly due to the development of South Dural and increased growth rates are also associated with the development of the Cherrybrook release areas.

As noted previously it is predicted that future growth in Hornsby Shire will occur primarily through urban consolidation and infill housing. HSC (1995a) noted little opportunity for a significant population increase in the rural section of the Berowra Creek catchment and that preferably additional persons would be housed within and adjacent to existing villages. Galston was identified as the village most capable of supporting additional residential development. The *River Settlements Study* (HSC 1993) indicated that the population of the settlements (Berowra Waters, Calabash Point and Dusthole Point, Neverfail Bay and Collingridge Point, Coba Point, Marramarra Creek, Sunny Corner, and Milsons Passage, see Figure 4.4) was approximately 300 people and rises to about 700 during holiday periods. At the time of the study there were 62 vacant lots within the river settlements, which, if all developed could result in a peak period population of 900 people. Further development of both Galston and the river settlements poses concerns with regard to onsite sewage disposal as discussed in Section 4.2.1.

Other factors which could influence development levels and population growth in the future include:

- any release of Crown land areas in the northern part of the study area for rural-residential uses;
- any residential development of privately owned rural land in the south-west of the catchment;
- any extension of the water and sewerage reticulation systems;
- a continuation in the shift from rural to rural-residential development; and
- development of the Shire's tourism industry.

4.2.1 Impacts of Development and Servicing Constraints

Roof water tanks are the primary source of potable water for the river settlements (town water is available to Berowra Waters and Calabash Point) and accordingly water consumption is far less than the average because of the need to conserve this resource. It is unlikely that the current limited water supply service will be extended due to the costs associated with servicing remote communities, and provision of reticulated water without reticulated sewerage would increase sewage disposal problems. Sewage disposal is via septic tanks or domestic sewage treatment systems and absorption trenches. Domestic sewage treatment plants, such as envirocycle, break down effluent to a liquid which is sprayed on the ground. Each system requires at least 200 m^2 of non-recreational land for the infiltration. Similarly septic tanks rely on the absorption capacity of the soil. The steep slopes and shallow soils of the settlements mean that absorption capacity is poor and therefore effluent can affect water quality in Berowra Creek (HSC 1993).

Another factor which limits population growth and permanent residence in the river settlements is the lack of road access. For Coba Point and Calabash Point access is possible for 4WDs via fire trails along the ridges leading to Bay Road. The trail to Coba Point, however, passes through Marramarra National Park and access is restricted to authorised vehicles. Expansion of this limited road network is not favoured by Council as this could have an adverse impact on the natural environment through the loss of trees, soil erosion and impacts on fauna (HSC 1993).

In the rural area reticulated water is available to the majority of properties south of Glenorie but opportunities for extension are limited due to the relative elevation of the reservoirs and the extent of the area to be serviced. The majority of the rural area is not sewered. Sewage is generally disposed of through either a pumpout service, domestic sewage treatment plants, septic systems or composting toilets. Grey water is usually disposed of onsite. In older dwellings, grey water was directed to absorption trenches for infiltration into the soil. For more recent dwellings effluent and waste water is directed to onsite treatment systems and then on to absorption trenches or irrigation areas (HSC 1995a). Methods of sewage disposal in the rural area are shown in Table 4.6.

Table 4.6 Rural Lands - Methods of Sewage Disposal

Location	Disposal Method			
	domestic sewage treatment plant	pumpout - residential properties	pumpout - commercial properties	composting toilets
Arcadia	40	0	0	0
Berrilee	8	0	0	0
Canoelands	3	0	0	0
Dural	70	1	11	1
Galston	148	82	11	1
Glenhaven	8	0	0	1
Glenorie	56	67	2	0
Fiddletown	4	0	0	0
Forest Glen	1	0	0	0
Total	**338**	**150**	**24**	**3**

Source: HSC 1995a

Agricultural activities within the Berowra Creek catchment consist of both intensive and extensive forms of production. Intensive agriculture includes the intensive stocking of land and the cultivation of flowers, vegetables and nursery plants. Extensive horticulture includes the cultivation of pasture and citrus and stone fruit trees.

The use of cleared land for intensive and extensive horticultural activities can have a range of impacts including:

- the erosion of bare soil between crops;
- deterioration of water quality in nearly watercourses through nutrient runoff and erosion; and
- soil contamination through the use of chemicals as pesticides, herbicides or weedicides, a residual component of which can remain in the soil.

Animal production, including poultry, livestock and horses can have similar impacts to horticultural activities, although the cause may be different. The impacts can include:

- erosion of bare soil caused by overgrazing; and
- deterioration of water quality in nearby watercourses through nutrient runoff containing animal wastes (HSC 1995a).

4.3 Waterway and Foreshore Uses

4.3.1 Recreation and Tourism

Recreational resources available in the Berowra Creek area include:

- bushland comprising Berowra Valley Bushland Park (about 3,800 ha in area), Muogamarra Nature Reserve (2,274 ha) and Marramarra National Park (11,759 ha) and associated walking trails;
- waterways comprising Berowra Creek and its tributaries, boating facilities and services at Berowra Waters and moorings throughout the navigable section of the creek;
- picnic facilities, barbecues and playgrounds which are concentrated on the western foreshores of Berowra Waters and at Crosslands;
- restaurants which are located mainly at Berowra Waters;
- camp grounds within Marramarra National Park and Berowra Valley Bushland Park; and
- formal adventure and accommodation facilities such as the Seventh Day Adventist Youth Camp near Crosslands and Camp Knox which is located just downstream of the study area.

Marramarra National Park is one of the least developed national parks in the Sydney metropolitan area, with only about 8,000 visitors per year. The park provides opportunities for low key recreational activities such as picnicking, camping, bushwalking, canoeing, swimming and fishing (recreational fishing is discussed in Section 4.3.2). Marramarra Creek and Gentlemans Halt are popular for camping and picnicking and provide basic facilities. A wharf has been constructed at Gentlemans Halt to facilitate access to the park by larger boats. Access to Marramarra Creek is from the Marramarra, Smugglers and Duckponds Ridge walking tracks, or by canoe from Berowra Waters. Access to Gentlemans Halt is from Singleton Road or the Canoelands Ridge walking tracks, or by boat from the Hawkesbury River. There is no vehicle access to picnic or camping areas and permits are required for camping in areas other than Marramarra Creek and Gentlemans Halt. Muogamarra Nature Reserve is open for a few weeks each year for the wildflower season when walks and talks are conducted under the NPWS's 'Chase Alive' program. At other times the reserve is only available for authorised research, education activities and guided tours. Students utilise the field studies centre in the nature reserve and school groups are permitted to camp near the centre on a limited basis. Research is carried out at the University of NSW's field station (NPWS 1994, 1997).

Picnic facilities in the Berowra Creek area are located at Crosslands Reserve, the Jungo, Berowra Waters and Galston Gorge. Crosslands is the recreation centre of the Berowra Valley Bushland Park and provides opportunities for recreational activities such as walking, cycling, camping and canoeing. Bushwalking can be undertaken through much of the park via constructed tracks such as the Benowie Walking Track, which is part of the Great North Walk. In addition to casual use, Hornsby Council runs a series of bushwalks and spotlight walks. Swimming occurs at Crosslands, at points along the Benowie Track (such as Fishponds Waterhole), and in the netted tidal pool at Berowra Waters. Fishing is concentrated downstream of Crosslands. Crosslands Reserve is available for short-term camping and attracts about 2,000 campers per year. Another camp ground is located at Tunks Ridge, which is accessible by foot only (HSC 1994b).

Provision for organised activities is made within Berowra Valley Bushland Park for horse riding and motor bikes. An area near Laurence Street, Pennant Hills is used for gymkhanas and other organised horse riding activities, and an area near Beaumont Road, Mt Kuring-gai is used by mini-bikes and off-road bikes for training and competition. Horses and motor bikes are not permitted elsewhere in the park (HSC 1996c).

A three lane boat ramp is located on the western side of Berowra Waters and the associated car park can accommodate 85 cars with trailers, plus another 48 cars. Berowra Creek is navigable for recreational vessels as far as the Woolwash (about 1 km upstream of Berowra Waters) but from this point on it is shoaled and water access up to Crosslands is generally only possible by canoe or shallow draught boat. A dinghy launch ramp is located at Crosslands.

The total number of moorings available within Berowra Creek is 257, comprising 140 private moorings, 73 residential moorings and 44 commercial moorings (any additional moorings would require development consent (HSC 1994d)). This does not include the mooring of boats at jetties, pontoons and marinas (the marina on the western side of Berowra Waters can accommodate 108 vessels). One mooring per residential property is permitted where boats cannot utilise a jetty or pontoon and a commuter pontoon is located on the eastern side of Berowra Waters. Boating facilities are shown in Figure 4.5.

Berowra Waters is an important tourist attraction for Hornsby Shire. Price Waterhouse Urwick (1993) found that:

- the majority of visitors to Berowra Waters are from Sydney, mainly from the North Shore;
- the village attracts mainly families and groups of friends in the 25-35 years age group;
- most people had heard about Berowra Waters from friends or live in the Shire;
- most people enjoyed the area's natural beauty and were out for a picnic lunch or to dine at a restaurant; and
- boating was the other main activity undertaken.

Restaurants at Berowra Waters include the Berowra Waters Inn, which attracts both international and domestic visitors and is only accessible by boat, and the Berowra Waters Tea House. A restaurant with overnight cabins is located at Sunny Corner (Peats Bight). There are three businesses associated with boating, the Berowra Waters Marina, Cruisecraft Marina and Berowra Waters Boatshed. These businesses comprise offices, kiosks, a restaurant, ship chandlery, boat brokerage, boat hire, houseboat charter, dinghy storage, berths, moorings, boat repair services and slipways.

Environmental concerns of residents with regard to tourism growth were investigated by Price Waterhouse Urwick (1993). The main concerns were found to be:

- impacts of large scale development;
- increased use of, and pressure on the waterways, particularly from increased boating activity;

- pressure to dredge the waterways to accommodate boating, resulting in damage to the seagrass beds and mangrove communities;
- pollution associated with vehicle emissions, garbage and sewage; and
- increased congestion.

Congestion at Berowra Waters occurs during weekends, especially Sundays, due to the limited capacity of the ferry (queuing for the ferry creates traffic jams) and car parking areas, and the narrow alignment of Berowra Waters Road. There is competition between visitors and property owners for parking spaces as many of the river settlement properties are only occupied on weekends and access is by boat, therefore cars have to left at Berowra Waters. Usage of the boat ramp on the western side of Berowra Waters cannot be expanded without an increase in shore-based parking, which is already at capacity. HSC (1993) has also recommended that, although marinas are a more space efficient way of storing boats, the current leasehold should not be expanded because of the constraints imposed by inadequate infrastructure, especially car parking.

SMEC (1997) noted that water-based activities are affected by poor water quality, as a result of both effluent discharge and urban activities in the catchment. Manidis Roberts Consultants (1991) also noted that Hornsby residents are interested in water sports but activities are not pursued due to concerns about pollution levels, especially in the Hawkesbury River.

4.3.2 Recreational and Commercial Fisheries

Species of fish targeted by recreational anglers include bream, mulloway, flathead, mullet, Australian bass, mud and blue swimmer crabs, and prawns (B. Harrison, NSW Fisheries pers. comm.).

The Economics Department of DLWC is currently assessing the economic value of recreational and commercial fishing in Berowra Creek, distinct from its current listing within broader Hawkesbury figures (Ron Hincks, DLWC pers. comm.).

The estimated value of commercial fishing in Berowra Creek for the financial year 1991-92 was $0.2 million (Hornsby Shire Council 1993). Meshing for bream, luderick and mullet occurs from Sam's Creek downstream to about Friendly Bay. The lower part of the creek, from about Berowra Point, is also trawled for prawns (EPA 1992).

4.3.3 Oyster Leases

There are 63 oyster leases within Berowra and Marramarra creeks, occupying approximately 744,000 m^2 (NSW Fisheries Database, figures current to 7 March 1997), and are located in the entrances to Kimmerikong Creek, Coba and Donnybrook Bays, and Peats Bight. The lower sections of Marramarra Creek are also used for oyster cultivation, to just upstream of, and within Friendly Bay (see Figure 4.5). 'Wild' oysters also grow on the rocky shoreline upstream to Bennets Bay.

Although the exact worth of oyster production for Berowra Creek has not been determined, extrapolating from the figures for the Hawkesbury (~3.5 M m^2 worth ~$2 million), the approximate value is about $40,000.

4.4 Cultural Heritage

Most known Aboriginal sites are near Maroota (Maroota Historic Site), Canoelands and in Marramarra National Park and Muogamarra Nature Reserve. A relatively large number of sites have also been recorded along the foreshores of Berowra Waters. There are 215 recorded sites within Hornsby Shire and 230 within the national park and nature reserve. Sites include a carved tree, stone arrangements, open artefact scatters, open middens, engravings, grinding grooves (most frequent in creek beds) and shelters with art, middens and deposits. Shell middens in the area have been dated to approximately 12,000 before present, and one engraving site in Muogamarra Nature Reserve includes over 30 figures of whales, kangaroos and other animals (HSC 1993, HSC 1995a, Koettig 1996, NPWS 1997).

The Berowra Creek area was first used in the early 1800s by timber cutters, limeburners (lime was made by burning shells), anglers and hunters. Land grants along the foreshore were made between 1836 and 1910 and agriculture was developed along the river flats, particularly at Marramarra Creek (where the remains of orchards are evident). Buildings and structures remaining from early European activities and settlement include:

- a ballast dump (visible at low tide) at the mouth of Marramarra Creek (unladen ships dumped rock ballast before loading produce for their return trip to Sydney);
- the house of George Collingridge, 'Capo di Monte', built in 1881, ruins of George Peat's house at Peats Bight and the Vicker's Family House, 'Taracoonee', at Sunny Corner;
- old tracks down to Calabash Point, Coba Point and Peats Bight;
- the stone jetty at Bennets Bay, built around the 1840s;
- a small cemetery (headstones indicate burials between 1884 and 1906), church ruins and the Sandell-Buckman monument on Bar Island;
- early commercial developments including the Fretus Hotel ruins at Calabash Point (1890s), the Gentlemans Halt Inn ruins, and the Berowra Waters boatshed and Tea House which opened in 1898 and 1922 respectively;
- the toilet block and tidal pool at Berowra Waters, which were constructed in 1930;
- Berowra Waters cable ferry terminals; and
- the Galston Gorge timber bridge, sandstone buttressing and water troughs (HSC 1993, Higgenbotham 1993, Perumal Murphy Wu 1993).

These items are listed in Hornsby Shire Council's Local Environmental Plan as being of heritage significance, together with Marramarra National Park and Berowra Valley Bushland Park. Other sites of historic interest are the site of the tent school associated with construction of the Pacific Highway in 1927 and paths and lookouts constructed for visitors in the 1930s (NPWS 1997). The major heritage sites along Berowra Creek (from Berowra Waters downstream) are shown in Figure 4.6.

Of landscape significance are the volcanic diatremes which occur in Muogamarra Nature Reserve at Peats Crater and Peats Bight and Marramarra National Park north of the entrance to Marramarra Creek (Blanche and Marramarra craters). These areas were once filled with igneous breccia which has since been largely eroded leaving crater-like depressions (NPWS 1997).

4.5 Summary

Most of the Berowra Creek catchment is bushland, with urban development (primarily detached dwellings) located to the east, and rural and rural-residential development to the west of the creek. Small river settlements are dotted along the creek. The main activities within the rural and rural-residential areas include orcharding, market gardens, nurseries, poultry production and agistment.

Recent changes to land uses in the catchment include a shift from traditional agricultural activities to rural-residential development and hobby farms and the development of the Cherrybrook urban release area.

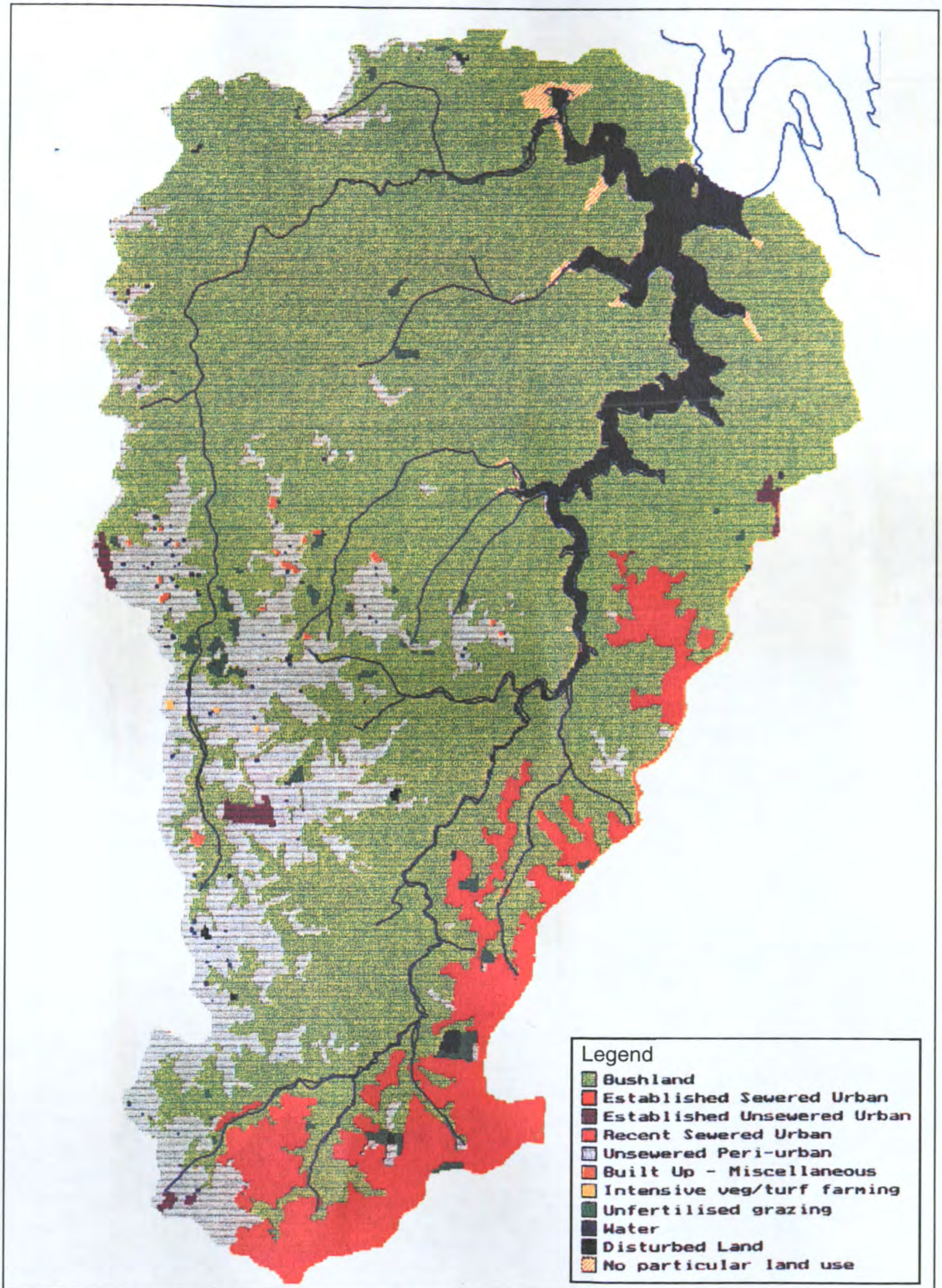
Future changes to current levels of urban development will most likely occur through increased densities in residential areas (as multi-unit housing is permitted in residential zones) and development of Landcom sites. For the rural areas, HSC (1995a) noted little opportunity for a significant population increase and that preferably additional persons would be housed within and adjacent to existing villages. Further development in the catchment is constrained by the costs and difficulties in providing water and sewerage services and the capability of the land to support development (e.g. steep slopes).

Recreational resources available in the Berowra Creek area include:

- bushland comprising Berowra Valley Bushland Park, Muogamarra Nature Reserve and Marramarra National Park and associated walking trails;
- waterways comprising Berowra Creek and its tributaries, boating facilities and services at Berowra Waters;
- picnic facilities, barbecues and playgrounds which are concentrated at Berowra Waters and Crosslands;
- restaurants at Berowra Waters;
- camp grounds within Marramarra National Park and Berowra Valley Bushland Park; and
- formal adventure and accommodation facilities.

Recreational activities are generally low key and include picnicking, camping, bushwalking, boating, canoeing, swimming and fishing. Berowra Waters is an important tourist attraction for Hornsby Shire but is subject to congestion during peak periods (queuing for the ferry, car parking at capacity). Commercial fishing is carried out in Berowra Creek as well as oyster farming.

The Berowra Creek area was first used in the early 1800s by timber cutters, limeburners, anglers and hunters, after which agriculture was developed along the river flats. Several buildings and structures remain from early European activities and settlement along the creek. Volcanic diatremes in Muogamarra Nature Reserve and Marramarra National Park are also of interest, as are Aboriginal sites. Most known sites are in Marramarra National Park and Muogamarra Nature Reserve, however, a relatively large number have been recorded at Berowra Waters.



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LAND USE

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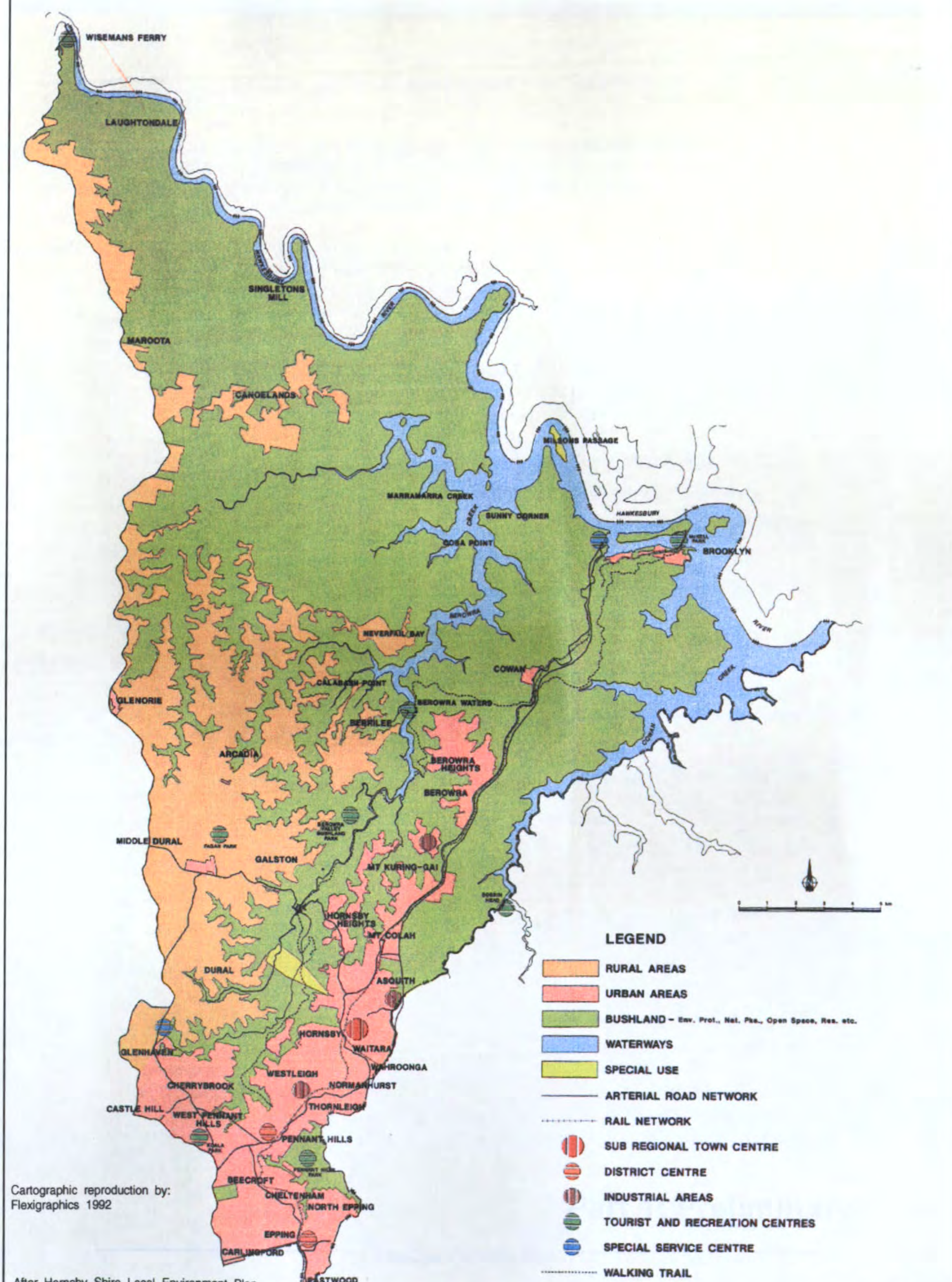
Figure 4.1

DRAWING 855BER41.CDR



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MAJOR LAND USE ZONES

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Figure 4.2

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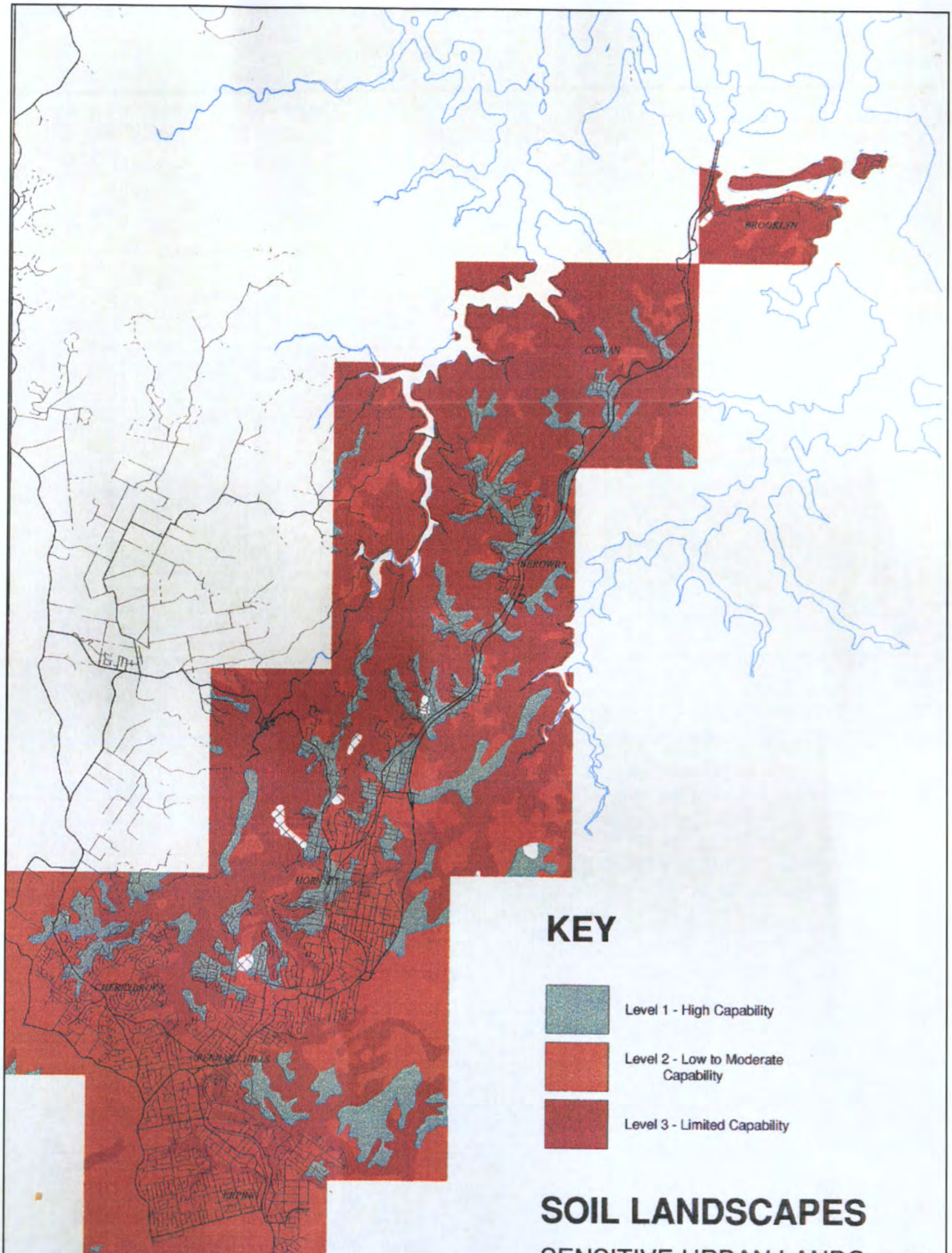

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URBAN LAND CAPABILITY

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Figure 4.3

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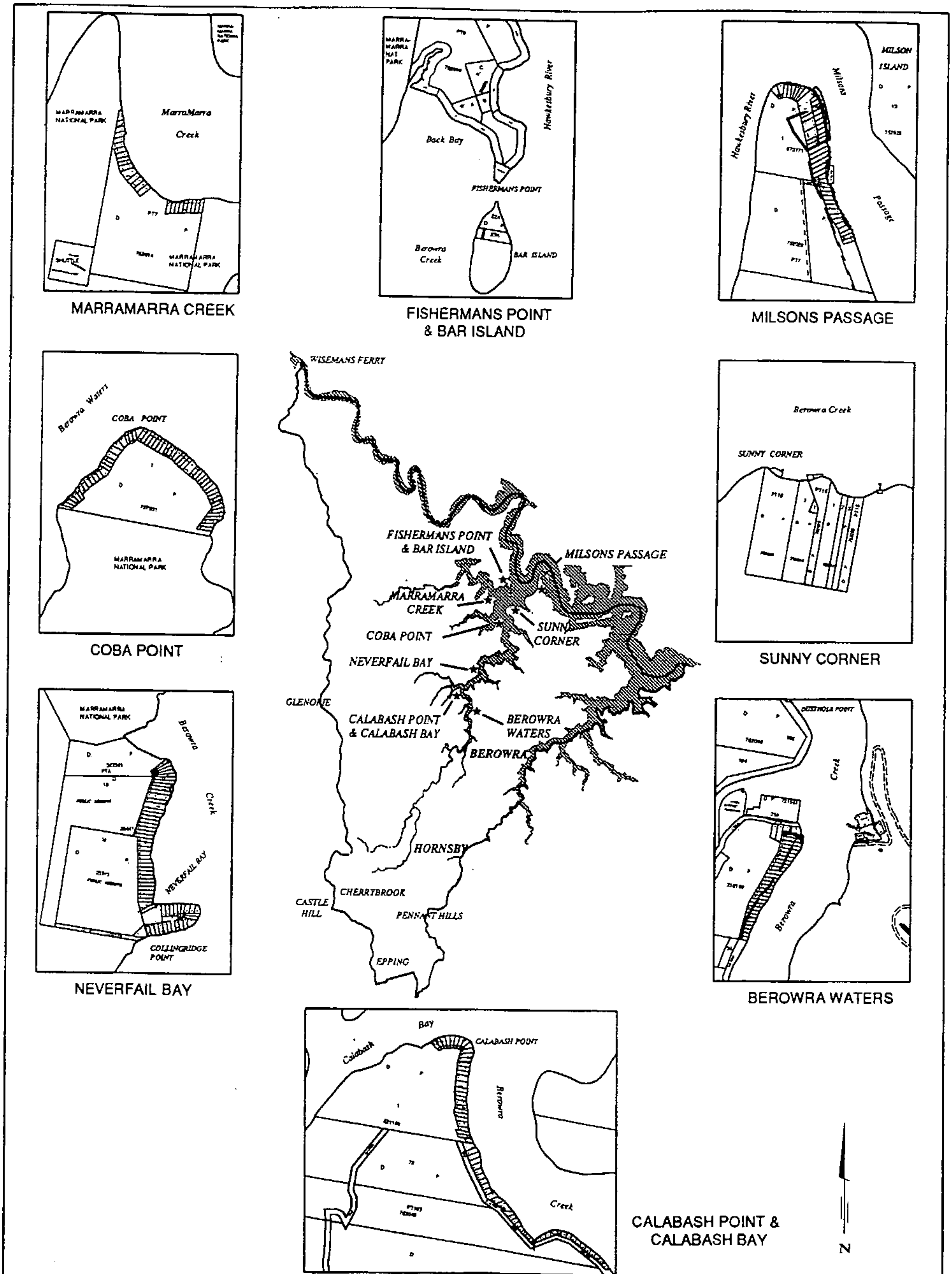

(After Hornsby Shire River Settlements Study, 1993)

Insets 1:20 000

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RIVER SETTLEMENTS

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Figure 4.4

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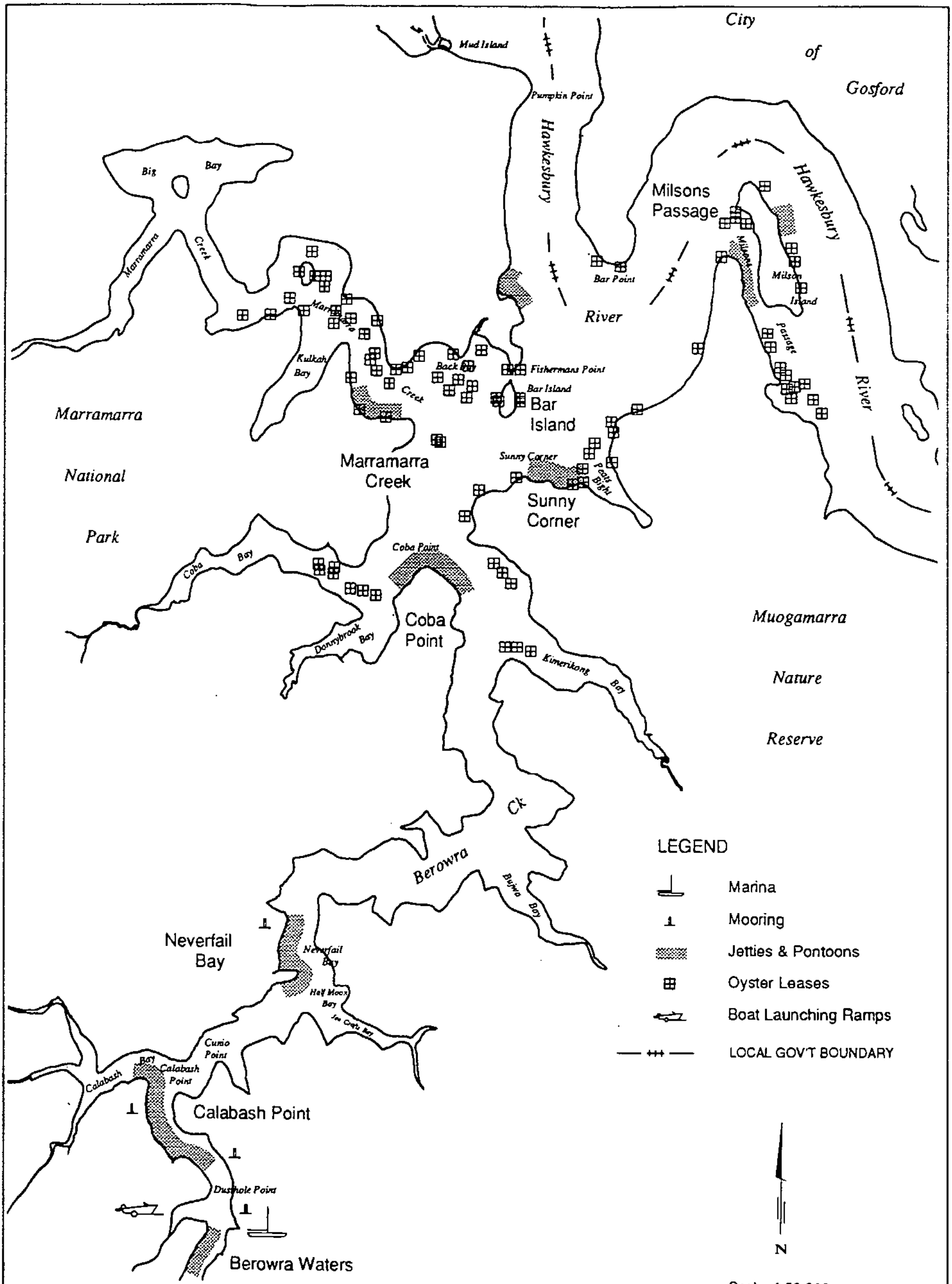

(After Hornsby Shire River Settlements Study, 1993)

Scale 1:50 000

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BOATING FACILITIES

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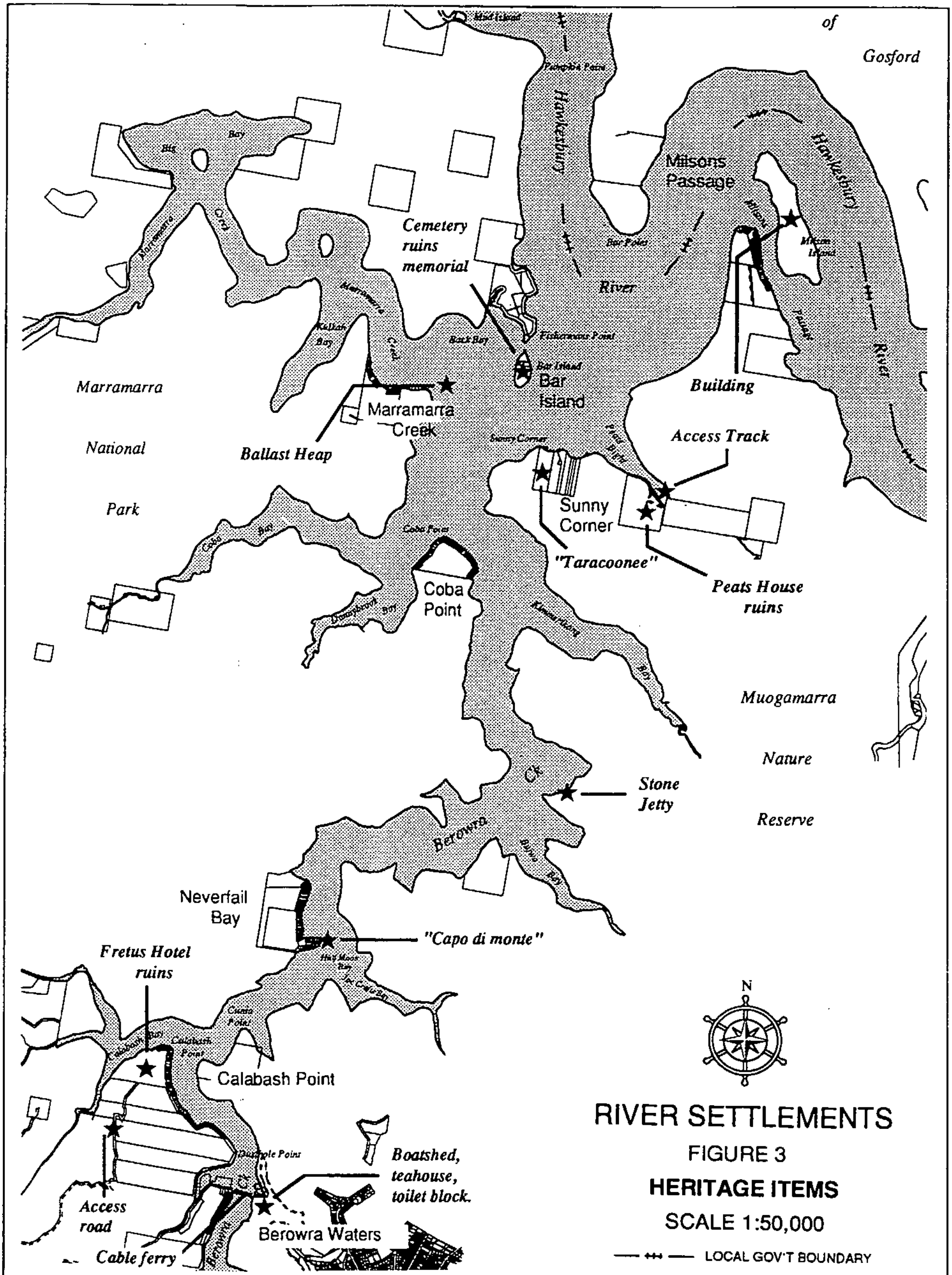
Figure 4.5

DRAWING 855BER45.DRW



(After Hornsby Shire River Settlements Study, 1993)

NSW DEPARTMENT OF PUBLIC WORKS AND SERVICES MANLY HYDRAULICS LABORATORY	EUROPEAN HERITAGE ITEMS	MHL Report 855 Figure 4.6

5. Weather and Climate

Berowra Creek and its tributaries are located within a temperate zone with uniform rainfall, with a summer of warm to hot temperatures and subtropical rainfall, and a winter of mainly reliable rainfall, weather and climate with cool to cold temperatures (Lee and Gaffney 1986).

Climate refers to the long-term behaviour of the weather. In discussing weather and climate, three time scales are considered: daily, annual and inter-annual. These time scales have considerable impact on the behaviour of the creek and hence it is important to understand the variability observed on these scales.

5.1 Rainfall

Rainfall is significant for 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.

The region falls within the Bureau of Meteorology Rainfall District 66, Metropolitan - East (Lee and Gaffney 1986). The rainfall trends for this region are shown in Figure 5.1. Median annual rainfall is approximately 1,200 mm. On average, the highest rainfall occurs in March and lowest rainfall in January (Lee and Gaffney 1986). Coles (1995) produced a mean annual rainfall map for an area including the catchment from ten rainfall stations for the period 1965-1972 and reported that mean annual rainfall ranges from 900 mm in the west to 1,400 mm in the south-east of the catchment, the higher amounts of rainfall coinciding with higher relief. Long-term inter-annual trends assessed by Coles indicate rainfall variation falls into two patterns; low rainfall (drought-dominated regime) and high rainfall (flood-dominated regime). Historically it was found that 1880s-1900 was a flood-dominated regime, 1901-1946 was a drought-dominated regime and 1947-present a flood-dominated regime. These varying regimes have implications for the behaviour of fluvial environments which in turn affect the estuarine environment.

The period between rainfall events, or dry periods, is also important for a number of processes, both in the catchment and the estuary (e.g. build-up of pollutants on catchment surfaces and development/breakdown of stratification in the estuary). The average duration of the periods between rainfall events of a certain magnitude is shown in Table 5.1. These values were obtained by analysing 45 years of daily rainfall data from the Bureau of Meteorology Station at West Pennant Hills. Statistical data from this analysis is also shown in Figure 5.2. Seasonal statistics are given in Appendix A.

Statistics derived from these data indicate that, on average, rainfall occurs every two to three days. However significant rainfall, to result in runoff, occurs less often and is of the order of 30-50 days. Large flushing events, such as rainfall events over 100 mm, can often be of the order of years apart. These values vary when considered on a seasonal basis, however it is apparent, on average, that autumn and then spring will have longer periods in between rainfall events for medium sized rainfall events (20-30 mm).

This analysis has implications for the flushing of the estuary and it is further discussed in Section 7.7.

Table 5.1 Statistics on Duration of Dry Periods (Days)

Rain (mm)	Average	Standard Deviation	Min.	Max.	10 percentile	50 percentile	90 percentile	Data Points
0	2.87	4.28	1	122	1	1	7	5628
10	16.56	23.11	1	196	1	7	45	968
20	33.67	46.31	1	324	1	14	96	473
30	54.32	69.52	1	366	1	27	155.6	292
50	129.80	150.09	1	583	1	67	350.4	119
75	316.27	421.26	1	1938	2.8	283.4	628.2	45
100	565.71	715.99	1	3109	24.3	398.5	925.3	24

5.2 Southern Oscillation Index and Drought

The Southern Oscillation Index 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 periods of drought have implications for the reduced flushing of the estuary as well as for the geomorphology of the drainage paths. Reduced rainfall results in reduced flows to the estuary and natural reduction of the flow channels. Return of higher rainfalls after a drought results in erosion of channels and delivery of sediment to the estuary.

Figure 5.3 shows the SOI for the period 1876 to 1997 (BoM 1997). High negative values of the SOI have been observed in 1905, 1914, 1940, 1977, 1982 and 1991. Moderate negative values of the SOI have been observed in 1911, 1919, 1925, 1946, 1953, 1957, 1965, 1969, 1972, 1987 and 1993, indicating the long-term recurrence of drought as well as the recent drought of the late 1980s-early 1990s.

5.3 Temperature and Humidity

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.

Average daily temperatures for the region range as follows: summer 16.6-26.7°C; autumn from 9.9-25.3°C; winter 7.6-18.9°C and spring 9.6-24.1°C (National Climate Centre 1991).

Average monthly humidity is tabulated in Table 5.2 (after Bureau of Meteorology 1975).

Table 5.2 Relative Humidity % (Sydney)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
9 a.m.	67	70	72	70	70	74	69	66	62	62	60	63
3 p.m.	63	64	62	58	54	57	50	51	51	56	57	61

5.4 Wind Speed and Direction

Wind speed and direction data is required for the assessment of mixing in the estuary (See Section 7.7).

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), 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 5.4.

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.

5.5 Solar Radiation

Solar radiation data is important in the assessment of heat flux variations within the creek 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 Berowra Creek area on average experiences 114 days per year of cloud cover more than 6/8ths of the sky.

5.6 Evaporation

Evaporation data is also required for the assessment of heat flux variations in the creek as well as the assessment of 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 (Chapman and Murphy 1989).

Table 5.3 Monthly Mean Pan Evaporation at Sydney

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

5.7 Summary of Climatic Processes

Climatic changes and weather-driven processes contribute greatly to the nature of the Berowra Creek ecosystem and hence weather and climate variability is important to the interpretation of natural versus anthropogenic changes in ecosystem variables.

Weather and climate impact upon hydrodynamic processes, geological and geomorphological processes and ecological processes occurring in the estuary and are important in determining the forcing factors driving much of the estuarine processes.

General trends are summarised below.

Rainfall

- mean annual rainfall ranges from 900 mm in the west of the catchment to 1,400 mm on the higher slopes;
- the duration between rainfall events is seasonal with autumn typically the season with the longest dry spells;
- long-term indicators such as the Southern Oscillation Index show that the drought/wet year cycle is erratic.

Temperature and Humidity

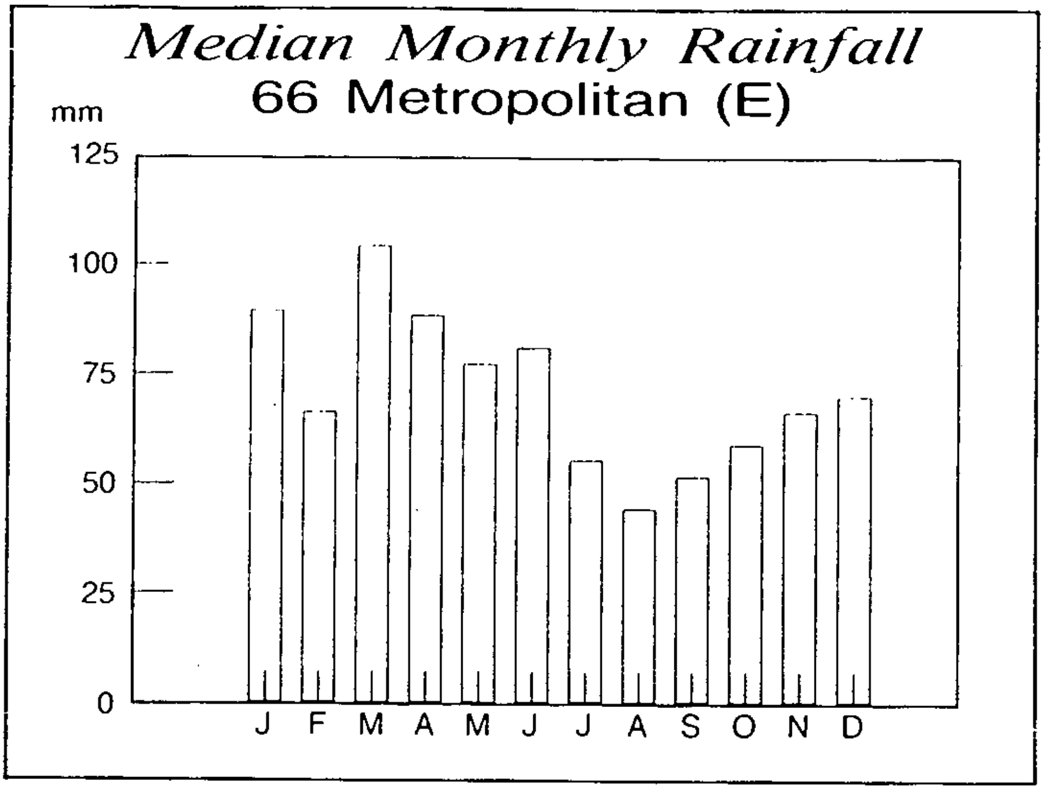
- average temperature ranges from 7.6-26.7°C;
- average relative humidity ranges from 50-74%.

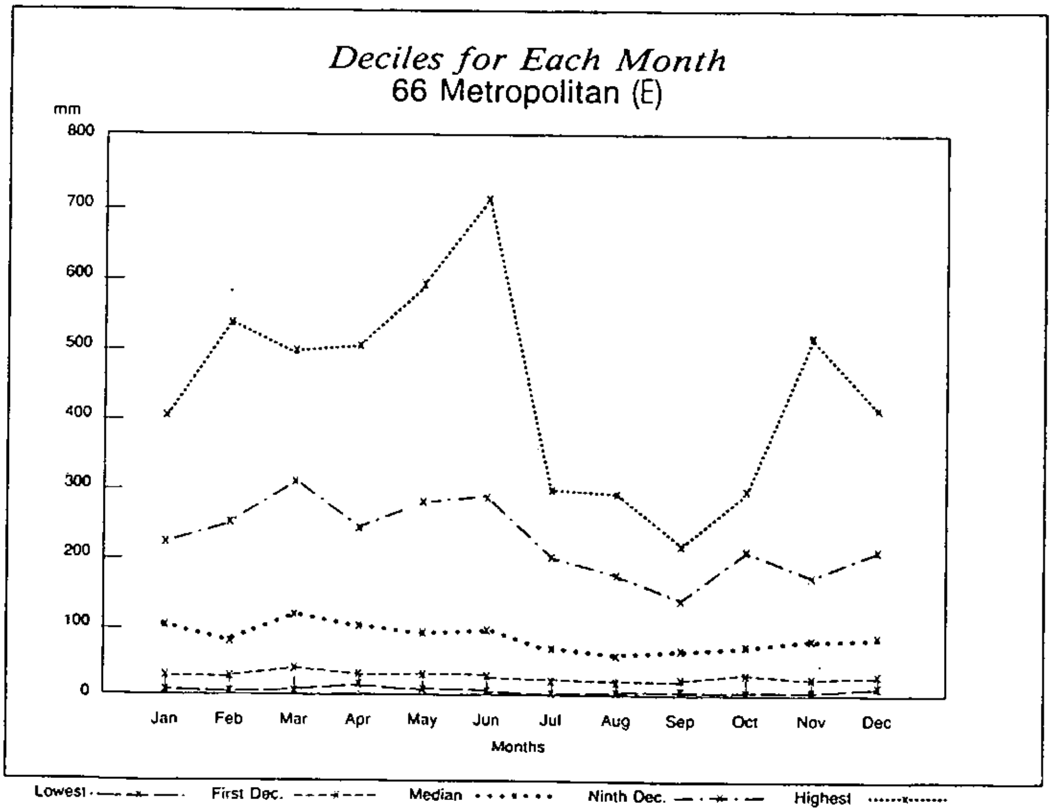
Wind Speed and Direction

- 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.

Solar Radiation and Evaporation

- solar radiation and evaporation are typical of temperate climate areas (high values in summer and lower values in winter, 0-1,000 W/m^2 and 85-252 mm respectively) however the steep nature of the catchment means that the water surfaces may only be partially exposed to the intensities recorded at meteorological stations .





Source: Lee and Gaffney (1986)

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RAINFALL TRENDS FOR THE REGION

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Figure 5.1

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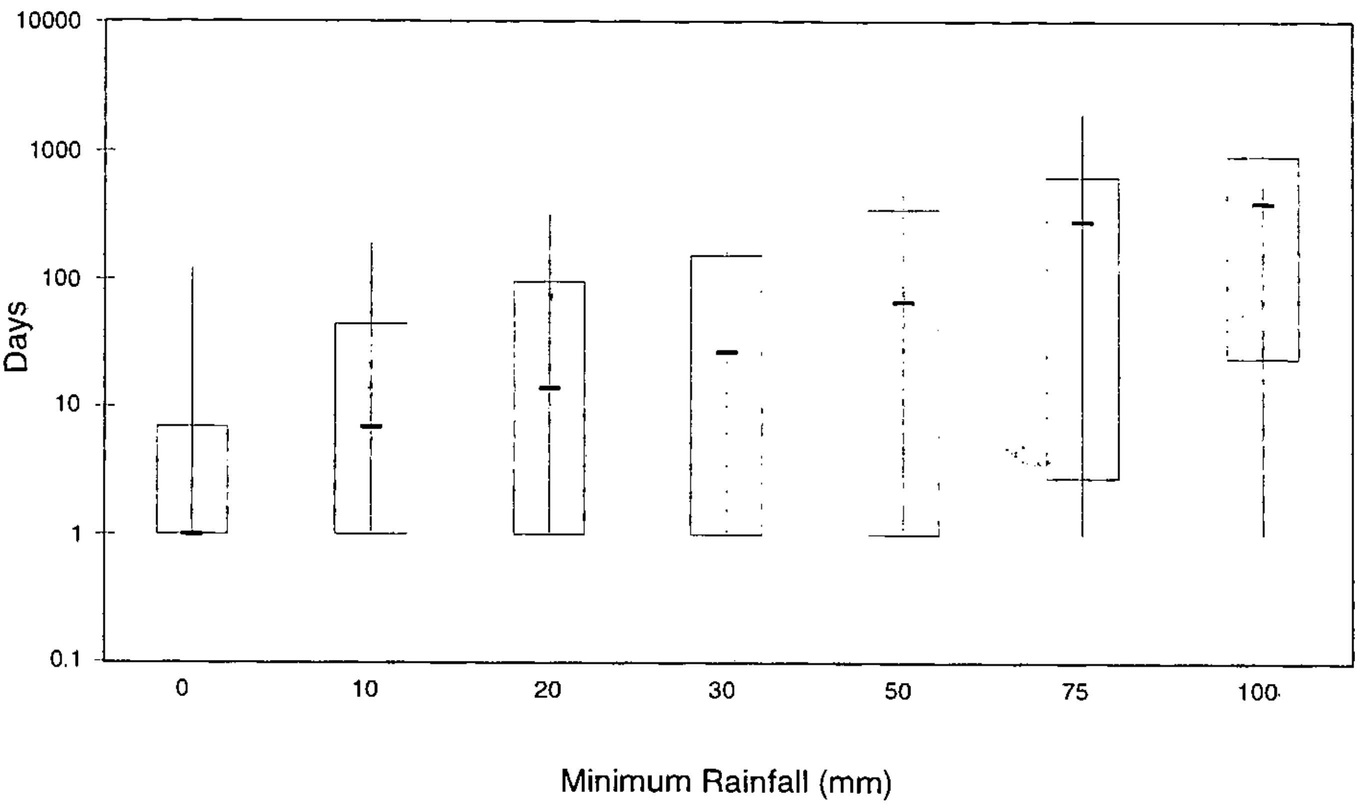

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DRY PERIOD ANALYSIS

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Figure 5.2

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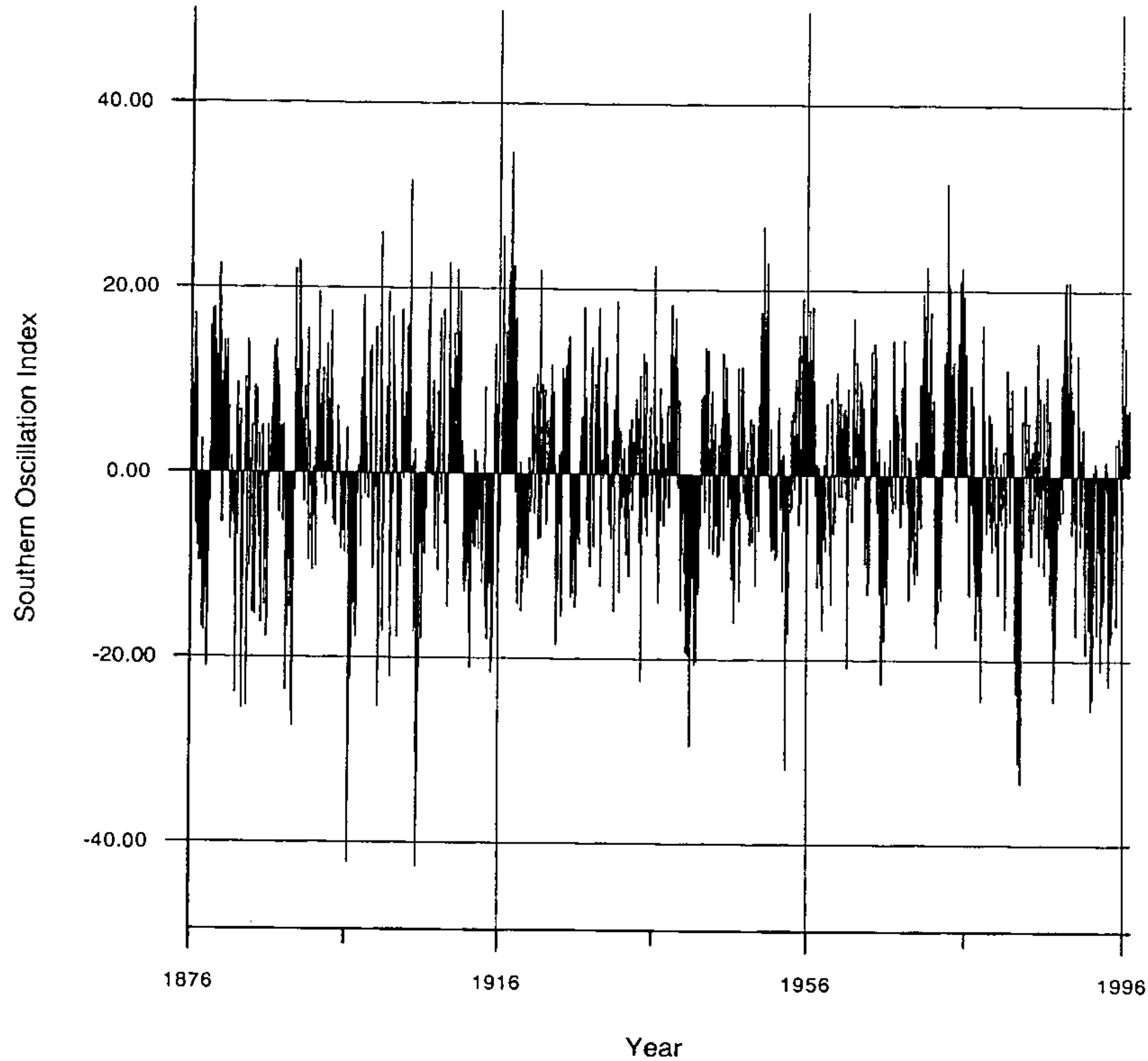

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SOUTHERN OSCILLATION INDEX 1876-1996

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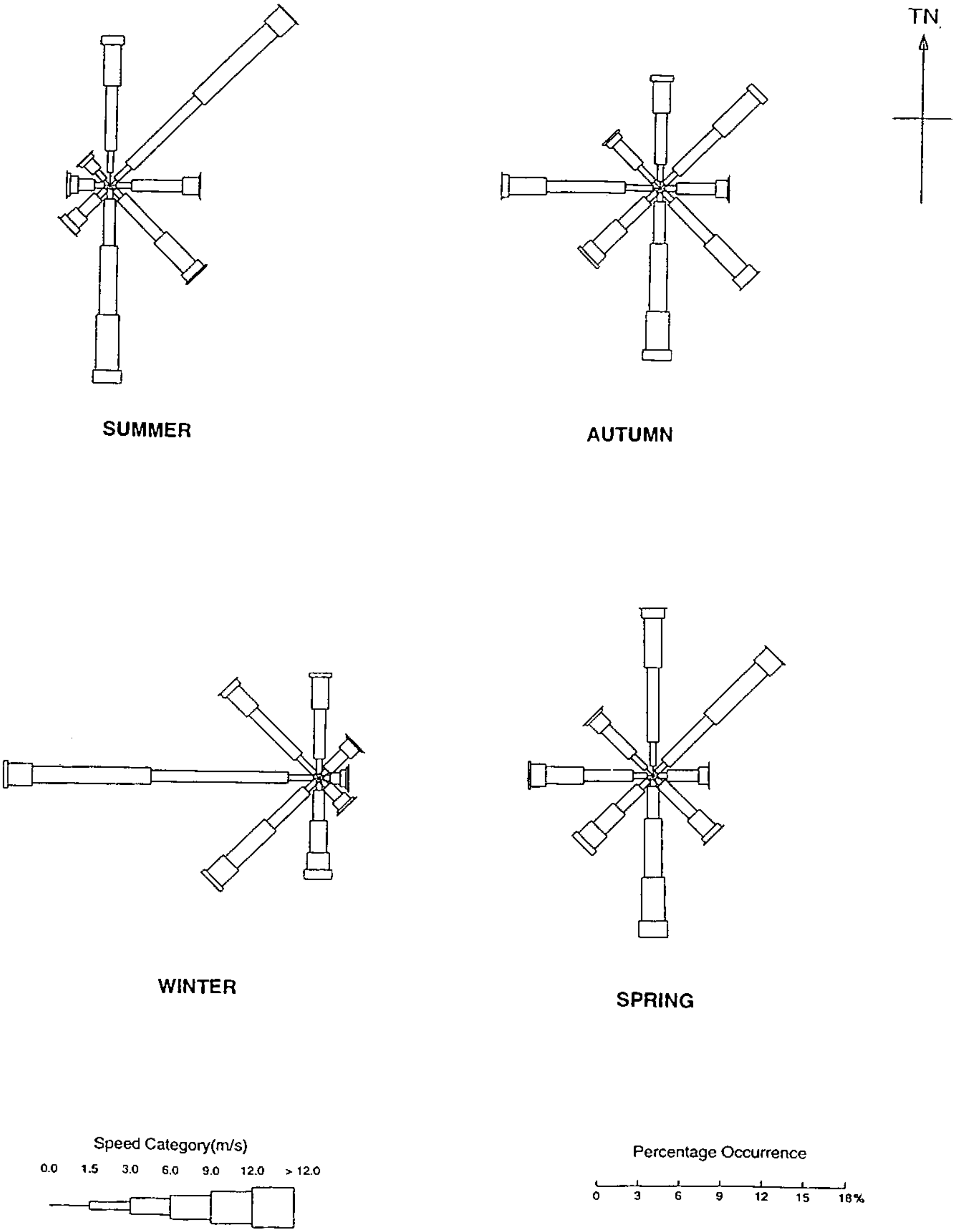
Figure 5.3



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SEASONAL WIND ROSES FROM ORS

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Figure 5.4

DRAWING 85SBER54.DRW

6. Geology and Geomorphology

6.1 Introduction

A review of the available geological and geomorphological data for the study area (Berowra Creek and Marramarra Creek catchments) has highlighted a considerable amount of information relevant to the Berowra Creek Estuary Processes Study. The information occurs in a variety of published and unpublished formats with much of the baseline data (topography, geology, soils, land use, land capability etc.) available in digital format from various Government departments and Hornsby Shire Council (Ambler and Hudson 1990, Breen et al 1986, Chapman and Murphy 1995, Coles 1995; Conroy et al 1986, Gowlland and Loxton 1872, Hornsby Shire 1995a, Hornsby 1996, Mann et al 1996, Parmeter and Graham 1995, Public Works Department 1987, Shotter 1994, Wallace 1974, Williams and Watford 1997). Most of this digital data has been consolidated within the GIS prepared by MHL for the estuary processes study (ARCVIEW). This review provides a brief outline of the available data, results of studies relevant to the geology and geomorphology of the study area, and concludes with a section on the direction of geological/geomorphological investigations in view of the data collected to date.

6.2 Geological Setting

The geology of the study area is summarised in the Sydney 1:100,000 scale map sheet and accompanying notes prepared by the NSW Department of Mineral Resources. A minor portion of the Marramarra Creek catchment occurs to the north of this sheet. The Quaternary geology is summarised in the Cowan and Hornsby/Mona Vale 1:25,000 scale Acid Sulphate Risk maps prepared by the Soil Conservation Service of NSW (Herbert et al 1983).

The geology of the study area is dominated by early to mid-Triassic sub-horizontally bedded sediments of the Sydney Basin. The Hawkesbury Sandstone is widespread and forms a dissected plateau characterised by deep gorges, incised drainage lines, and prominent sandstone escarpments throughout much of the area. Towards the southern part of the Berowra and Marramarra catchments, shales of the Wianamatta (Ashfield Shale) group overlie the Hawkesbury Sandstone and occupy ridgelines between Cherrybrook, Glenorie and Fiddletown. Sandstones, shales, and claystones of the Narrabeen Group (Garie Formation) crop out below the Hawkesbury Sandstone escarpment in the lower reaches of the Berowra Creek and Marramarra Creek catchments. Isolated basaltic intrusions (volcanic breccia and dykes) occur in both catchments.

The Quaternary geology (unconsolidated to semi-consolidated sediments) is comprised of a series of fluvial and estuarine deposits (fluvio-deltaic and tidal flat sediments) which have accumulated within the deeply incised bedrock valleys. Significant deposits of late Quaternary sediments of presumed mid to late Holocene age (less than 6,500 years old) are encountered in Marramarra Creek, Kulkah Bay, Coba Bay, Peats Bight, Kimmerikong Bay, Joe Crafts Bay, Calabash Bay, and along the margins of Berowra Creek upstream of the Woolwash. Today, many of these deposits are colonised by mangrove and/or saltmarsh deposits (Herbert et al 1983, Williams and Watford 1997).

Quantification of the volumes of late Quaternary sediments (plan area multiplied by assumed thickness) will provide the basis for establishing time-averaged (over past 6,500 years) rates of sediment supply to the estuary. While this data is an approximation of actual sediment volumes, it will facilitate comparisons between sub-catchments in terms of rates of sediment supply as influenced by other catchment characteristics (i.e. topography, geology, soil type, catchment disturbance etc.).

6.3 Geomorphology

The geomorphology of the study area is typical of that encountered in the northern Sydney region; extensive sandstone plateaus dissected by ancient river courses have evolved over periods of millions to tens of millions of years in a stable tectonic setting characterised by very low rates of terrestrial denudation. The ancient landscape has been inundated several times over the late Quaternary (last 300,000 years) by rising global sea levels, the most recent rise associated with the postglacial marine transgression some 18,000 to 6,500 years ago. The marine transgression drowned the bedrock valleys of the lower Hawkesbury, creating an extensive estuarine basin that has progressively infilled with coarse and fine grained fluvial sediments over the past 6,500 years (Hudson 1997, Roy 1994).

Today, Berowra and Marramarra creeks are typical of partially infilled drowned river valley-type estuaries. River deposits comprised of coarse grained quartzose sediments derived from the predominantly sandstone catchments have accumulated in the upper sections of the estuaries as fluvio-deltaic deposits characterised by narrow elevated floodplains, emergent sandy shoals, and shallow water depths. River sands have migrated slowly downstream over a period of thousands of years, partially infilling the relatively deep estuarine mud basin. Fine grained fluvial sediments (muds) from both the Berowra and Hawkesbury catchments continue to infill the deeper sections (mud basin) of the estuary downstream of the Woolwash. Actual rates of coarse and fine grained sedimentation within the estuary are unknown (Roy 1973, Wallace 1974, Ambler and Hudson 1990).

Mangrove and saltmarsh communities have colonised the margins of Berowra and Marramarra creeks and their tributaries as sections of the estuary have shoaled through the continued accumulation of fine and coarse grained sediments. Comparisons of historical aerial photography suggest that there has been a 30% increase in mangrove area within the study area between 1941 and 1992. The areas of greatest mangrove expansion occur near the confluence of the Marramarra and Berowra creeks with the Hawkesbury River (Williams and Watford 1997, Saintlin 1995).

6.4 Soils

Soils of the study area are summarised in the Sydney and Gosford/Lake Macquarie 1:100,000 scale soils landscape sheets prepared by the Soil Conservation Service of NSW (Chapman and Murphy 1989, Parmeter and Graham 1995, Murphy 1992). A soil landscape refers to a distinct assemblage of topography and soils which can be described and mapped. Major soil landscapes occurring in the study area include the Hawkesbury, Lucas Heights, Glenorie, Oxford Falls and Gymea units. Considerations of soils type, dispersability and topographic position determine the suitability or otherwise of the various landscapes for rural or urban purposes (see Table 1, Hornsby Shire Council, 1995a). Soil units within the catchment are shown in Figure 6.1.

In general, all soil types are susceptible to erosion due to catchment modifications associated with urban development, agriculture and bushfires. Calculated rates of sediment erosion of up to 109 t/ha (topsoil) and 394 t/ha (subsoil) are estimated for the Hawkesbury soil landscape (Atkinson 1984, Blong et al 1982, Hornsby Shire 1995a and 1996a, Parmeter and Graham 1995, Paton et al 1995).

Estimated rates of soil erosion from urban, rural and natural catchments within the study area indicate that developing urban areas represent the greatest risk in terms of potential sediment delivery (coarse and fine grained sediments) to drainage lines. It is anticipated that catchments that have experienced substantial urban development will have contributed relatively high volumes of sediment to drainage lines, and ultimately, the estuary. This conclusion appears to be over-simplistic given the potential impact natural factors such as bushfire frequency and climatically induced changes in rainfall patterns and river flow regimes may have on erosion rates and sediment delivery. Estimated rates of soil erosion are likely to show considerable spatial and temporal variability and have value in assessing the relative rates of erosion rather than absolute volumes of sediment delivered into the estuary (Parmeter and Graham 1995, Shotter 1994, Coles 1995).

6.5 Bathymetry

A detailed survey of Berowra Creek and its tributaries was conducted by the NSW Department of Land and Water Conservation in August 1995. The survey covered Berowra and Marramarra creeks, and their tributaries, to the navigable limit. Survey data were reduced to a common datum (Australian Height Datum ≈ Mean Sea Level) and plotted at 1 m contour intervals (Figures 6.2a and 6.2b).

The 1995 survey identified a number of bathymetric features (shoals, scour holes, tributary deltas etc.) which occur within an estuarine basin which is at its shallowest near the confluence of Berowra Creek and the Hawkesbury River (water depths around 2 m) and upstream of the Woolwash (water depths less than 1 m). Greatest water depths occur within the central portion of Berowra Creek between Dusthole Bay and Coba Point where water depths reach up to 18 m in isolated depressions.

Prior to the 1995 survey, there had been two systematic hydrographic surveys completed in Berowra Creek; one in 1984 by the NSW Public Works Department and one in 1872 by the Royal Australian Navy (Gowlland and Loxton 1872, Myles 1984). The 1984 survey consisted of a series of 28 cross-sections between Bar Island and the Woolwash. The 1872 survey covered the lower Hawkesbury and Berowra Creek as far upstream as Calabash Point. While additional historical survey data is being sought, it appears that the 1872 and 1984 surveys will provide the best comparisons with the 1995 survey for the purpose of determining historic bathymetric changes.

A preliminary comparison of the 1872 and 1995 surveys suggest that some areas of the estuary have shoaled while others appear to have changed little over the intervening 124 years. A systematic comparison of all historical survey data with the 1995 survey is currently being undertaken. The results of these analyses will be important in establishing historical patterns of sedimentation within the study area.

6.6 Estuarine and Fluvial Sediments

Available sediment data has been entered into the MHL GIS. These data include sediment samples collected by the University of Sydney, NSW Geological Survey, Hornsby Shire Council and other organisations examining extractive resources and sediment contaminants within the study area. Typical information recorded includes sediment location, water depth, date collected, type of sediment, grainsize distribution, results of chemical analyses etc. Sediment data can be displayed in a variety of tabular and map formats for display or analytical purposes.

Preparation of a preliminary surficial sediment map has identified areas of coarse (fluvial delta: gravelly quartz sands) and fine (mud basin: muds) grained fluvial sedimentation within the estuary. The results are broadly consistent with previous work that has highlighted the accumulation of coarse grained fluvial sediments upstream of the Woolwash, near the confluence of Berowra Creek and the Hawkesbury River, and at the entrances to a number of the major tributaries draining into Berowra Creek. Fine grained fluvial muds are accumulating within the deeper sections of the estuary (Ambler and Hudson 1990, Coles 1995, Hudson 1997, Mann et al 1996, NSW Public Works Department 1987, Roy 1973, Shotter 1994, Wallace 1974).

Better resolution of the surficial sediment types is necessary to establish bathymetric/ sedimentological associations within the estuary and determinations of the volumes of coarse and fine grained sediment accumulating within the system over historic and geologic time frames. This data is also relevant to geochemical studies which have demonstrated the strong correlation between sediment grainsize and sediment toxicity. A surface sediment sampling program is planned for early May to complete the mapping of surface sediment types within the study area.

There is very little reliable subsurface sediment data for fluvial and estuarine deposits (Ambler and Hudson 1990, Wallace 1974). The available information is concentrated primarily within fluvial deposits collected as part of sand resource studies upstream of the Woolwash. These data show the fluvial sand deposits to be in excess of three metres thick and to be comprised of medium to coarse grained quartz sand with variable amounts of charcoal, wood fragments, mud, and minor shell fragments. Core samples of the estuarine and fluvial sediments are necessary to establish long-term rates of sedimentation, to clarify the continuity at depth of surficial sediments, and to assess background levels of sediment contamination.

6.7 Summary

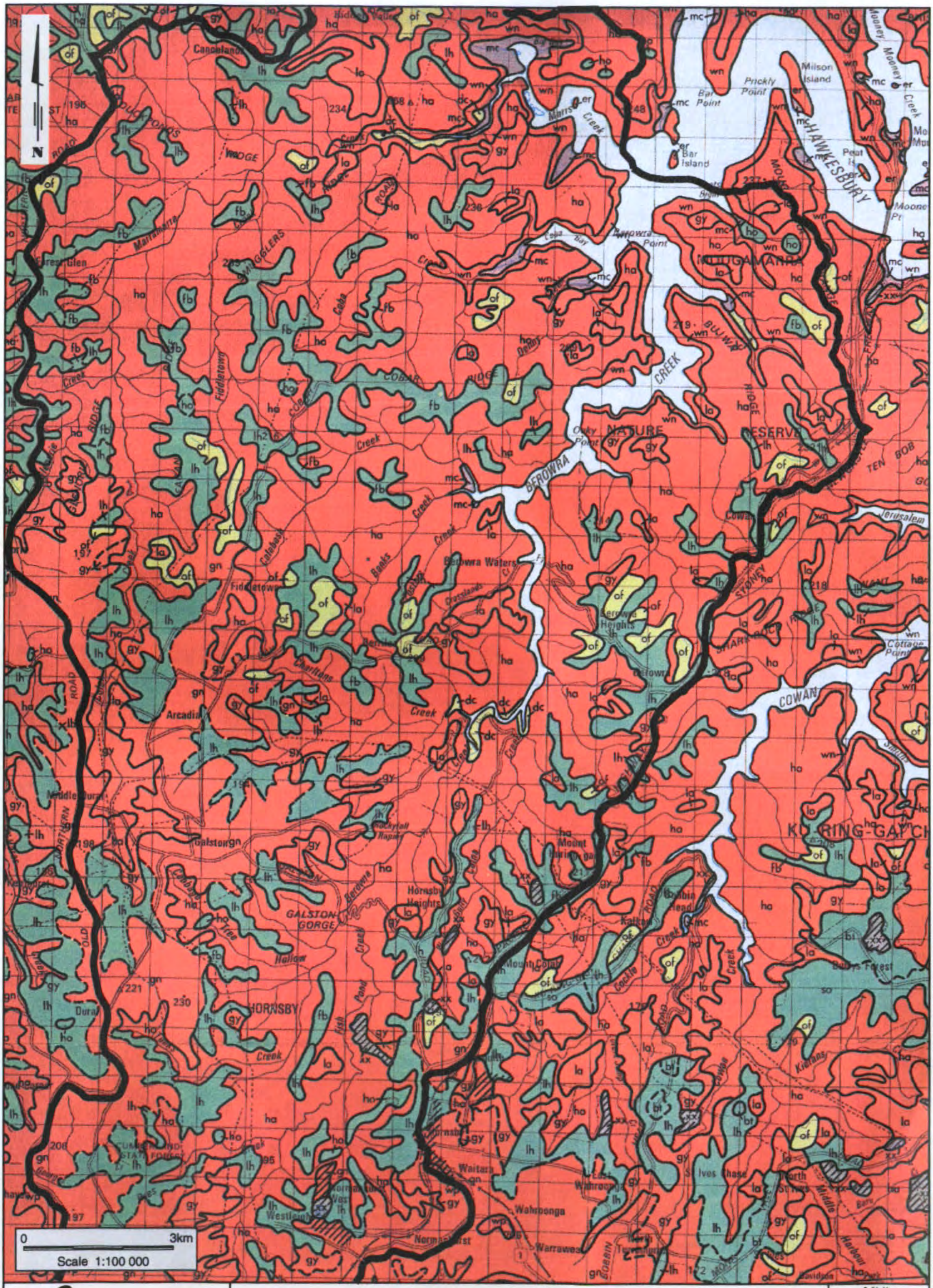
Berowra Creek is a typical drowned river valley estuary formed some 6,500 years ago at the end of the postglacial marine transgression. From this time up until the present the estuary has partially infilled with coarse and fine grained fluvial sediments. Coarse grained sediments (gravelly quartz sands) have accumulated in fluvial deltaic deposits in the main Berowra and Marramarra creeks channels and a number of their smaller tributaries. Water depths in the vicinity of these deltaic deposits are commonly less than 1 m. Fine grained sediments (muds) have accumulated in the deeper (underfilled) sections of the estuary where water depths reach a maximum of 18 m. There is some evidence (sediment mineralogy, bathymetric features, historical changes in mangrove areas) to suggest that fine grained fluvial sediments from the Hawkesbury River are deposited in the lower reaches of Berowra Creek, particularly during floods.

Considerable baseline data is available to characterise the natural variability of catchments within the study area. Calculations of long-term sedimentation rates based on estimates of late Quaternary sediment volumes and historic bathymetric changes provide an opportunity to assess the impact catchment modifications have had on rates of sediment supply to the estuary.

Quantification of sedimentation rates based on indirect methods requires the collection of undisturbed core samples for the purpose of characterising subsurface sediments and obtaining material for radiometric dating. No radiometric dates are available for sedimentary deposits in the study area; this type of data is fundamental to establishing rates and volumes of estuarine sedimentation.

Ongoing geological investigations aimed at developing a conceptual model of estuarine sedimentation for the study area will rely on the integration of the available data and collection of new information on the estuarine deposits (surface and subsurface samples). The results of these investigations will become available to the rest of the project team and will have particular significance for issues of contaminated sediment dispersal, potential sediment-water interactions, and dredging.

Results of geological investigations within Berowra Creek will be relevant to other drowned river valley estuarine systems within the Hornsby Shire and adjacent local government areas.



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SOILS

MHL Report 855

Figure 6.1

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SOIL LANDSCAPE GROUPINGS

RESIDUAL

fb

FAULCONBRIDGE (15 km²)

Landscape - level to gently undulating crests and ridges on plateau surfaces of the Hawkesbury Sandstone. Local relief <20 m, slopes <5%. Infrequent rock outcrop. Partially cleared woodland.

Soils - shallow (<50 cm) *Earthy Sands (Uc4.21, Uc5.22)* and *Yellow Earths (Gn1.21, Gn2.21, Gn2.24)*, some *Siliceous Sands/Lithosols (Uc1.2)* associated with rock outcrop.

Limitations - shallow, highly permeable soil, rock outcrop, very low soil fertility.

so

SOMERSBY (14 km²)

Landscape - gently undulating to rolling rises on deeply weathered Hawkesbury Sandstone plateau. Local relief to 40 m, slopes <15%. Rock outcrop is absent. Crests are broad and convex, valleys are narrow and concave. Extensively cleared, low open-woodland and scrubland.

Soils - moderately deep to deep (100-300 cm) *Red Earths (Gn2.14)* and *Yellow Earths (Gn2.24, Gn2.23)* overlying laterite gravels and clays on crests and upper slopes; *Yellow Earths (Gn2.21, Gn2.24)* and *Earthy Sands (Uc5.11, Uc5.22)* on mid slopes; *Grey Earths (Gn2.81)*, *Leached Sands (Uc2.23)* and *Siliceous Sands (Uc1.22)* on lower slopes and drainage lines; *Gleyed Podzolic Soils (Dg3.82, Dg4.51)* in low lying poorly drained areas.

Limitations - localised permanently high water tables, areas of laterite and stony soil, very low soil fertility, highly permeable soil.

lh

LUCAS HEIGHTS (123 km²)

Landscape - gently undulating crests and ridges on plateau surfaces of the Mittagong Formation (alternating bands of shale and fine-grained sandstones). Local relief to 30 m, slopes <10%. Rock outcrop is absent. Extensively or completely cleared, low open-forest and woodland.

Soils - moderately deep (50-150 cm), hardsetting *Yellow Podzolic* and *Yellow Soloth Soils (Dy2.41)*; *Yellow Earths (Gn2.24)* on outer edges of crests.

Limitations - stony soil, low soil fertility, low available water capacity.

bt

BLACKTOWN (160 km²)

Landscape - gently undulating rises on Wianamatta Group shales and Hawkesbury shale. Local relief to 30 m, slopes are usually <5%. Broad rounded crests and ridges with gently inclined slopes. Cleared woodland and tall open-forest.

Soils - shallow to moderately deep (<100 cm) *Red* and *Brown Podzolic Soils (Dr3.21, Dr3.11, Db2.11)* on crests, upper slopes and well drained areas; deep (100-300 cm) *Yellow Podzolic Soils* and *Soloths (Dy2.11, Dy3.11)* on lower slopes and in areas of poor drainage.

Limitations - moderately reactive highly plastic subsoil, low soil fertility, poor soil drainage.

hn

HORNSBY (2 km²)

Landscape - gently undulating rises to steep low hills on deeply weathered basaltic breccia. Local relief to 70 m, slopes range from 3% to 65%. Diatremes (volcanic necks) and shallow intrusions often located in sandstone valley floors. Mostly cleared, tall open-forest and weed infested closed-forest.

Soils - deep (150-300 cm) *Yellow Podzolic Soils (Dy4.11)* on upper and midslopes; *Yellow-Brown Earths (Gn2.41)* and *Red Podzolic Soils (Dr4.11)* on sandstone colluvium; *Yellow Podzolic Soils (Dy2.21)* on volcanic breccia; deep (>200 cm) *Structured Loams (Um6.21)* in drainage lines. Associated soils include *Prairie Soils (Gn3.91, Gn4.31)*, deep *Krasnozems (Gn3.11)* and *Chocolate Soils (Db1.11, Db4.11)*.

Limitations - highly plastic, low wet-strength, highly reactive subsoil, occasional steep slopes with an extreme soil erosion hazard and localised mass movement hazard.

COLLUVIAL

wn

WATAGAN (67 km²)

Landscape - rolling to very steep hills on fine-grained Narrabeen Group sediments. Local relief 60-120 m, slopes >25%. Narrow convex crests and ridges, steep colluvial side slopes, occasional sandstone boulders and benches. Tall open-forest with closed-forest in sheltered positions.

Soils - shallow to deep (30-200 cm) *Lithosols/Siliceous Sands (Uc1.24)* and *Yellow Podzolic Soils (Dy3.21, Dy3.41, Dy4.11)* on sandstones; moderately deep (100-300 cm) *Brown Podzolic Soils (Db1.11)*, *Red Podzolic Soils (Dr2.21)* and *Gleyed Podzolic Soils (Dg2.21)* on shales.

Limitations - mass movement hazard, steep slopes, severe soil erosion hazard, occasional rock outcrop.

ha

HAWKESBURY (381 km²)

Landscape - rugged, rolling to very steep hills on Hawkesbury Sandstone. Local relief 40-200 m, slopes >25%. Rock outcrop >50%. Narrow crests and ridges, narrow incised valleys, steep sideslopes with rocky benches, broken scarps and boulders. Mostly uncleared open-woodland and tall open-forest.

Soils - shallow (<50 cm), discontinuous *Lithosols/Siliceous Sands (Uc1.21)* associated with rock outcrop; *Earthy Sands (Uc5.11, Uc5.23)*, *Yellow Earths (Gn2.24)* and some *Yellow Podzolic Soils (Dy4.11)* on inside of benches and along joints and fractures; localised *Yellow and Red Podzolic Soils (Dy4.11, Dy5.21, Dr5.21)* associated with shale lenses; *Siliceous Sands (Uc1.2)* and secondary *Yellow Earths (Gn2.41)* along drainage lines.

Limitations - extreme soil erosion hazard, mass movement (rock fall) hazard, steep slopes, rock outcrop, shallow, stony, highly permeable soils, low soil fertility.

wp

WEST PENNANT HILLS (5 km²)

Landscape - rolling to steep sideslopes on Wianamatta Group shales and shale colluvium. Local relief 40-100 m, slopes >20%. Partially cleared, tall open-forest.

Soils - deep (>200 cm) *Red and Brown Podzolic Soils (Dr2.11, Dn3.11, Db1.11)* on upper and midslopes; *Yellow and Brown Podzolic Soils (Dy4.11, Dy5.11, Db1.11)* on colluvial benches; *Yellow Podzolic Soils (Dy3.11)* and *Gleyed Podzolic Soils (Dg4.11)* in drainage lines and poorly drained areas.

Limitations - mass movement hazard, steep slopes, high soil erosion hazard, localised seasonal waterlogging, impermeable plastic shrink-swell subsoil.

FLUVIAL

dc

DEEP CREEK (6 km²)

Landscape - level to gently undulating alluvial floodplain draining the Hawkesbury Sandstone. Local relief <5 m, slopes <3%. Depositional floors of steeply dissected valleys of the Hornsby Plateau. Partially cleared tall open-woodland and weed infested tall open-forest and closed-forest.

Soils - deep (>200 cm) *Podzols (Uc2.2, Uc2.3)* on well drained terraces, *Siliceous Sands (Uc1.2, Uc1.4)* on current floodplain and *Humus Podzols (Uc2.2)* in low lying areas.

Limitations - flooding, extreme soil erosion hazard, sedimentation hazard, localised very low fertility and permanently high water tables.

of

OXFORD FALLS (24 km²)

Landscape - hanging valleys on Hawkesbury Sandstone. Local relief to <80 m, slopes <15%. Occasional broad benches and broken scarps, valley floors are relatively wide, gently inclined and often poorly drained. Low open-woodland, scrub, heathland and sedgeland.

Soils - moderately deep to deep (50->150 cm) *Earthy Sands (Uc5.23)*, *Yellow Earths (Gn2.84, Gn2.94)*, *Siliceous Sands (Uc1.21)* on slopes, deep (>200 cm) *Leached Sands (Uc2.12)*, *Podzols (Uc2.32, Uc2.36)* and *Grey Earths (Gn2.81)* on valley floors.

Limitations - very high soil erosion hazard, perched water tables and swamps, highly permeable soil, very low to low soil fertility, localised rock outcrop.

bg

BIRRONG (23 km²)

Landscape - level to gently undulating alluvial floodplain draining Wianamatta Group shales. Local relief to 5 m, slopes <3%. Broad valley flats. Extensively cleared tall open-forest and woodland.

Soils - deep (>250 cm) *Yellow Podzolic Soils (Dy2.42, Dy3.12)* and *Yellow Solodic Soils (Dy3.42)* on older alluvial (terraces); deep (>250 cm) *Solodic Soils (Dy3.42)* and *Yellow Solonetzic Soils (Dy3.43)* on current floodplain.

Limitations - localised flooding, high soil erosion hazard, saline subsoils, seasonal waterlogging, very low soil fertility.

lc

LANE COVE (2 km²)

Landscape - level to gently undulating alluvial floodplain draining both the Wianamatta Group shales and Hawkesbury Sandstone. Local relief <5 m, slopes <5%. Partially cleared tall open-forest with disturbed grass understorey.

Soils - deep (>200 cm) *Alluvial Loams (Um6.23, Um1.43)* and various buried alluvial and marine soils.

Limitations - flooding, high soil erosion hazard, seasonal waterlogging.

AEOLIAN

nh

NORTH HEAD (5 km²)

Landscape - elevated gently undulating dunefields of wind blown sands on coastal headlands. Local relief <5 m, slopes <15%. Heathland and scrub with occasional woodland.

Soils - deep (>200 cm) *Podzols (Uc2.3)* overlying bedrock; buried *Podzols*, buried sandstone soils, occasional shallow (<50 m) *Siliceous Sands (Uc1.21)* and *Yellow Podzolic Soils (Dy5.41, Dy5.81)* on edge of this unit.

Limitations - extreme wind erosion hazard, high water erosion hazard, non-cohesive and highly permeable soil, very low soil fertility.

tg

TUGGERAH (48 km²)

Landscape - gently undulating to rolling coastal dunefields. Local relief to 20 m, slope gradients generally 1-10%, but occasionally up to 35%. North-south oriented dunes with convex narrow crests, moderately inclined slopes and broad gently inclined concave swales. Extensively cleared open forest and woodland.

Soils - deep (>200 cm) *Podzols (Uc2.31, Uc2.32, Uc2.34)* on dunes and *Podzol/Humus Podzol* intergrades *(Uc2.23, Uc2.21, Uc2.3, Uc4.33)* on swales.

Limitations - extreme wind erosion hazard, non-cohesive, highly permeable soil, very low soil fertility, localised flooding and permanently high water tables.

np

NEWPORT (37 km²)

Landscape - gently undulating plains to rolling rises of Holocene sands mantling other soil materials or bedrock. Local relief <10 m, slopes <10% on lower slopes and plateau surfaces and up to 35% against obstacles, facing prevailing winds. Extensively cleared low open-woodland, scrub and open-heathland.

Soils - shallow (<50 cm), well sorted *Siliceous Sands (Uc1.21, Uc4.24, Uc4.31)* overlying moderately deep (<150 cm) buried soils including *Yellow Podzolic Soils (Dy 5.41, Dy 5.51, Dy5.62)* with sandy topsoils on crests and gentle slopes; Deep (>200 cm) *Podzols (Uc2.32)* on steep slopes, lower slopes and in depressions.

Limitations - very high soil erosion hazard, localised steep slopes, very low soil fertility, non-cohesive topsoil.

MARINE

na

NARRABEEN (4 km²)

Landscape - beaches and coastal foredunes on marine sands. Beach plains with relief to 6 m, slopes <3%, foredunes with relief <20 m and slope gradients up to 45%. Spinifex grassland/herbland to closed-scrub on foredunes.

Soils - deep (>200 cm) *Calcareous Sands (Uc1.11, Uc1.12)* on beaches, *Siliceous Sands (Uc1.21, Uc1.22)* and occasional calcareous compressed sands on foredunes.

Limitations - extreme wind and wave erosion hazard, non-cohesive soil, very low soil fertility, high soil permeability.

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SOILS LEGEND

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Figure 6.1a

DRAWING 85561a.CDR

wp — WEST PENNANT HILLS (5 km^2)

Landscape - rolling to steep sideslopes on Wianamatta Group shales and shale colluvium. Local relief 40-100 m, slopes >20%. Partially cleared, tall open-forest.

Soils - deep (>200 cm) *Red and Brown Podzolic Soils (Dr2.11, Dr3.11, Db1.11)* on upper and midslopes; *Yellow and Brown Podzolic Soils (Dy4.11, Dy5.11, Db1.11)* on colluvial benches; *Yellow Podzolic Soils (Dy3.11)* and *Gleyed Podzolic Soils (Dg4.11)* in drainage lines and poorly drained areas.

Limitations - mass movement hazard, steep slopes, high soil erosion hazard, localised seasonal waterlogging, impermeable plastic shrink-swell subsoil.

EROSIONAL

er — ERINA (11 km^2)

Landscape - undulating to rolling rises and low hills on fine-grained sandstones and claystones of the Narrabeen Group. Local relief to 60 m, slopes <20%. Rounded narrow crests with moderately inclined slopes. Extensively cleared tall open-forest with open-heathland in exposed areas.

Soils - moderately deep to deep (100->200 cm) *Yellow Podzolic Soils (Dy3.21)* on sandstone crests and slopes; moderately deep (100-150 cm) *Red Podzolic Soils (Dr2.21)* on shale crests and steeper slopes; deep (>200 cm) *Yellow Podzolic Soils (Dy3.21)* on shale lower slopes; some deep (>200 cm) *Yellow Earths (Gn2.21)* on footslopes.

Limitations - very high soil erosion hazard, impermeable plastic low wet-strength subsoil, localised run-on, seasonal waterlogging of footslopes.

la — LAMBERT (99 km^2)

Landscape - undulating to rolling low hills on Hawkesbury Sandstone. Local relief 20-120 m, slopes <20%. Rock outcrop >50%. Broad ridges, gently to moderately inclined slopes, wide rock benches with low broken scarps, small hanging valleys and areas of poor drainage. Open and closed-heathland, scrub and occasional low open-woodland.

Soils - shallow (<50 cm), discontinuous *Earthy Sands (Uc5.11, Uc5.22)* and *Yellow Earths (Gn2.2)* on crests and inside of benches; shallow (<20 cm) *Siliceous Sands/Lithosols (Uc1.2)* on leading edges; shallow to moderately deep (<150 cm) *Leached Sands (Uc2.21), Grey Earths (Gn2.81)* and *Gleyed Podzolic Soils (Dg4.21)* in poorly drained areas; localised *Yellow Podzolic Soils (Dy4.1, Dy5.2)* associated with shale lenses.

Limitations - very high soil erosion hazard, rock outcrop, seasonally perched water tables, shallow, highly permeable soil, very low soil fertility.

gy — GYMEA (111 km^2)

Landscape - undulating to rolling rises and low hills on Hawkesbury Sandstone. Local relief 20-80 m, slopes 10-25%. Rock outcrop <25%. Broad convex crests, moderately inclined side slopes with wide benches, localised rock outcrop on low broken scarps. Extensively cleared open-forest and woodland.

Soils - shallow to modeately deep (30-100 cm) *Yellow Earths (Gn2.24)* and *Earthy Sands (Uc5.11, Uc5.23)* on crests and inside of benches; shallow (<20 cm) *Siliceous Sands (Uc1.21)* on leading edges of benches; localised *Gleyed Podzolic Soils (Dg4.21)* and *Yellow Podzolic Soils (Dy4.11, Dy5.11, Dy5.41)* on shale lenses; shallow to moderately deep (<100 cm) *Siliceous Sands (Uc1.2)* and *Leached Sands (Uc2.21)* along drainage lines.

Limitations - localised steep slopes, high soil erosion hazard, rock outcrop, shallow highly permeable soil, very low soil fertility.

gn — GLENORIE (152 km^2)

Landscape - undulating to rolling low hills on Wianamatta Group shales. Local relief 50-80 m, slopes 5-20%. Narrow ridges, hillcrests and valleys. Extensively cleared tall open-forest.

Soils - shallow to moderately deep (<100 cm) *Red Podzolic Soils (Dr2.11)* on crests; moderately deep (70-150 cm) *Red and Brown Podzolic Soils (Dr2.11, Dr2.21, Db1.11, Db1.21)* on upper slopes; deep (>200 cm) *Yellow Podzolic Soils (Dy4.11, Dy5.11)* on lower slopes and *Humic Gleys (Uf6.61), Yellow Podzolic Soils (Dy5.11)* and *Gleyed Podzolic Soils (Dg4.11)* along drainage lines.

Limitations - high soil erosion hazard, localised impermeable highly plastic subsoil, moderately reactive.

MARINE

na — NARRABEEN (4 km^2)

Landscape - beaches and coastal foredunes on marine sands. Beach plains with relief to 6 m, slopes <3%; foredunes with relief <20 m and slope gradients up to 45%. Spinifex grassland/herbland to closed-scrub on foredunes.

Soils - deep (>200 cm) *Calcareous Sands (Uc1.11, Uc1.12)* on beaches, *Siliceous Sands (Uc1.21, Uc1.22)* and occasional calcareous compressed sands on foredunes.

Limitations - extreme wind and wave erosion hazard, non-cohesive soil, very low soil fertility, high soil permeability.

ww — WOY WOY (9 km^2)

Landscape - level to gently undulating non-tidal beach ridges on marine sands. Local relief <3 m, slopes <5%. Water table at a depth of <200 cm. Progressive beach ridges in sheltered bays. Extensively cleared closed-scrub and low woodland.

Soils - deep (>200 cm) *Siliceous Sands (Uc1.22, Uc5.11)* and occasional *Podzols (Uc2.3)* on sandy rises *Humus Podzols (Uc4.2)* in poorly drained areas, *Calcareous Sands (Uc1.11, Uc1.13)* near beaches.

Limitations - permanently high water tables, localised flooding, periodic waterlogging in depressions, very low to low soil fertility, localised areas of high soil erosion hazard.

ESTUARINE

mc — MANGROVE CREEK (7 km^2)

Landscape - level to very gently undulating tidal flats (mudflats, mangrove and saltmarsh) on Quaternary marine sediments. Local relief and elevation <3 m, slope gradients <3%. Regularly inundated by tidal waters. Mangrove open-scrub, saltmarsh herbland, sedgeland and low open-forest.

Soils - deep (>200 cm), waterlogged *Calcareous Sands, Solonchaks (Uc1.11)* and *Siliceous Sands (Uc1.21, Uc5.11)* on mangrove flats, deep (>200 cm) *Calcareous Sands and Solonchaks (Uc1.1)*, some *Siliceous Sands (Uc1.2, Uc5.1)* and *Humic Gley Soils (Dy4.53)* on saltmarsh and forest flats.

Limitations - regular tidal flooding and waterlogging, high acid sulphate potential saline soils, very low soil fertility, organic soil materials.

cb — COCKLE BAY (3 km^2)

Landscape - level to very gently undulating slopes on marine/alluvial sediments. Local relief <10 m, slopes <5%. Water table <200 cm. Predominantly cleared open-woodland and heathland.

Soils - deep (>200 cm) *Podzols (Uc2.2)* and *Yellow Podzolic Soils (Dy5.81)* on upper slopes, deep (>200 cm) *Yellow Podzolic Soils* and *Yellow Soloths (Dy3.81)* on midslopes, deep (>200 cm) *Gleyed Podzolic Soils* and *Grey-Soloths (Dg2.81)* on lower slopes.

Limitations - high water table, seasonally waterlogged soil, very high soil erosion hazard, high run-on, very low soil fertility.

SWAMP

et — ETTALONG (1 km^2)

Landscape - level to very gently undulating coastal swamps. Local relief <5 m, slopes <2%. Water table at <100 cm. Hummocky surface, shallow lakes and very shallow water tables. Closed-sedgeland and tall open-forest.

Soils - deep (>150 cm) *Organic Acid Peats (O), Peaty Podzols (Uc1.23)* and *Humus Podzols (Uc2.12)* often overlying buried *Siliceous Sands*.

Limitations - flooding, permanently high water table, extremely acid organic soil of low fertility.

wa — WARRIEWOOD (12 km^2)

Landscape - level to gently undulating swales, depressions and infilled lagoons on Quaternary sands. Local relief to <10 m, slopes <3%. Water table at <200 cm. Mostly cleared of native vegetation.

Soils - deep (>150 cm), well sorted, sandy *Humus Podzols (Uc2.32)* and dark, mottled *Siliceous Sands (Uc1.21)*, overlying buried *Acid Peats (O)* in depressions; deep (>200 cm) *Podzols (Uc2.12, Uc2.32)* and pale *Siliceous Sands (Uc1.2)* on sandy rises.

Limitations - localised flooding and run-on, high water tables, highly permeable soil.

DISTURBED

DISTURBED TERRAIN (66 km^2)

Landscape - level plain to hummocky terrain, extensively disturbed by human activity, including complete disturbance, removal or burial of soil. Local relief <10 m, slopes <30%. Land fill includes soil, rock, building and waste materials. Original vegetation completely cleared, replaced with turf or grassland.

Soil - turfed fill areas commonly capped with up to 40 cm of sandy loam or up to 60 cm of compacted clay over fill or waste materials.

Limitations - dependent on nature of fill material. Mass movement hazard, unconsolidated low wet-strength materials, impermeable soil, poor drainage, localised very low fertility and toxic materials.

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SOILS LEGEND

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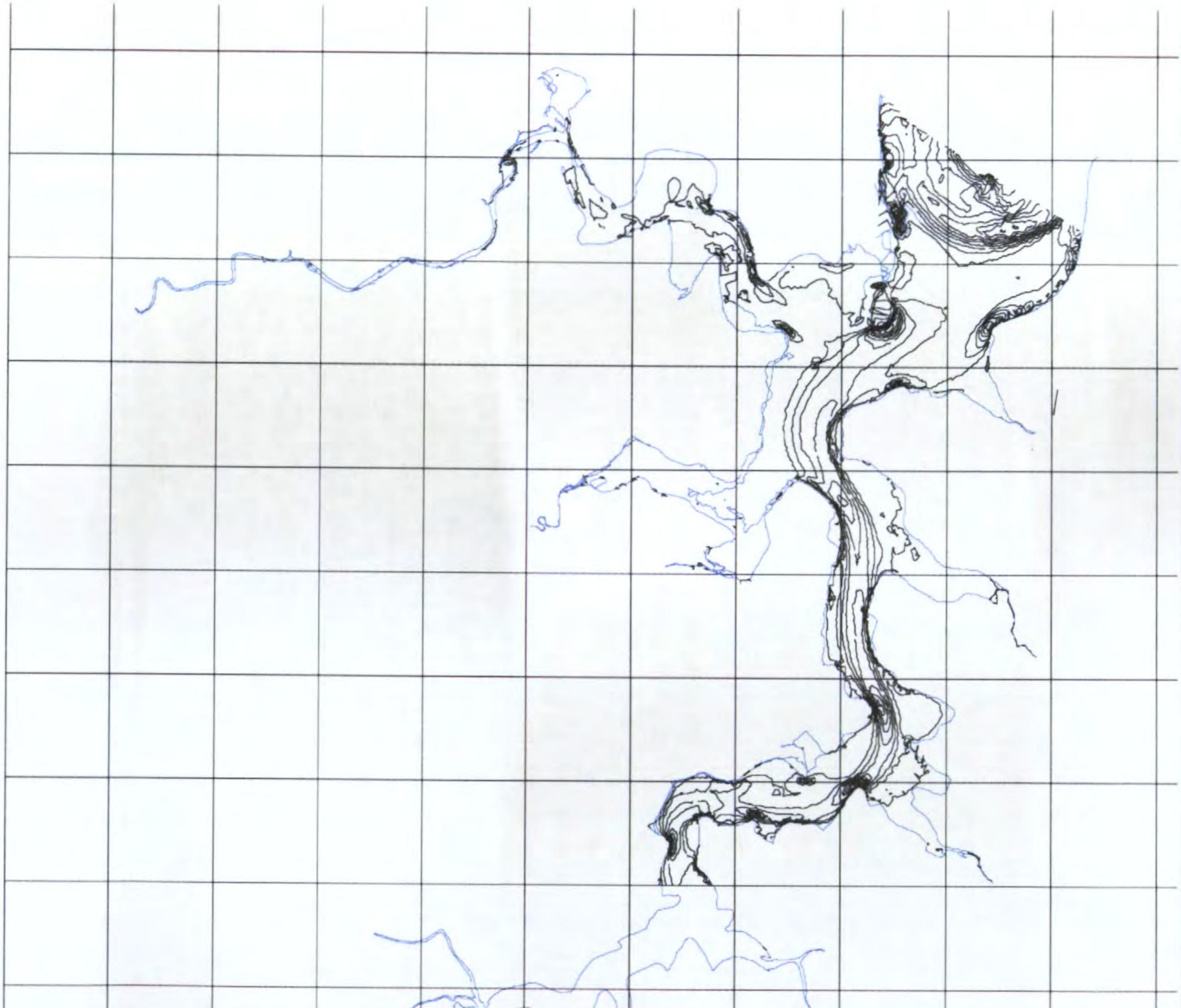
Figure 6.1b

DRAWING 85561B.CDR



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BATHYMETRY - NORTH

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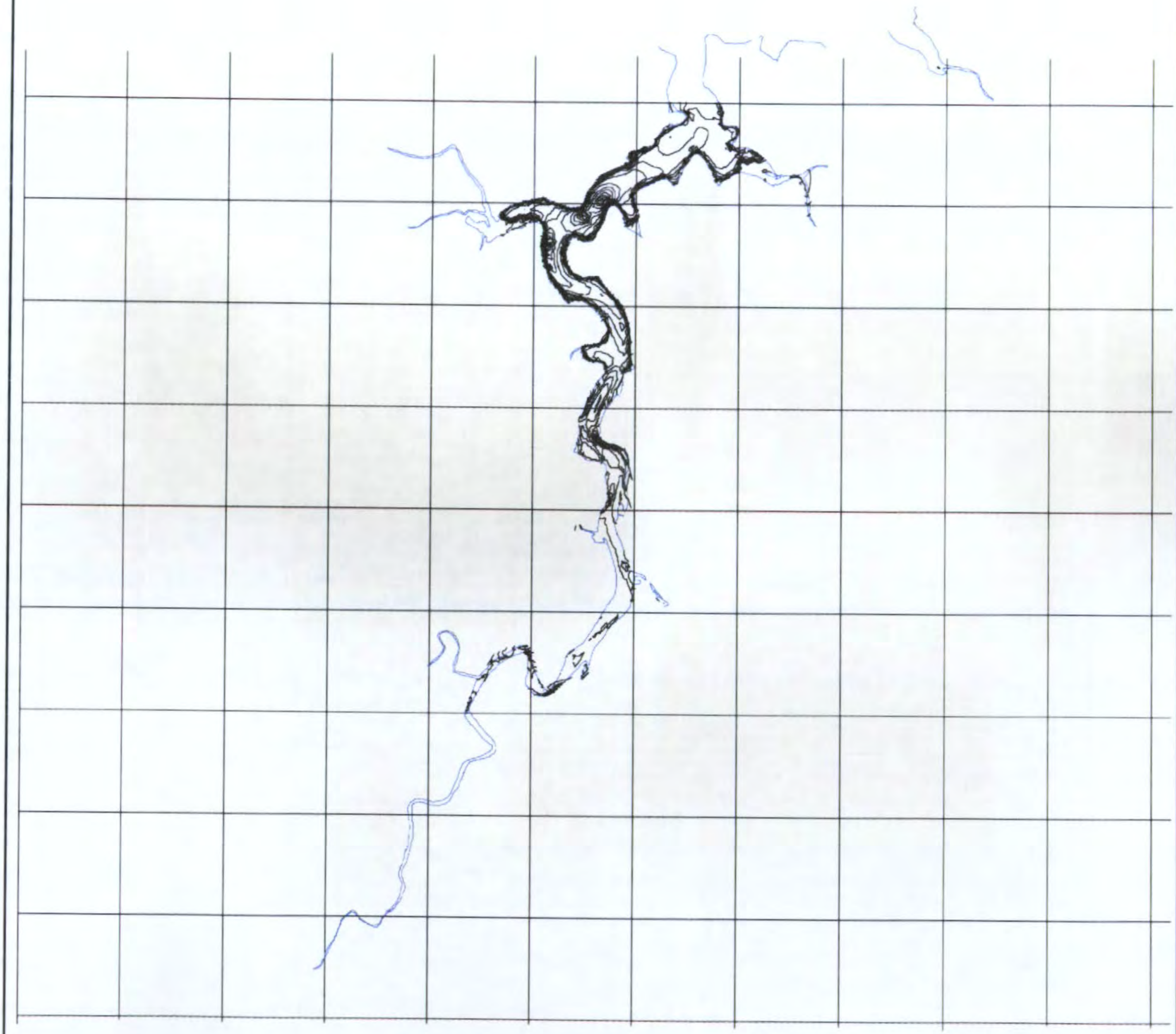
Figure 6.2a

DRAWING 85562a.CDR



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BATHYMETRY - SOUTH

MHL Report 855
Figure 6.2b

DRAWING 85562b.CDR

7. Hydrodynamics

7.1 Catchment Inflows

Catchment inflows include direct rainfall, stormwater drainage and overland flows, waste water treatment plant flows, sewer overflows and groundwater flow. The proportion of each inflow of the total inflow varies as shown in the following sections.

7.1.1 Direct Rainfall

Direct rainfall is that which falls directly on the water surface of the estuary. The volume of water delivered to the estuary by this means equates to the rainfall depth recorded at the nearest station (mm) multiplied by the waterway surface area (11.5 km^2). Over a year the average rainfall of 1,200 mm delivers a volume of 13.8 x 10^6 m^3.

7.1.2 Stormwater Drainage and Overland Flows

The major water input to the estuary occurs via streamflow from the many creeks draining the Berowra catchment as outlined in Section 3.2.

After sufficient rainfall, water reaches the streams as surface runoff, interflow and baseflow. Surface runoff and interflow ceases soon after rainfall, but baseflow, being the contribution to streamflow from groundwater, is continual in the lower parts of the larger sub-catchments, although it decreases with time after rainfall ceases.

In urbanised areas, most of the surface runoff, much of the interflow and some of the baseflow is collected by constructed stormwater drainage systems. This water generally reaches the streams more rapidly than water from non-urbanised areas because of the substantial impervious areas (roofs, roads, footpaths etc.) created by urbanisation, as well as the lower hydraulic resistance of the drainage system itself. Detention basins may be introduced to compensate this rapid runoff.

Urban developments often result in an increase in total runoff volume, but this may be compensated for by a decrease in interflow and baseflow, as less water enters the soil profile in smaller events.

The net result of these complex interactions in the Berowra catchment has been explored by modelling the hydrologic processes associated with different land uses and the hydraulic transport in the streams (AWT EnSight 1995). The catchment area which contributes runoff to the Berowra estuary was divided into 27 sub-catchments to estimate inflows to the estuary, by using dynamic HSPF models (Figure 7.1). Flow from each sub-catchment was modelled as the sum of surface runoff, interflow and baseflow generated from areas of different land use (Figure 4.1) and routed hydraulically to the subcatchment outlet.

The results were aggregated into 10 time varying loadings for input to the estuary model and their locations are shown schematically in Figure 7.2.

Calibration of the model of the major stream (Berowra Creek at Galston) and two of its tributaries (Pyes and Tunks creeks) was carried out for a 22-month period (1.5.94-20.2.96).

Table 7.1 Statistics for 10 inflows (m^3/s)
(Refer to Figure 7.2 for location)

Location	b3#2	b2#4	b1#15	b1#11	b1#9	b1#8	b1#6	b1#4	b1#2	c2#1
Average	0.401	0.053	0.071	0.075	0.011	0.027	0.034	0.015	0.085	0.109
Median	0.190	0.009	0.016	0.033	0.004	0.005	0.022	0.013	0.071	0.073
Max	9.300	2.100	2.800	3.600	0.370	1.100	1.800	0.230	2.100	1.900
Min	0.100	0.001	0.003	0.005	0.001	0.001	0.004	0.002	0.008	0.050

where:
- b3#2 Galston Gorge
- b2#4 Crosslands
- b1#15 Calna Creek Confluence
- b1#11 Cunio Point
- b1#9 Oaky Point
- b1#8 Bujwa Bay
- b1#6 Ants Nest Point
- b1#4 Coba Point
- b1#2 Marramarra Confluence
- c2#1 Calna Creek at Tidal Limit

The relative contribution from stormwater (piped) cannot be seen readily from these aggregated statistics because the urban (sewered residential) areas are a small component of the total area (about 15% from Table 4.2).

7.1.3 Wastewater Treatment Plants and Sewer Overflows

There are two wastewater treatment plants (WWTP) in the Berowra catchment. West Hornsby WWTP currently serves a population of over 40,000 and discharges effluent to Waitara Creek at 10 ML/day average dry weather flow (ADWF). Hornsby Heights WWTP serves a population of about 20,000 and discharges effluent at 5 ML/day ADWF to Calna Creek.

Effluent from both plants undergoes tertiary treatment and chlorination before discharge, if flow is less than three times ADWF. Flows between three and six times ADWF receive primary treatment and chlorination at West Hornsby, whereas they receive only chlorination prior to discharge at Hornsby Heights.

Both plants have good records of actual flows including bypasses.

Overflows from the reticulation system within the catchment are currently being modelled and reported on (Sydney Water 1997) with the final draft reports expected in early 1998. Draft reports indicate that there are approximately 38 overflow points for the West Hornsby system (Webb McKeown 1996a) and approximately 25 overflow points for the Hornsby Heights system (Webb McKeown 1996b). Details of the frequency and volume of overflow will be provided when these reports are finalised.

7.1.4 Flooding

Large floods have been recorded in 1893 and 1942 with the latter said to have deposited large amounts of sediment upstream of Berowra Waters resulting in reduced water depths between there and Crosslands (HSC 1994e). A detailed flood study has not been undertaken for this area.

7.1.5 Groundwater

Groundwater flows were considered for the assessment of the existing environment for the environmental impact statement (SMEC 1997) where a search of DLWC bores in the area of the treatment plants indicates that low to moderate yields (0.4 to 5 L/s) of fresh to saline groundwater have previously been produced from the fractured Hawkesbury Sandstone aquifer. Water table depths ranging between 6 and 30 metres have been observed in irrigation bores (fracture zones at between 20 and 90 metres). The direction of groundwater flow is unknown but is assumed to flow towards the creek. The saline waters suggest that estuarine penetration may be occurring in the groundwater, however this cannot be confirmed. Alternately, salinity could be a function of the type of aquifer.

7.2 Tidal Flows

Tidal flows in the Berowra Creek estuary have been monitored at four sites over a four-month period (MHL 1996). The locations of these sites are shown in Figure 7.3. From this data the tidal constituents for each site have been determined using the Foreman (1977) method and are listed in Appendix B.

The tidal amplitudes and phases are presented in Tables B1d to B4d in Appendix B. The phase lag between Berowra Point and Crosslands is around 30 minutes and mean spring range decreases from 1.36 m to 1.26 m.

Gentlemans Halt is the nearest water level station in the Hawkesbury River upstream of the confluence of the river and Berowra Creek and has tidal characteristics similar to the Berowra Point location.

7.3 Hawkesbury River Effects

The effects of the Hawkesbury River are twofold. Firstly, it is the means by which the tide is conveyed to Berowra Creek. Secondly, freshwater flows and flooding in the Hawkesbury may enter the creek providing additional loads.

Water levels in Berowra Creek and the Hawkesbury River during a rainfall event between 23 and 29 September indicate the complex interaction between the creek and the river (Figure 7.4). To illustrate these effects the astronomical tidal event is subtracted from the observed water levels and the residual signal shows non-tidal influences such as fresh water input and atmospheric effects.

The residuals drawn in Figure 7.5 and 7.6 show the peak level due to the rainfall that commenced late on 24 September occurs at ~1800 hours 25 September at Crosslands, at ~0000 hours 26 September at Berowra Point and Gentlemans Halt in the Hawkesbury River. The peak at Crosslands occurred during a rising tide and was not able to propagate downstream until the next ebbing tide. Hence the 6-hour delay in peak level between Crosslands and Berowra Point (Figure 7.6). Longer-term water level changes are associated with the Hawkesbury River event and the smoothed residual signal (Figure 7.7) demonstrates that the higher level at Gentlemans Halt will result in flow from the Hawkesbury to Berowra Creek.

It is not possible to quantify the flow volumes for this event but hydrodynamic modelling (to be undertaken in the later stages of the estuary processes study) may provide estimates.

7.4 Evaporation

Evaporative effects over the water surface may be estimated from bulk aerodynamic formulae or by using the gross monthly evaporation averages. Summing the monthly averages of evaporation over the water surface (11.5 km^2) gives an total annual volume of 20.9 x 10^6 m^3 of water lost to evaporation.

7.5 Salinity and Temperature Effects on Hydrodynamics

Data collected over the period May to November 1995 and presented in MHL (1996) suggest that Berowra Creek is a strongly stratified estuary using the classification of Scott and Imberger (1988).

Gradients in salinity and temperature cause water density differences which then result in water movement. While the currents generated by density differences are usually small (~m/s), their persistence over long periods can result in significant water and mass exchange.

Salinity at sites in the estuary and the adjacent reaches of the Hawkesbury River is shown in Figure 7.8 for the period of 12 September-21 November 1995. Samples collected by the EPA at different locations in the water column demonstrate the persistence of vertical bottom salinity and longitudinal (Crosslands salinity < Bar Point Salinity) gradients. The effects of fresh water inflow on the salinity structure are shown with the rainfall event around 29 September. Here it can be seen that fresh water inflows flush Crosslands to draw salinity to 0 ppt.

Vertical gradients in water density are particularly important for water circulation and mixing characteristics. Vertical gradients inhibit exchange between surface and deeper waters while longitudinal gradients produce longitudinal exchange flows such as the salt wedge.

Progressive vector diagrams are shown in Figures 7.9-7.12. These diagrams were created from current data collected by MHL using S4 current meters located at mid and lower depths in the water column. The vector is a distance of a particle travelling at the recorded speed in each time increment measured, in the recorded direction. The start of the data is assumed at 0,0. The result is a track of a particle of water in either the 'top' or 'bottom' of the water column.

The diagrams indicate that the surface waters at Cunio Point are tidally influenced, however the bottom waters are not and instead are unidirectional through the tidal cycle and progressively move upstream.

At Berowra Ferry the surface and bottom waters are both tidally influenced with a net movement upstream for a period and then a net movement downstream in the top waters (less so in the bottom waters).

It is important to note that no significant rainfalls occurred during the current data collection period.

7.6 Flushing

Flushing of the creek is dominated by five processes:

- tidal exchange;
- wind induced mixing and flushing;
- surface runoff;
- gravitational circulation; and
- vertical exchange in deep basins.

The dominance of each of these processes has been estimated by application of empirical formulae calculating the time it takes for the entire volume of the estuary to be exchanged with water from the Hawkesbury River.

MHL (1996) presents a first-pass analysis of the flushing times of each process operating alone. These durations are presented in Table 7.2 from shortest to longest flushing time. These estimates must be viewed with caution as a number of assumptions are used in their derivation that result in an accuracy of estimate of around a factor of 5-10. Nonetheless, the estimates suggest a large runoff event could flush the system within a day. Tidal exchange may flush the surface waters in around five days while the waters in the deeper basins take more than a month to flush.

In reality the mixing results from a combination of processes. However it is not possible to combine the processes using an empirical assessment.

It is also not possible to estimate the exchange of water between the creek and Hawkesbury River because the Hawkesbury River salinity varies with time (Figure 7.8).

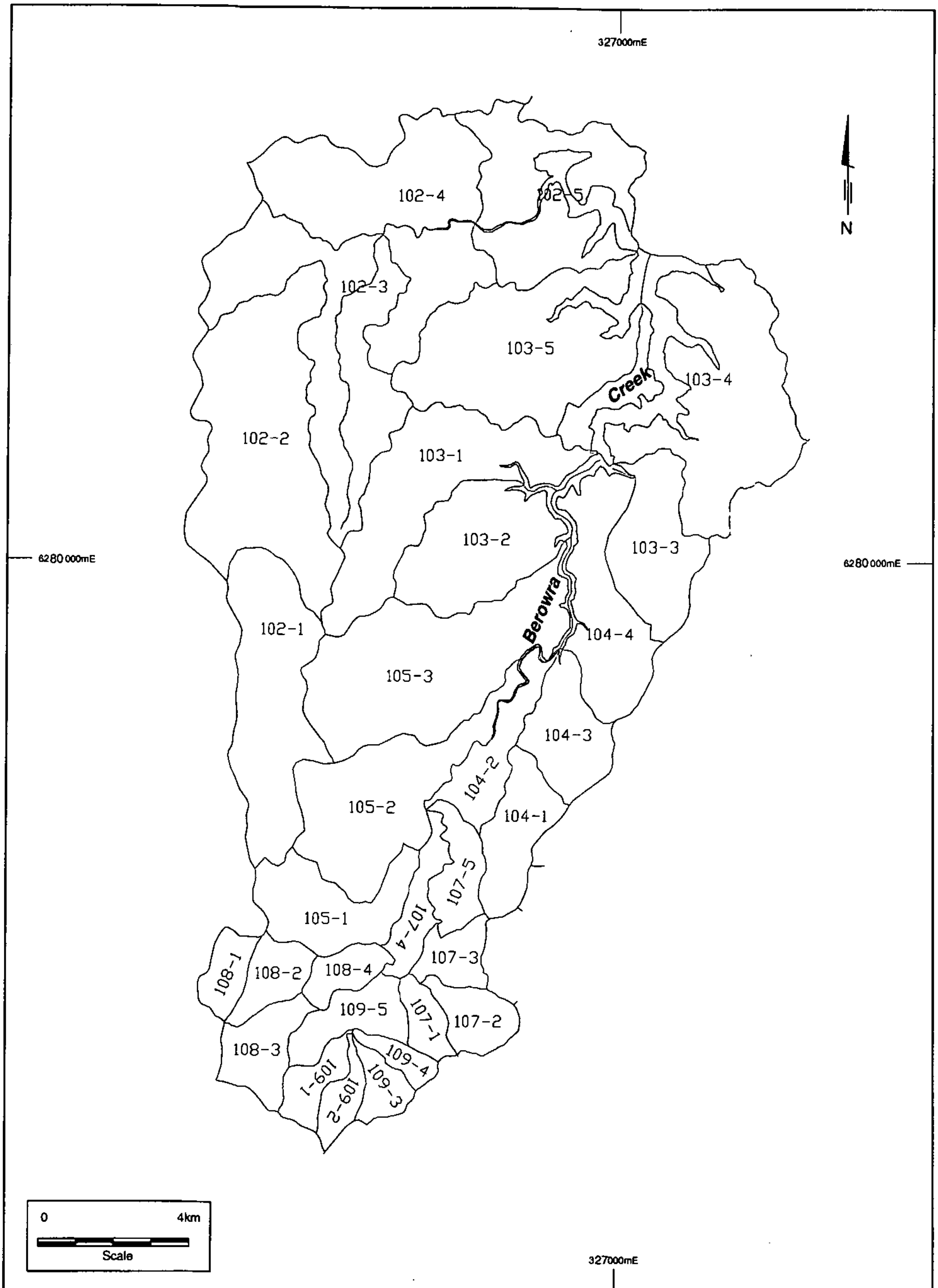
Table 7.2 Flushing Times by Process

Process	Flushing Time
Gravitational circulation	~ 2 days
Surface runoff	~ 12 hours (dependent on storm magnitude)
Tidal exchange	~ 4.5 days
Vertical exchange in deep basins	~ 39 days
Wind induced mixing and flushing	~ 600 days

7.7 Summary of Hydrodynamic Processes

Hydrodynamic processes include:

Processes	Components
Inflows	Direct rainfall, surface runoff, wastewater treatment plant flow, sewer overflows, groundwater flow, Hawkesbury River flows, flood tidal flow
Outflows	Ebb tidal flow, evaporation
Circulation	Wind driven, density gradient driven, tidal action, fresh water inflow action



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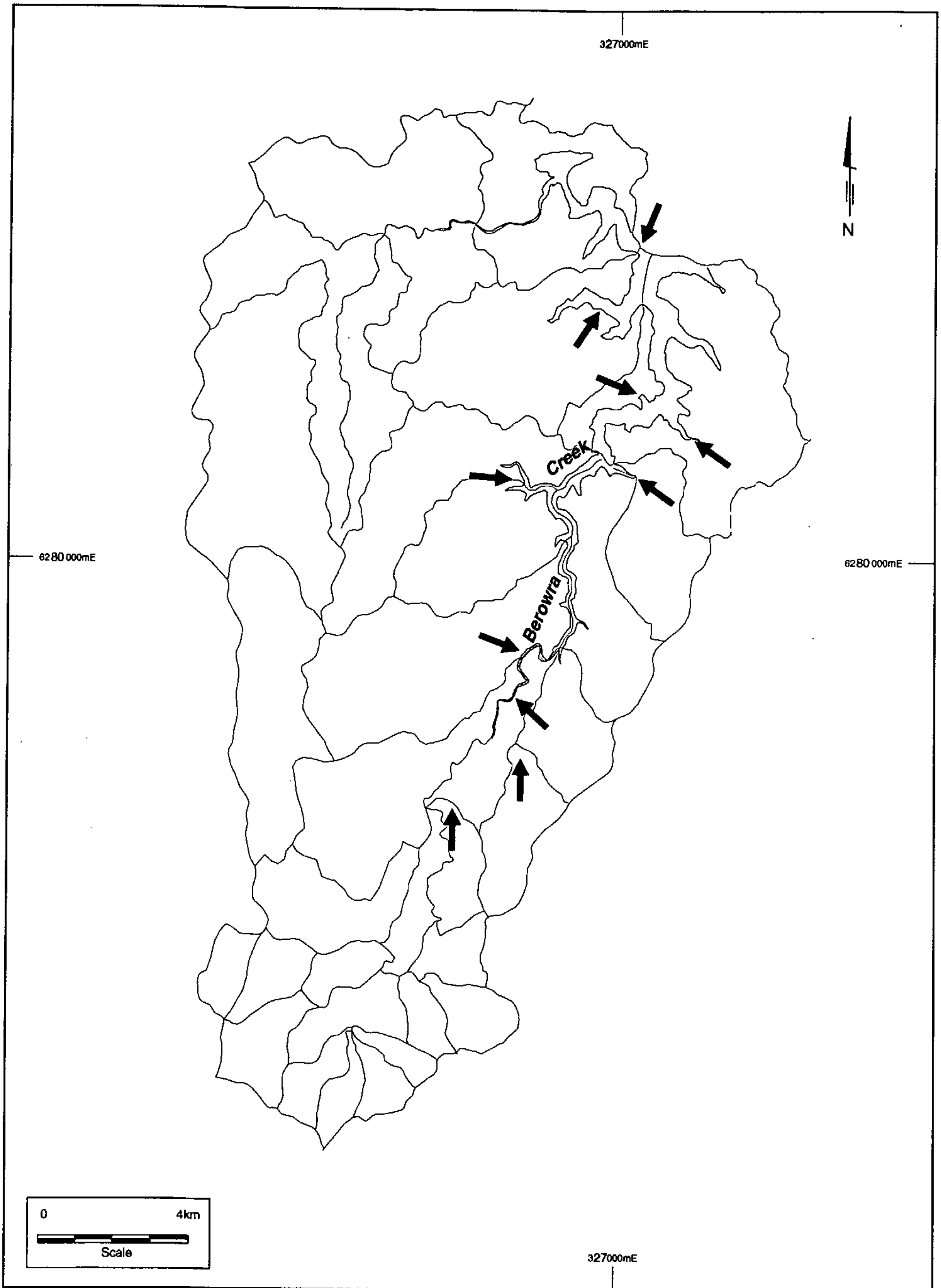
BERLOWRA CREEK SUB-CATCHMENTS

MHL Report 855

Figure 7.1

DRAWING 855BER71.CDR



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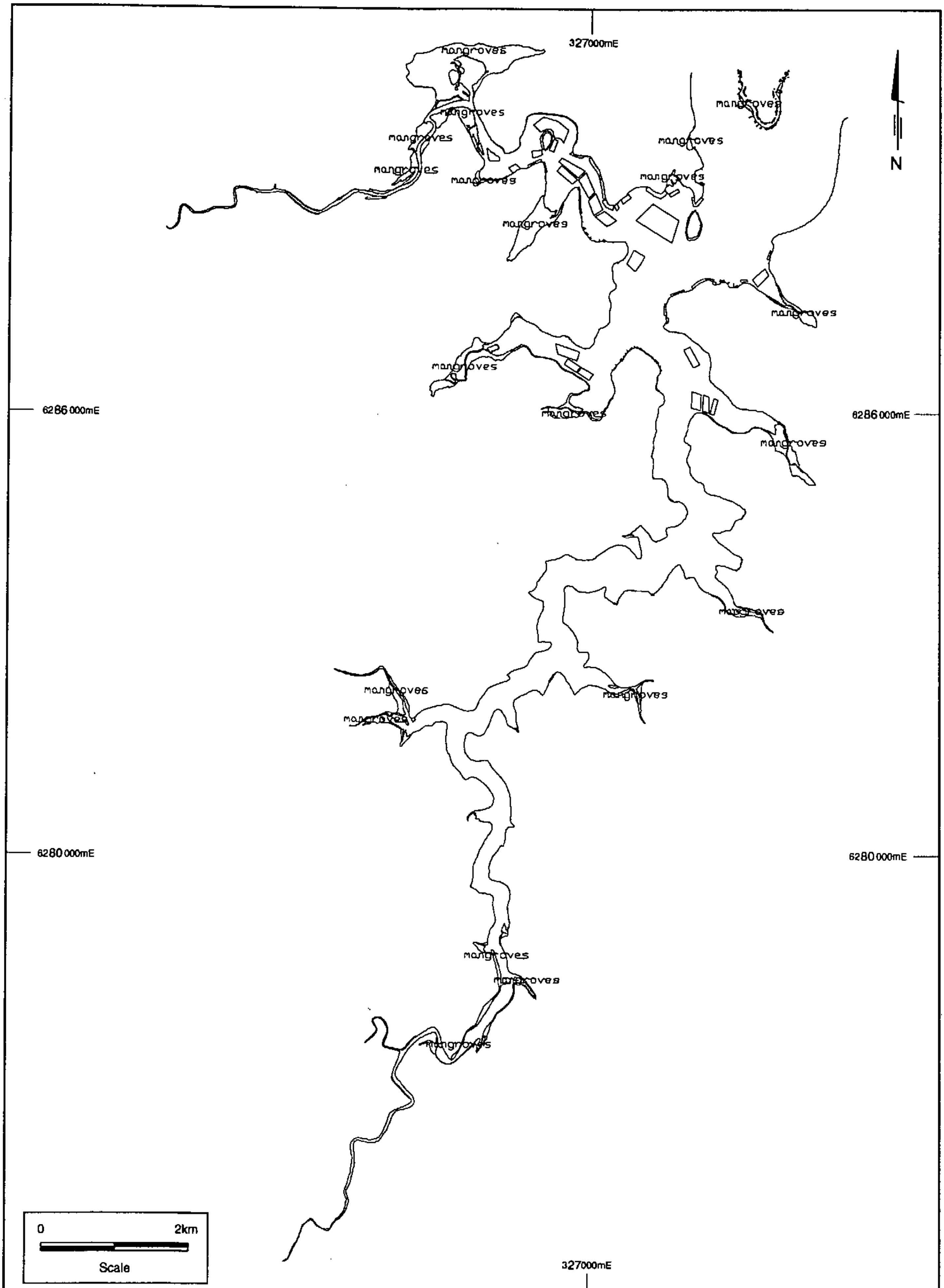
MODELLED CATCHMENT INFLOW LOCATIONS TO ESTUARY

MHL Report 855

Figure 7.2

DRAWING 855BER72.CDR



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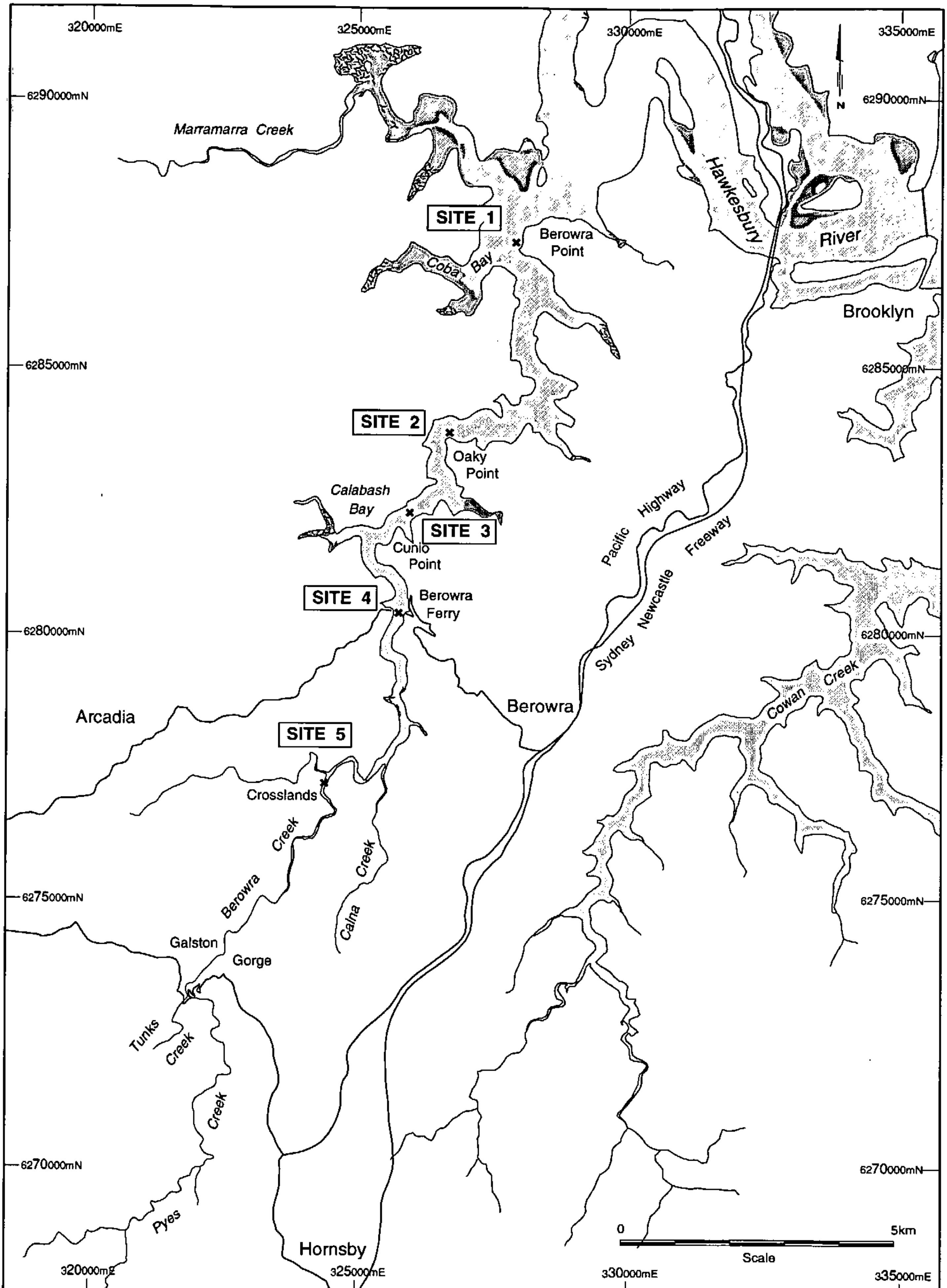
MANGROVES AND OYSTER LEASES

MHL Report 855

Figure 9.1

DRAWING 855BER91.CDR



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MHL DATA COLLECTION SITES

MHL Report 855

Figure 7.3

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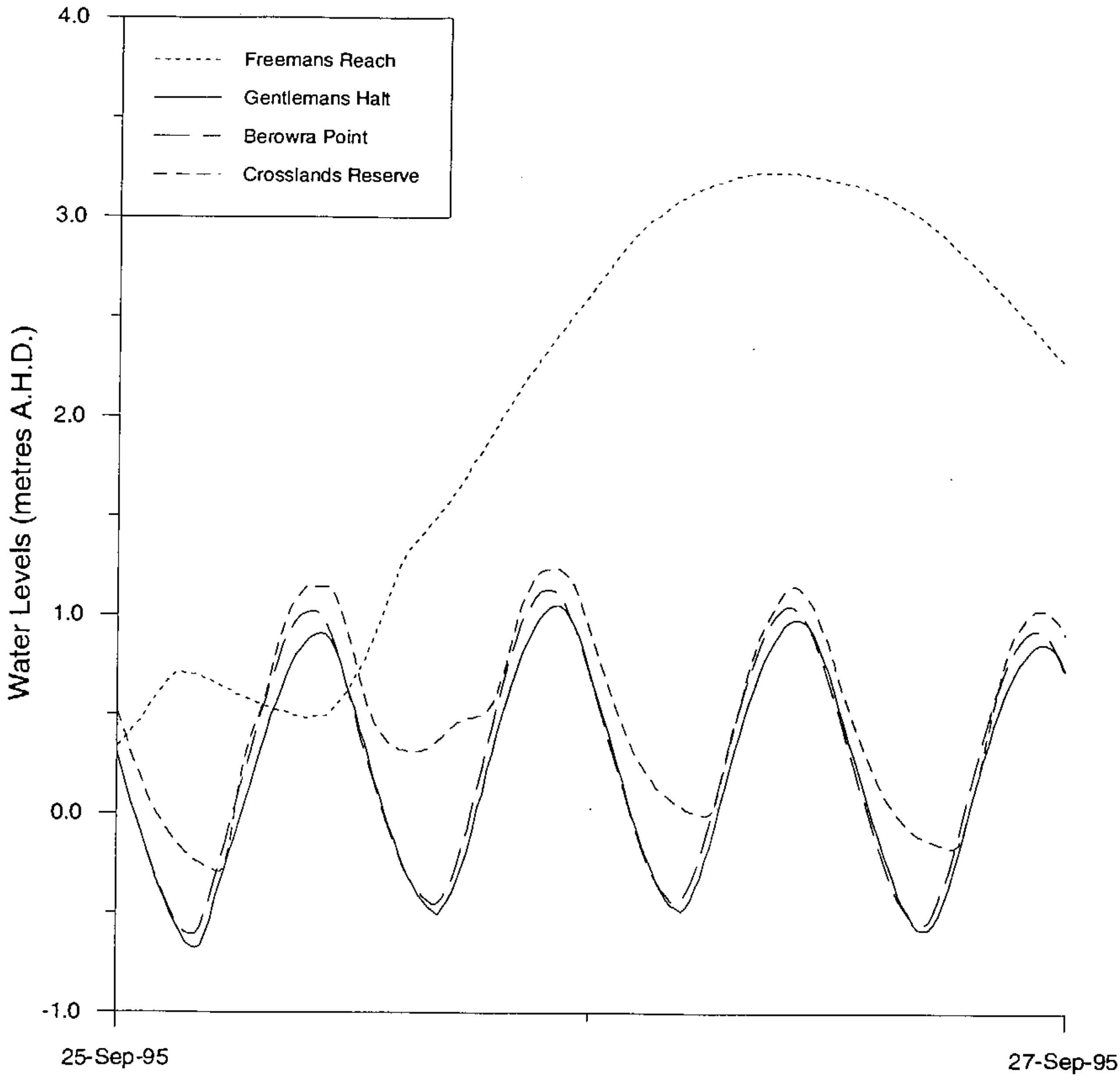

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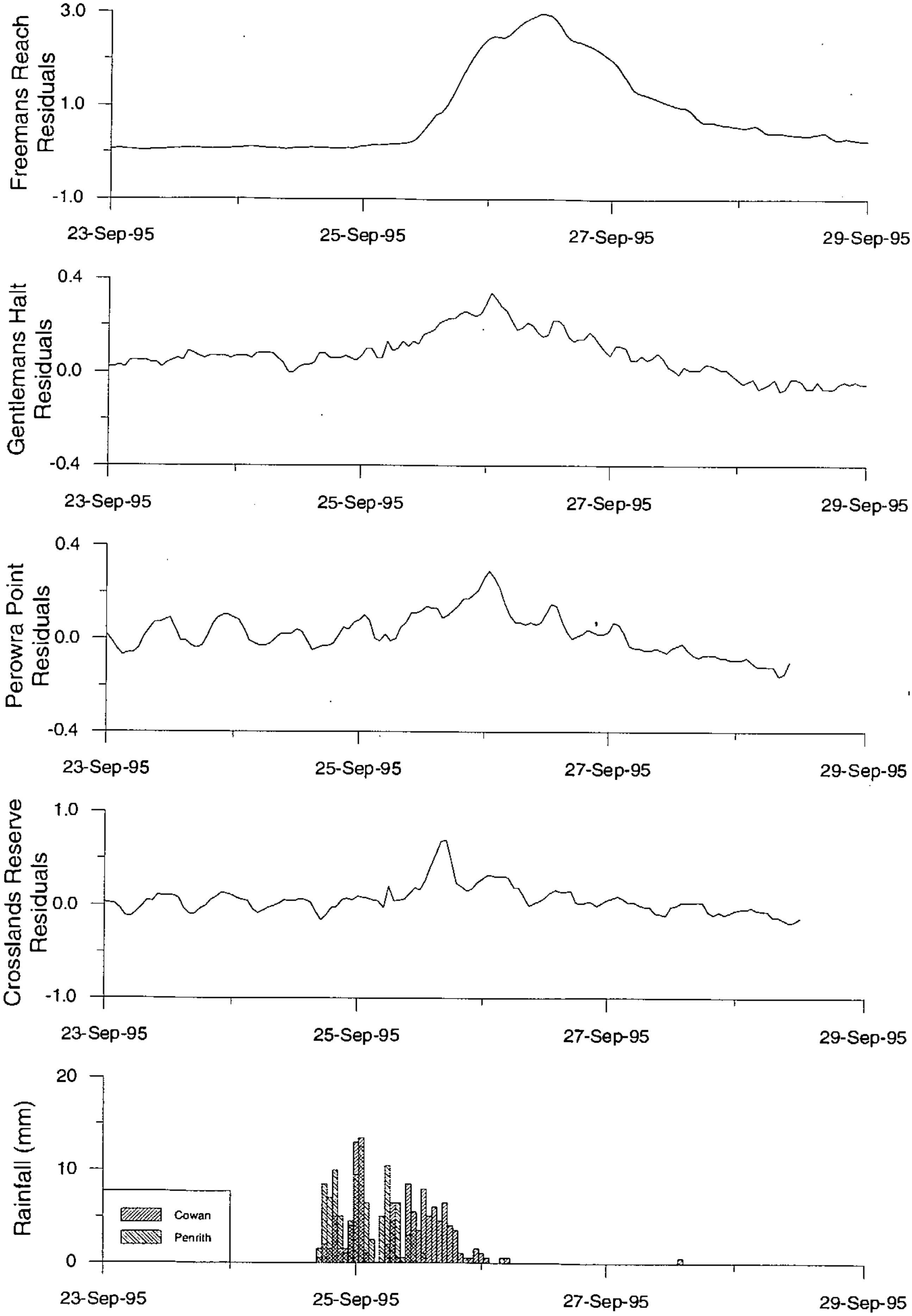
WATER LEVELS DURING SEPTEMBER 1995 RAINFALL EVENT

MHL Report 855
Figure 7.4
DRAWING 855BER74.DRW



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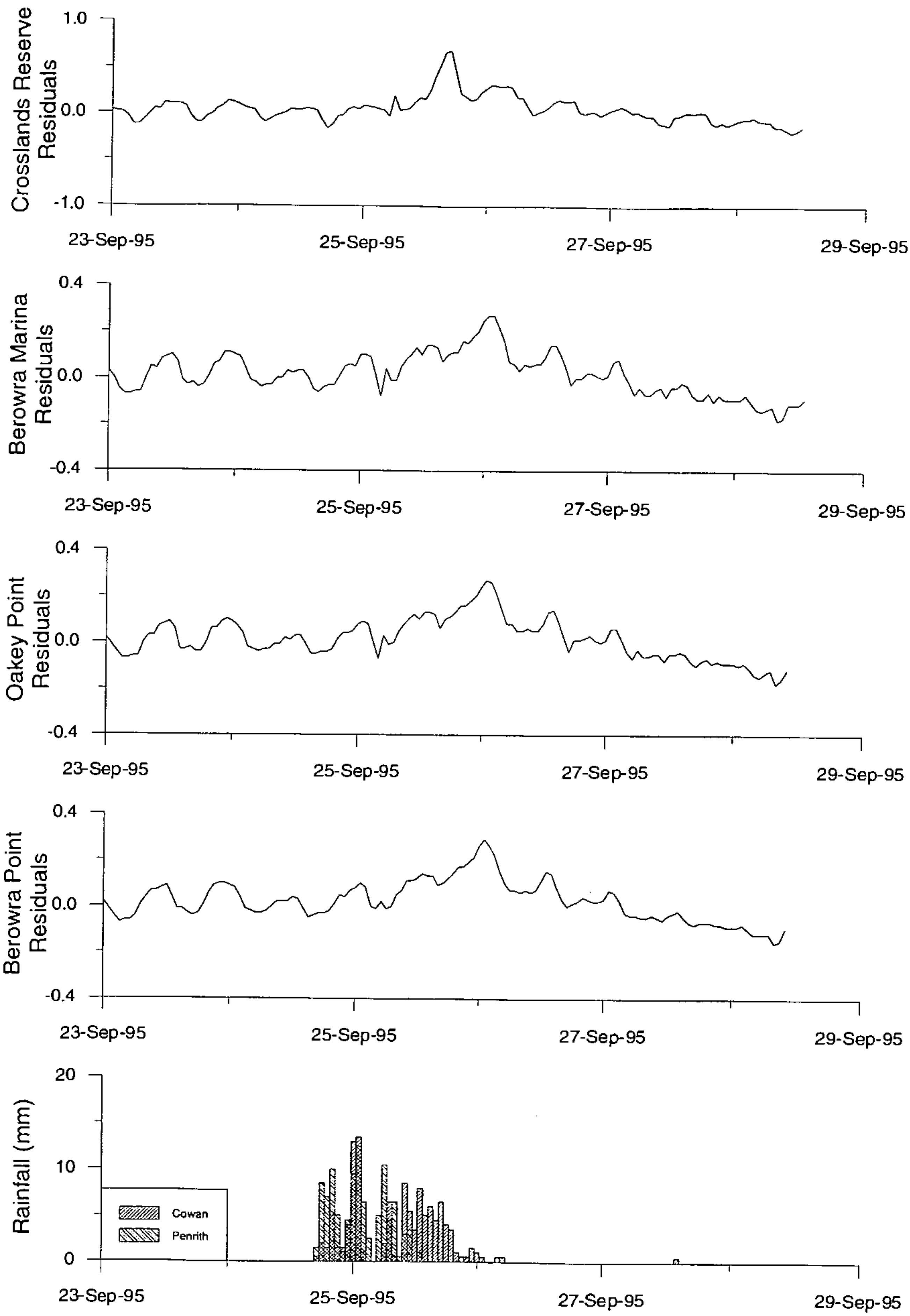
TIDAL RESIDUALS AND RAINFALL
HAWKESBURY RIVER AND BEROWRA CREEK

MHL Report 855
Figure 7.5

DRAWING 855BER75.DRW



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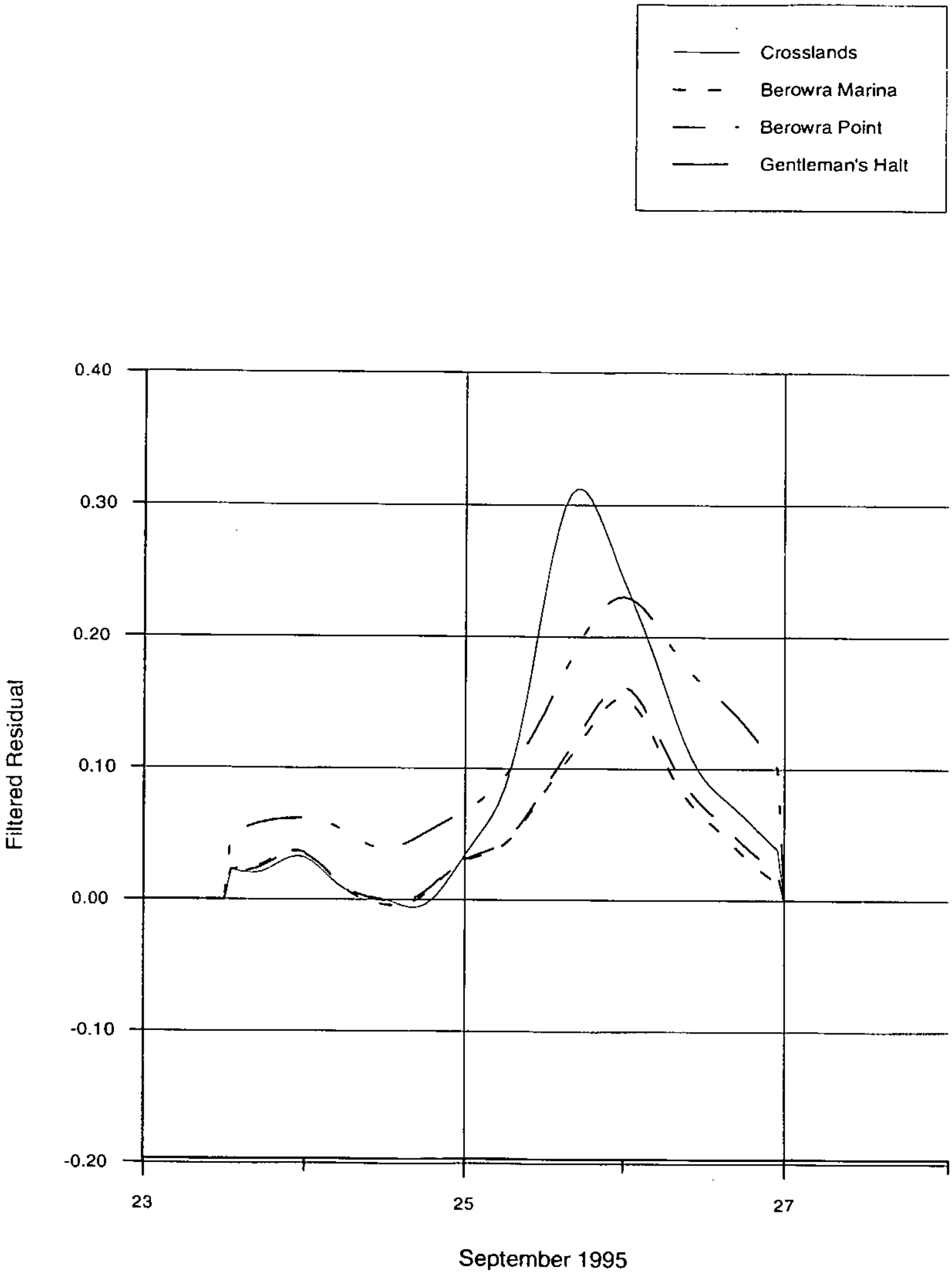
TIDAL RESIDUALS AND RAINFALL
BEROWRA CREEK

MHL Report 855

Figure 7.6

DRAWING 855BER76.DRW



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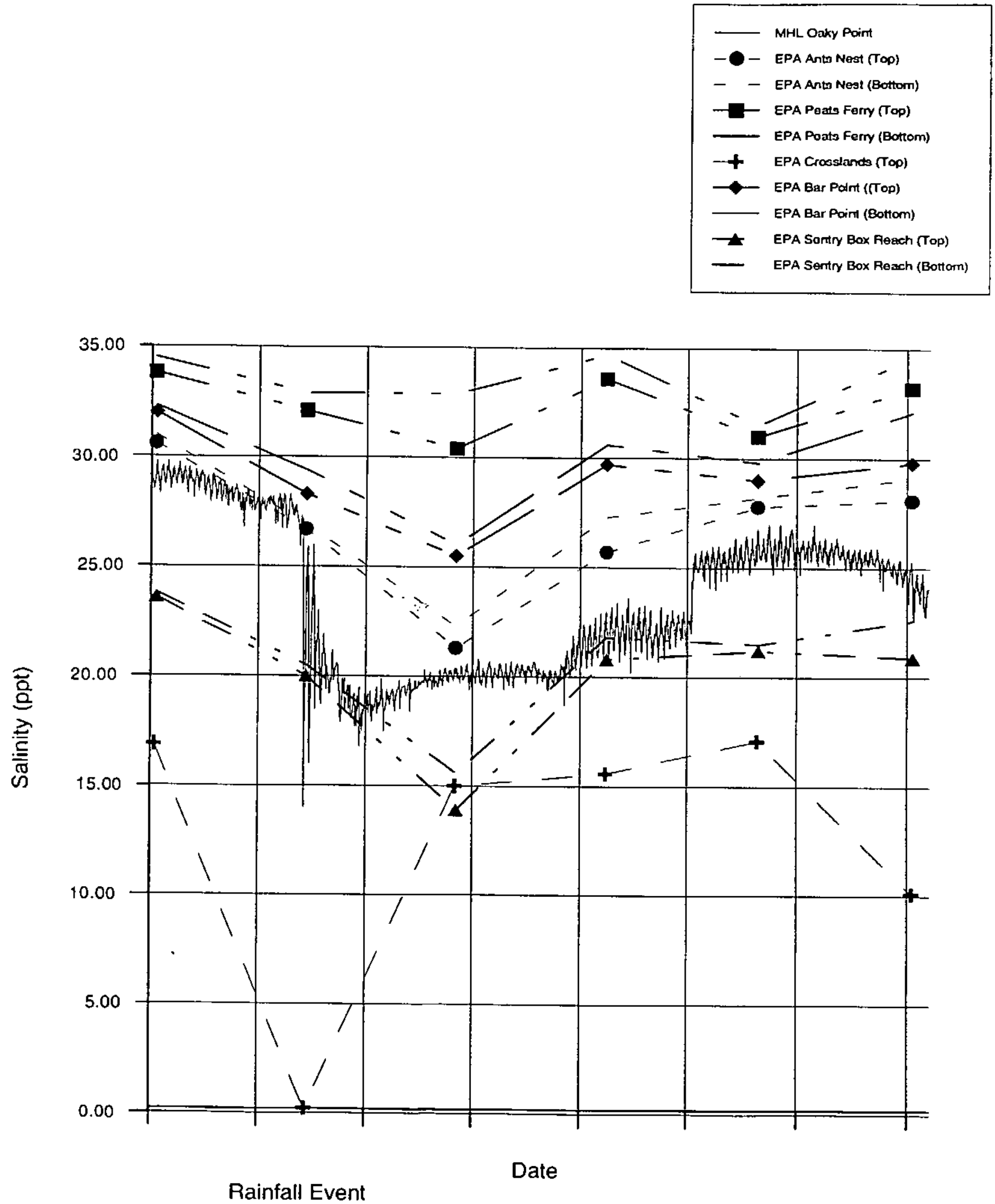
FILTERED RESIDUALS
HAWKESBURY RIVER AND BEROWRA CREEK

MHL Report 855
Figure 7.7

DRAWING 855BER77.DRW



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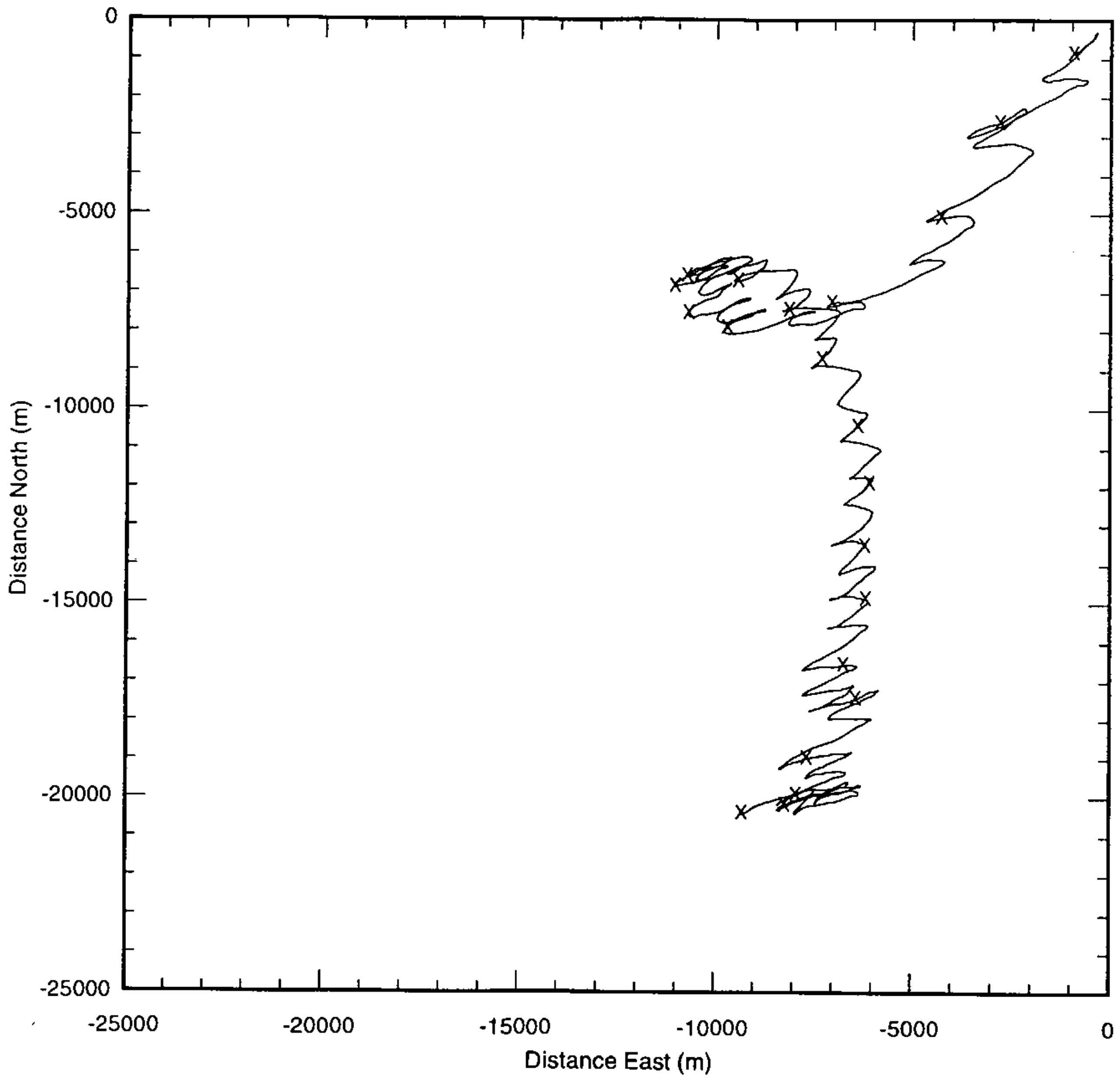
SALINITY BEFORE AND AFTER RAINFALL EVENT

MHL Report 855

Figure 7.8

DRAWING 855BER78.DRW



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PROGRESSIVE VECTOR - BEROWRA CREEK
CUNIO POINT TOP

MHL Report 855

Figure 7.9

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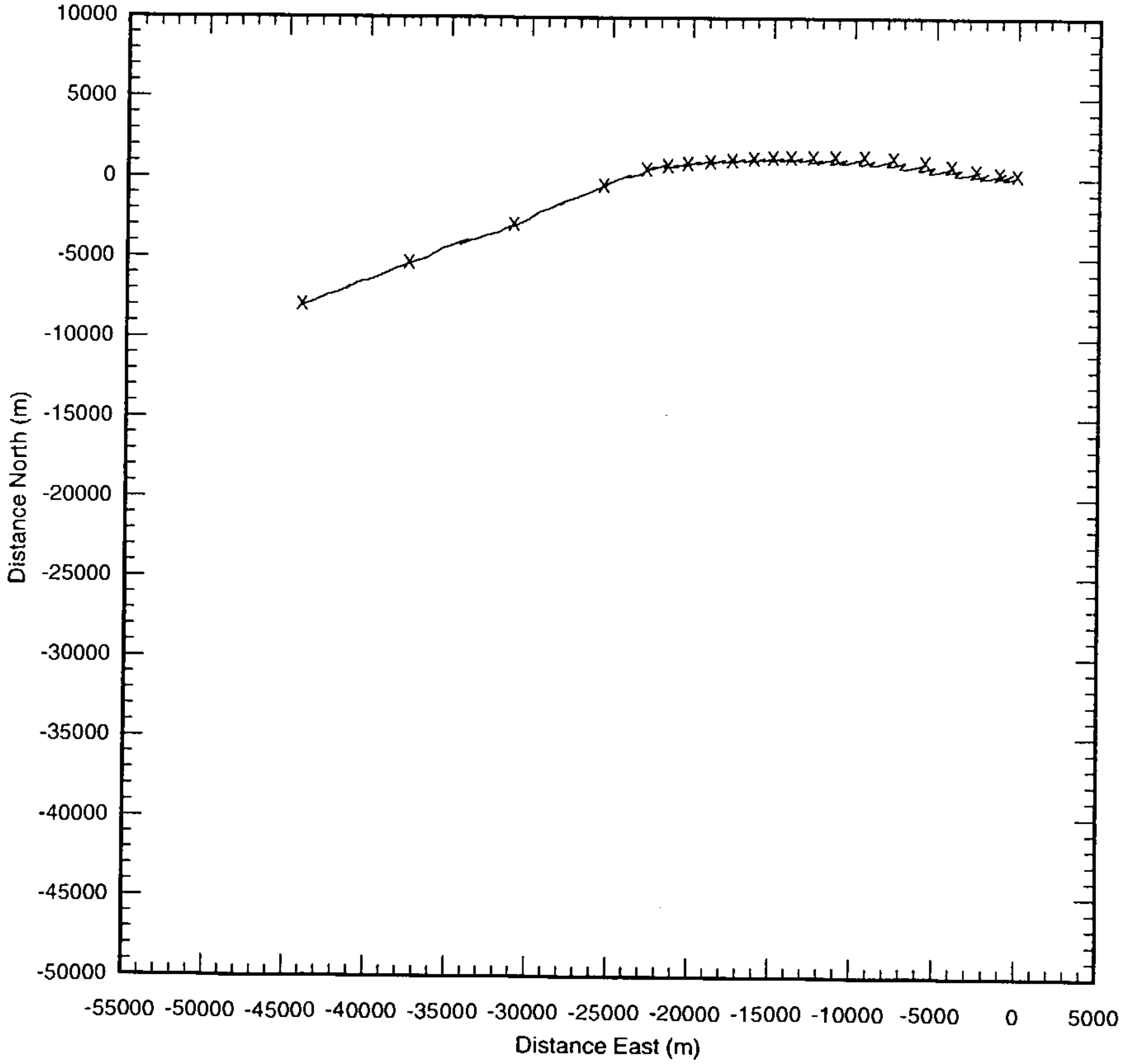

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PROGRESSIVE VECTOR - BEROWRA CREEK
CUNIO POINT BOTTOM

MHL Report 855

Figure 7.10

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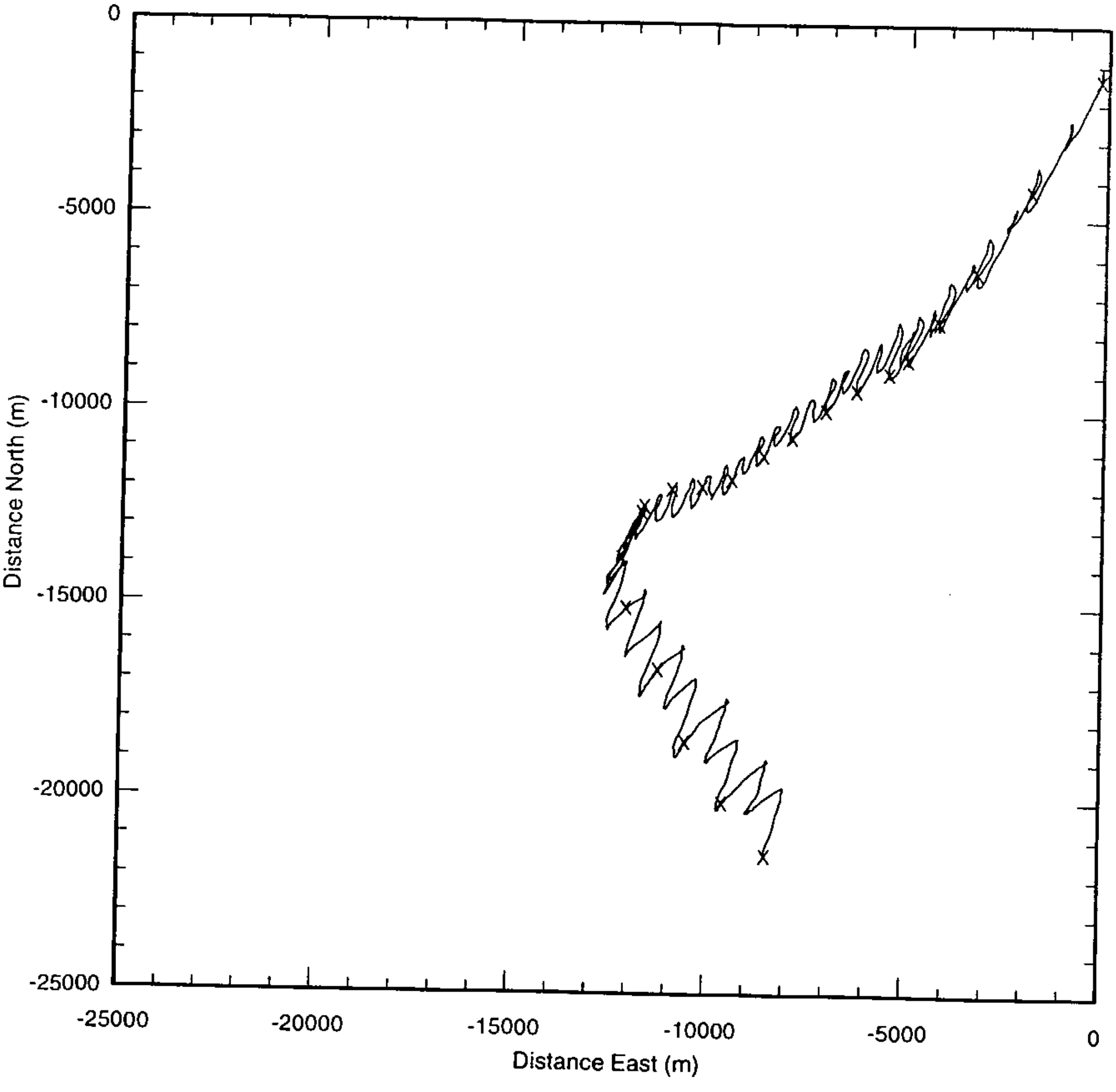

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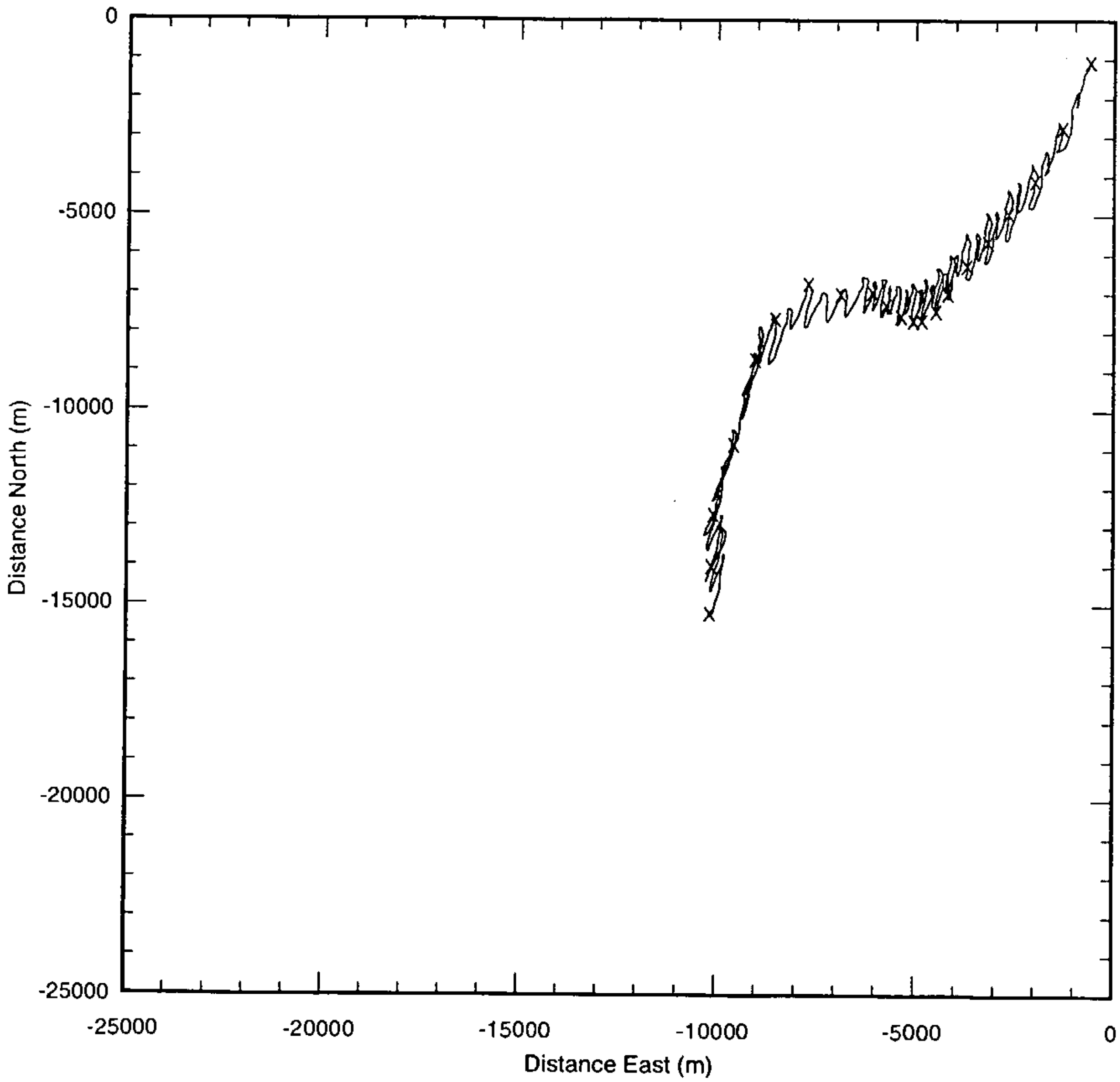
PROGRESSIVE VECTOR - BEROWRA CREEK
BEROWRA FERRY TOP

MHL Report 855

Figure 7.11

DRAWING 855BE711.DRW



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PROGRESSIVE VECTOR - BEROWRA CREEK
BEROWRA FERRY BOTTOM

MHL Report 855
Figure 7.12

DRAWING 855BE712.DRW

8. Water Quality

Available water quality data is assessed for Berowra Creek in terms of:

- catchment runoff;
- estuarine waters; and
- estuarine sediments.

8.1 Catchment

Various substances are carried with the flow generated from the catchment as a result of rainfall. These will be referred to as pollutants, although some may not be of direct concern.

Sediment production and deposition is undesirable from both a catchment and a waterway viewpoint. The catchment may well lose productivity as a result, while the waterway ecosystems may be adversely affected by anoxia at the bed, shading in the water column and eutrophication due to accompanying nutrients. In addition to erosion and washoff of soil, point sources such as WWTPs may also make a significant contribution to sediment loads.

Sediment may be carried in suspension or as bedload; the amounts being dependent upon source availability and transport capacity. The availability of sediment is related to land use as well as natural soil erodibility. Soil disturbance due to agricultural practices and urban development is a major determinant. Transport capacity is related to flow velocity and channel geometry which also determines locations of scour and deposition.

A second major water quality issue is that of eutrophication, the abnormal elevation of nutrient status, which is needed to support algal blooms. In this catchment, eutrophication is largely due to human intervention, such as urban development (nutrients attached to sediment produced), application of fertilisers (increased dissolved components), WWTP inputs, boat pumpouts and picnic area facilities. Substances of particular concern in this context are phosphorus, nitrogen and soluble silica, which are all macronutrients required by (at least some types of) algae.

Thirdly, there are the algal blooms themselves, some of which are potentially toxic. In this estuary, red tides (toxic dinoflagellates) are of particular concern. However, there is almost no direct contribution of these or any other algae from the catchment, as there is insufficient detention time in the streams for algal growth to occur.

Fourthly, there are the inputs of toxic compounds such as heavy metals and organic pesticides, which are contributed by both urban runoff and WWTPs. These may have a direct impact on the aquatic biota.

8.1.1 WWTP Inputs

WWTP effluent data on biological oxygen demand (BOD), suspended solids (SS), total nitrogen (TN), ammonia (NH_3) and total phosphorus (TP) is available as part of the EPA licensing program. Current performance (mg/L) of the two WWTPs is shown in Table 8.1.

Table 8.1 Current Performance of WWTPs

WWTP	BOD	SS	TN*	NH_3	TP*
West Hornsby	2	2	27	0.1	0.2
Hornsby Heights	2	1	47	0.3	0.3

*(TN and TP are 90 percentile for the period 1994-95)

There are another five EPA licensed discharges in the catchment, as well as many septic tanks associated with shoreline development. The latter would have little absorption capacity due to the geology. These were included in the EIS modelling study (AWT EnSight 1997).

The EIS for the treatment plant upgrades considers a reduction in the TN to 5 mg/L (SMEC 1997).

8.1.2 Boat Pumpouts and Picnic Areas

Estimates of the nutrients (P, N) derived from these sources were also made by AWT EnSight (1997), using average weekly figures of boat numbers and picnic area visitors. Recent sampling on Easter Saturday (29 March 1997) indicated that there is not a large source in Berowra Creek.

8.1.3 Stormwater (Piped) and Overland Flow

As explained in Section 7.1.2, the information currently available from the HSPF modelling has aggregated the flows from all land uses within a sub-catchment. The loads for each of the pollutants simulated by the model (which include those discussed in Section 8.1, except heavy metals and organics) are similarly combined.

Estimates of the contributions of the West Hornsby WWTP to the total loads in Berowra Creek at Galston Gorge have been made by AWT EnSight (1996) using dry weather and wet weather (autosampler) data from 1995-96 financial year. The relative contributions are:

- Suspended solids 1%
- Ammoniacal nitrogen 46%
- Oxidised nitrogen 70%
- Total nitrogen 74%
- Total phosphorus 14%

These figures indicate that the WWTPs contribute more nitrogen local runoff from the local catchment and urban areas.

8.2 Estuarine Waters

This section has been completed with reference to published guidelines including ANZECC (1992) and Long et al (1995).

Comments on the quality of the estuarine waters are derived from an assessment of EPA water quality data collected at six sites in Berowra Creek from 2.8.94 to 2.7.96 (26 sampling times) and HSC data for Marramarra Creek collected from 10.10.94 to 31.12.96 (27 sampling times).

The following variables have been assessed:

- water clarity and suspended matter;
- phytoplankton;
- nutrients;
- metals and pesticides; and
- pathogens.

8.2.1 Water Clarity and Suspended Matter

Water clarity affects light penetration through the water column that in turn affects the depth of solar heating of surface waters and the photic depth - depth to which sufficient light is available for photosynthesis. Light penetration is affected by the amount of suspended material in the water column, both organic (phytoplankton and detrital material) and inorganic (fine and coarse sediments).

In general suspended matter at any location results from local resuspension of bottom material, local production of phytoplankton and material brought into the location from adjacent areas by fresh water and tidal flows.

The shallow embayments with fringing mangroves tend to be more turbid than the main arm, presumably because of the higher organic load, and resuspension over the shallow flats.

Comparing data with guidelines indicates that:

- Turbidity exceeded guidelines (ANZECC 1992) at all six main creek sites on between 16 (at Crosslands) to 4 (Cunio Point) sampling occasions. Turbidity levels in Marramarra Creek exceeded guidelines on nine occasions. Rainfall events in November and December 1994 and September 1995 appear to be associated with high levels of turbidity at most sites sampled.

- Non-filterable residue exceeded guidelines on 24 occasions in Marramarra Creek (range 4 to 51 mg/L), and 3 (Cunio Pint) to 17 (Ants Nest) times mid-estuary.

8.2.2 Phytoplankton

Phytoplankton ecology is largely determined by:

- available light (irradiance),
- temperature,
- nutrients (nitrogen, phosphorus, silica).

Other factors that may also be important include:

- depth of the water column,
- presence/absence of stratification,
- losses due to grazing and sinking

Phytoplankton populations are usually made up of a number (often 100s) of species. Periodically a single group or species within the population will become dominant, producing a 'bloom. Phytoplankton blooms are 'denser than normal' standing stocks of single celled algae. They are periodic occurrences in most ecosystems, a natural phenomenon that feeds the lower trophic levels of our food chain and thus are largely beneficial. They become problematic when they:

- persist too long
- become too dense (collapse leads to water column deoxygenation); or
- are toxic.

In Berowra Creek environmental monitoring has been good for some of the essential parameters necessary to understand the phytoplankton ecology and poor for others.

The primary determinants of whether an aquatic ecosystem will produce an algal bloom are set by irradiance and nutrient availability. In temperate and polar ecosystems a seasonal increase in temperature is also important. Despite its importance, there seem to be no measurements that can be used to reliably estimate irradiance in the water column in Berowra Creek. Quantitative measurements of light extinction have been estimated in some northern hemisphere estuaries based on measurements of total suspended solids as follows:

$$k = 0.77 + 0.06 * TSS$$

where: TSS is total suspended solids (or SPM, suspended particulate matter)
k is the light extinction co-efficient

and

$$I_0 = I_d e^{-kd} \qquad \text{Eqn. 2}$$

where: d is depth
I_0 is the irradiance at the surface
I_d is the irradiance at depth (m).

Although Equation 1 has been shown to work well, explaining more than 90% of the variation in k, it is mostly untested in Australian estuaries.

Based on this approach, light extinction in Berowra Creek would vary markedly between sites being highest at Oaky where it would reach ~1.7 m^{-1} during periods of high TSS and significantly lower at the other sites, ~1 m^{-1}. The impact of high light attenuation means that 0.5% of the surface irradiance reaches only 2.3 m depth during periods of high TSS. This very high light attenuation would severely reduce the growth of algae, possibly driving the water column into net respiration.

Given this preliminary analysis of the underwater light field it seems likely that irradiance is a major factor determining the ecology of phytoplankton along this section of Berowra Creek.

Data are available to compare phytoplankton abundance in Berowra Creek to levels recommended in the ANZECC guidelines (1992). In fortnightly sampling from August 1994 to December 1996, chlorophyll-a levels exceeded guidelines on 2 to 22 occasions at mid-estuary sites (Ferry crossing, Cunio Point, Oaky Point and Ants Nest Point) and 8 times in Marramarra Creek, usually in the months of December, January and February, extending into March and April in 1996.

There are good data available for phytoplankton species composition. The choice of sampling fortnightly in Berowra Creek is a distinct improvement from traditional quarterly sampling. However it is still at the low end of the required temporal frequency as recommended by UNESCO for studies on eutrophication (Margalef 1978).

Phytoplankton sampling (EPA, HSC, AWT, 'AlgaeWatch') has been adequate to describe the seasonal succession of the algal community from diatom dominated to periodic dinoflagellate blooms. An analysis of samples from three sites (Berowra Ferry, Cunio Point and Oaky Point) collected by the EPA were analysed in detail for species composition and abundance (Senogles 1996). Results showed a winter dominance of diatom and cyclic diatom-dinoflagellate association in spring and summer, although there was much variation at the smaller scale of sites. Data on phytoplankton abundance and community composition has been collected as part of the 'AlgaeWatch' project by Roger and Marilee Campbell. Data are from the Calabash Bay area and are collected simultaneously with water quality data, the latter a regular Streamwatch activity. General trends in these data are similar to those collected by the EPA and Hornsby Council. Data from 1995 indicate the occurrence of algal blooms in February-March and November of that year, and corresponded with elevated levels of phosphates and nitrates and, in the case of the February bloom, a marked increase in BOD. The dominant species in the February-March bloom were the diatoms Skeletonema and Prorocentrum. The dominant species in the November bloom are yet to be reported, but previous work suggests dinoflagellates were dominant.

This pattern persists in many aquatic ecosystems, fresh, estuarine and marine. The shift in community composition from diatom to dinoflagellate dominance has been attributed to many factors, but it mainly attributed to increased stratification. Increased stratification can cause an increase in nutrient concentration in the bottom layers of water via several pathways. The effects on phytoplankton community composition can be severe as diatoms with the limited ability to regulate buoyancy are essentially trapped in either the nutrient deficient surface layer or in the nutrient rich but light deficient bottom layer. Only motile species can exploit this stratified system by absorbing nutrients at night in the bottom layer and migrating to the surface during the day to increase photosynthesis. The strategy of vertical migration is especially effective in shallow stratified systems with poor light penetration that are so typically Australian. Thus, there is some understanding of the mechanisms responsible for seasonal succession in algal communities that are likely to be operating in Berowra Creek.

However, the practice of limiting phytoplankton sampling to three stations is unlikely to result in an adequate description of the true nature of the phytoplankton dynamics in this ecosystem, based on the highly variable horizontal distribution of chlorophyll-a measured by the EPA using continuous *in vivo* fluorescence.

Phytoplankton, especially those buoyant enough to be visible to the average human observer, are very susceptible to advection in surface currents. Horizontal movement can lead to concentration or dispersal. In the case of Berowra Creek localised concentrations of phytoplankton seem most likely to be the result of horizontal, tide and wind-driven advection. Phytoplankton blooms have typically been reported from approximately the ferry crossing downstream to approximately Joe Crafts Bay. Given the information presented in this report on tidal behaviour and flushing times, it is likely that the observed distribution of phytoplankton blooms is largely determined by water movements. However, without further detailed studies it will be difficult to know what portion of the phytoplankton bloom problem is due to in situ production relative to concentration by advection.

The available data indicate relatively persistent vertical stratification at Berowra Ferry and Cunio Point. It is not clear how widespread this condition is. However, as indicated above, stratification has important consequences for the ecology of the phytoplankton, being a factor that can favour a dinoflagellate-dominated phytoplankton community (Hamilton et al. 1996). It seems likely this will only be true when the bottom layer contains more nutrients than the surface layer and the distance between them is less than the maximum distance which motile species can migrate daily (< 20 m). It seems highly probable that Berowra Creek has significant dinoflagellate booms because of this combination of these factors (stratification and greater nutrient concentrations in the bottom waters) but the magnitude of this potential problem is difficult to assess because there are no measurements available of nutrient concentrations in the bottom layer during stratified conditions.

Results from a survey of dinoflagellate cysts in surface sediments indicate that Berowra Creek already contains toxic or potentially toxic diatoms and dinoflagellates (Hallegraeff 1997). Highest densities and diversities of cysts in the survey were found in sediments from Calabash Bay Senogles (1996) found that the common red tide forming dinoflagellate *Gymnodinium sanguineum* was a common contributor to blooms in Berowra Creek. She also recorded the toxic species *Gyrodinium galatheanum* and *Procentrum* spp. While acknowledging that it is impossible to *a priori* eliminate toxic or potentially toxic species from a large and open aquatic ecosystem, the implications for management of toxic phytoplankton in Berowra Creek are unclear. The species found in creek sediments and other potentially toxic and commercially harmful species are found throughout Australian estuaries. As required by law, all oysters from Berowra Creek undergo a cleaning or 'depuration' process before marketing. Berowra Creek oysters are depurated at Sandbrook Inlet, off the main Hawkesbury River . Given that the water used in the depuration process itself is free from toxic dinoflagellates, this procedure has generally been successful in reducing the occurrence of poisoning due to ingestion of cultivated oysters.

Although early warning of a toxic bloom can be obtained from phytoplankton monitoring, this method is not infallible. Regardless, phytoplankton monitoring is recommended for any estuary with a large shellfish industry presence.

8.2.3 Nutrients

Comparing data with guidelines indicates that:

- NOx concentrations (nitrate plus nitrite) were generally high at upper and mid-estuary sites (Crosslands, ferry crossing, Cunio Point and less frequently at Oaky Point), with Crosslands usually returning the highest values. NOx exceeded guidelines in Marramarra Creek on seven occasions. Recommended total nitrogen levels were exceeded on two or three occasions. At most sites, elevated total nitrogen levels were associated with a rainfall event in late September 1995.

- Total phosphorus concentrations exceeded guidelines on seven sampling occasions at Crosslands, and on between zero and three sampling occasions at other mid-estuary sites (ferry crossing, Cunio Point and Oaky Point). Total phosphorus levels exceeded guidelines in Marramarra Creek on one occasion. High levels of total phosphorus were associated with the significant rainfall event in late September 1995 at Crosslands, Berowra Ferry and Cunio Point, but had fallen to below guideline levels at Oaky Point and Ants Nest.

8.2.4 Metals and Pesticides

Data for levels of metals and pesticides in water from Berowra Creek has not been located.

8.2.5 Pathogens

Data for faecal coliforms from Ferry Crossing show high levels in March 1995. Enterococci levels from the same site are high on numerous occasions throughout the sampling year. Faecal coliform counts are high in Marramarra Creek in December 1995.

No faecal coliform counts were collected regularly for other sites in the creek in the 1/94 to 7/96 data set.

8.3 Estuarine Sediments

While various authors have presented guidelines against which the quality of sediments can be compared, at present there is no wide agreement within Australia as to which guidelines or standards should be used. Preparation of ANZECC guidelines is currently under way, and they are expected to be available within approximately six months (G. Bately, pers. comm). The available information for Berowra Creek is therefore compared to guidelines published by Long et al. (1995), which were recently and logically derived and are widely accepted. Long et al. (1995) give criteria in terms of ERL (minimal effects range); concentrations below this figure (usually cited in mg/kg or ppm) indicated levels at which effects on biota would rarely be observed. Concentrations of nutrients in sediments are categorised by the US EPA.

8.3.1 Nutrients

Mann et al. (1996) measured nutrients in sediments from seven creeks in Hornsby Shire. Two creeks (Smugglers Creek and Murray Anderson Creek) were considered as reference sites, as they drained National Park catchments that were considered unimpacted. Smugglers Creek is the only appropriate reference creek, as Murray Anderson Creek drains into Cowan Creek. Two of the impacted creeks sampled drain into Berowra Creek: Sam's Creek and Still Creek drain an industrial area and rural area, respectively.

Average values for total nitrogen in Sam's Creek were below published criteria for 'lightly polluted' sediments (US EPA), but twice as high as those recorded in the reference creek (Smugglers Creek), and one sample exceeded published criteria. Average values for total N in Still Creek were over seven times those recorded in Smugglers Creek, and all readings but one exceeded published sediment criteria for total N.

Average values for total phosphorus in Sam's Creek were approximately one and a half times those in the reference creeks, but lower than published criteria. Average values in Still Creek were almost four times those recorded in the reference creek and above published criteria. Sediments in Still Creek were characterised by greater mud and total organic carbon content than either Sam's Creek or the reference creek, Smugglers Creek.

In a separate study, Mann et al. (1996) sampled nutrients in fine sediments from a deep (>13 m) hole east of Calabash Point. Levels of total N were high, exceeding published criteria and high compared to average values of samples from Berowra, Cowan, Mullet and Mooney Mooney creeks (all in the Hawkesbury catchment). Levels of total P were also greater than published criteria, but did not differ significantly from levels in comparable samples from Berowra, Cowan, Mullet and Mooney Mooney creeks.

An EPA (1996) study found high levels of nitrogen in sediment samples taken from 1990-1993. These sediments also contained high proportions of fine particles and organic matter.

It would appear that the high levels of nutrients in the sediments may provide a source of nitrogen particularly during anoxic conditions. Preliminary estimates of sediment nutrient release suggest that this source is not as significant as the major creek inputs.

8.3.2 Metals and Pesticides

Shotter (1994) measured metal concentrations in the fine fraction of sediments from Berowra Creek, Mangrove, Waitara and Calna creeks. She found that elevated levels of metals occurred in the mud basin of Berowra Creek relative to the main Hawkesbury channel, and the most contaminated sites occurred in Waitara and Calna creeks which act as receiving waters for STP effluent.

Shotter (1994) also found that aldrin, dieldrin and chlordane were the main organochlorines found in high concentrations in sediments in Berowra Creek and its tributaries. Aldrin in samples from Waitara Creek was found in levels 17 times to 174 times that allowed in sediments used for food production. The most likely source for aldrin is the STP (Shotter 1994).

Mann et al. (1996) analysed sediments from seven creeks in the Hornsby shire. Two of these were considered as reference sites, as they drained National Park catchments and were considered unimpacted. Two of the creeks sampled drain into Berowra Creek: Sam's Creek and Still Creek drain an industrial area and rural area, respectively. When compared to a conservative interpretation of published sediment criteria for trace metals (Long et al. 1995), some samples from Stills Creek exceeded criteria for arsenic, nickel and lead. Some samples from Sam's Creek exceeded published criteria for chromium, copper and zinc.

Levels of polycyclic aromatic hydrocarbons in Still Creek and Sam's Creek were below published criteria (Long et al. 1995). Levels of the organochlorines DDE and endosulphan sulphate exceeded published criteria in samples from Still Creek, but were not detected in Sam's Creek.

Levels of trace metals in sediments from a deep hole near Calabash Point were examined by Mann et al. (1996). Levels of arsenic, nickel and lead exceeded or equalled those listed as likely to cause minimal effects (Long et al. 1995). Levels of organochlorine compounds and polycyclic aromatic hydrocarbons in sediments from Calabash Point were below detection limits.

EPA (1996) measured the levels of heavy metals from 12 locations in Berowra Creek. They reported high levels of copper which decreased in samples further away from popular recreational boating sites.

Data collected by the University of Sydney Environmental Geology Group in 1994 and 1995 (HNCMT 1997) for metal, organochlorine and nutrient contamination of sediments in the Hawkesbury-Nepean River indicate for Berowra Creek that:

- Berowra Waters had the highest concentrations of dieldrin (up to 38 µg/kg) and DDE (29 µg/kg) in the creek with a progressively increasing concentration of contaminants moving upstream from the confluence of the creek with the Hawkesbury River. The authors suggest that the dominant source is from the ferry area and the catchment;

- also high values of Cu (lower mud basin - 20-27 µg/g rising to 100 µg/g adjacent to the ferry and then declining upstream), Pb (100 µg/g adjacent to the ferry), Zn (adjacent to Berowra Waters 130 µg/g), DDD, gamma and total chlordane (max of 30 µg/kg);

- Aldrin (one sample with high concentration - 169 µg/kg)

8.3.3 Cysts

It was not possible to examine in detail a report on a survey of dinoflagellate cysts from Berowra Creek commissioned by the EPA. Information from a summary of the report is contained in the phytoplankton section of this report (see Section 8.2.2).

8.4 Summary of Water Quality Processes

The key processes influencing water quality in Berowra Creek may be summarised as follows:

- Nutrients inputs from the catchment including natural sources, urban runoff and STPs and internal nutrient cycling are leading to elevated nutrient concentrations at some times.

- The nutrients are available for primary production and phytoplankton blooms occur.

- Bloom intensity is largest in summer but blooms of different algal taxa may occur year round.

- Flushing of the creek plays an important role in the spatial variability of the blooms. It is likely that in dry years blooms will be more persistent than in wet years when increased flushing will dilute the blooms.

- Faecal coliform concentrations during wet weather flows appear to be limited to the upper estuary near the inflow creeks.

9. Ecology

9.1 Terrestrial Vegetation

9.1.1 Current Distribution

A total of 18 vegetation communities were identified within the Berowra Creek catchment, 17 of which are represented in Berowra Valley Bushland Park (Smith and Smith 1990) and 11 in Muogamarra Nature Reserve (Thomas and Benson 1985). The vegetation of the catchment is primarily influenced by aspect and drainage and has a high floristic diversity as is associated with Hawkesbury Sandstone settings. The most extensive communities within the catchment are low woodland, woodland and open forest formations and are as follows:

- Community 9 (Thomas and Benson 1985)/Community A & L (Smith and Smith 1990): Open Forest with a dominance of Sydney Peppermint *(Eucalyptus piperita)*, Red Bloodwood *(E. gummifera)*, Bastard White Mahogany *(E. umbra)* and Smooth-barked Apple *(Angophora costata)*. This community is predominantly found on protected, steep, south-facing slopes and is the most extensive community within the catchment covering around 65% of the total area.

- Community 7 (Thomas and Benson 1985)/Community Q (Smith and Smith 1990): Open Forest found along the foreshores of Berowra Creek and the Hawkesbury River. This community is dominated by Black She-oak *(Allocasuarina littoralis)*, Rough-barked Apple *(Angophora floribunda)* and Grey Gum *(Eucalyptus punctata)* and commonly found on dry and exposed slopes.

- Community 13 (Thomas and Benson 1985)/Communities D and F (Smith and Smith 1990): Woodland comprising Smooth-barked Apple *(Angophora costata)*, Yellow Bloodwood *(Eucalyptus eximia)*, Bastard White Mahogany *(E. umbra)*, Red Bloodwood *(E. gummifera)* and Black She-oak *(Allocasuarina littoralis)*. This community is widespread throughout the study area and occurs on the north- and west-facing slopes above the waterline.

- Community 15 (Thomas and Benson 1985)/Community C (Smith and Smith 1990): Low Open woodland found on plateaus and ridgetops comprising Scribbly Gum *(Eucalyptus haemastoma)*, Red Bloodwood *(E. gummifera)*, Narrow-leaved Stringybark *(E. oblonga)*, Yellow Bloodwood *(E. eximia)* and Narrow-leaved Apple *(Angophora bakeri)*.

Each of the above communities is well represented within the region in both National Parks and Nature Reserves, including Ku-ring-gai Chase National Park and Marramarra National Park. Communities which are poorly represented in other reserves in the region and warrant conservation include:

- Community B (Smith and Smith 1990)
- Community E (Smith and Smith 1990)
- Community J (Smith and Smith 1990)
- Community P (Smith and Smith 1990), and
- Community 11 (Thomas and Benson 1985).

A full list of communities located within the catchment is contained in Appendix C and mapped on the 1:50,000 scale plan (Figure 9.1.1a). For the 1:50,000 vegetation map, Benson and Howell's 'Natural Vegetation of the Sydney Area' 1:100,000 sheet (1994) was used to map the broad-scale vegetation types of the catchment. Where possible (Berowra Valley Bushland Park and Muogamarra Nature Reserve), this mapping was defined by other authors (Smith and Smith (1990) and Thomas and Benson (1985) respectively). The three vegetation classifications adopted for the survey supplemented by the foreshore vegetation mapping, provide sufficient level of detail for the formulation of a catchment management plan. The variation in the number of vegetation units and scale of mapping simply reflects the original level of survey effort dedicated to each study.

An additional 1:15,000 scale map was created indicating the foreshore vegetation of the catchment (Figure 9.1.1b). This map includes only vegetation types up to the ridgeline above the main channel and to a distance of approximately 1 km up creeks and gullies. The dominant vegetation communities of the foreshore area (as detailed by Thomas and Benson 1985) include Communities 7 and 9 (Open-Forest), Community 19 (Mangroves), Community 20 (Saltmarsh) and Community 22 (*Casuarina glauca*).

The ground truthing process undertaken on 3 and 10 April 1997 detected only minor differences between the existing vegetation mapping and the actual distribution of communities. These differences were based on subtle changes in canopy cover and species composition.

9.1.2 Disturbance

Thomas and Benson (1985) noted that weed invasion within Muogamarra Nature Reserve is restricted to a few sites and that with the exception of Peats Crater is of only minor significance. Peats Crater area has been previously cleared for dairying and although native regeneration is occurring, weed species are still widespread. Common weeds in this area include Couch (*Cynodon dactylon*), Camphor Laurel (*Cinnamomum camphora*), Ribwort (*Plantago lanceolata*), Blackberry (*Rubus* sp) and Paddy's Lucerne (*Sida rhombifolia*). Bujwa Bay has also been identified by Thomas and Benson (1985) as containing an area of weeds which appear to be of garden origin. Foreshore locations within the catchment which were identified in the present survey as containing weed infested areas include Sunny Corner, Oaky Point, Collingridge Point, Berowra Waters (east and west of watercourse), Marramarra Creek and Calabash Bay. Other communities in the catchment which appear to be conducive to weed growth include:

- Community O: Smith and Smith (1990) found this community to be one of the most weed-dominated communities within Berowra Valley Bushland Park, with 41% of the species being introduced. Small-leaved Privet (*Ligustrum sinense*), Large-leaved Privet (*Ligustrum lucidum*), Mist-flower (*Ageratina riparia*) and Wandering Jew (*Tradescantia albiflora*) were the most common weeds in this community.

- Community P: Smith and Smith (1990) found weeds such as Lantana (*Lantana camara*) to be prominent within the understorey vegetation of this community.

- Community J: Smith and Smith (1990) found weeds to comprise 14% of the species recorded in the survey plots.

- Community V: This Swamp Oak (*Casuarina glauca*) community is associated with the floodplains of the major watercourse and suffers greatly from extensive weed invasion. A total of 53% of the community was covered by weed species.

Thomas and Benson (1985) highlight two areas which possibly may be subject to weed invasion in the future: Kimmerikong Creek and Bujwa Bay. Weed invasion in these areas would be primarily the result of nutrient-rich runoff entering the creeks from nearby urban areas.

AWT EnSight (1995) reported that riparian vegetation was disturbed, with introduced species making up 30 % to 40 % of the flora. The main weed species along the creek was the small-leaved Privet (*Ligustrum sinense*). They considered that weed invasion may pose a risk to the Geebung (*Persoonia mollis* ssp *maxima*, a particularly rare plant along Calna Creek.

The information provided in the previous reports pertaining to weed distribution was verified during the ground truthing, however, a number of additional areas of infestation were also recorded. An indication of the extent and location of the areas of weed disturbance within the catchment, as determined through the ground truthing, was mapped on a 1:15,000 scale map (Figure 9.1.1b).

9.1.3 Threatened Species

Twenty-four significant plant species have been located within the catchment, 18 of which are listed as rare or threatened nationally on the National Parks and Wildlife Service Wildlife Atlas (1995). Of the 24 significant plant species:

- ten have habitat requirements consistent with the ridge tops and plateau of the catchment, and

- seven have habitat requirements and distribution patterns consistent with gullies and sheltered slopes near the water's edge.

Two species of particular significance in the catchment are *Darwinia peduncularis* and *Tetratheca glandulosa.*

- *Darwinia peduncularis* has been recorded from only a few scattered localities on the Hornsby Plateau and the Blue Mountains. On the Hornsby Plateau, the only reserve in which it has been recorded is the Berowra Valley Bushland Park. The habitat of this species is on or near rocky outcrops and is most likely to be found in communities A and F (Smith and Smith 1990).

- *Tetratheca glandulosa* is endemic to the Hornsby Plateau, between Port Jackson and Mangrove Mountain. Within the catchment this species is most likely to occur in communities C, F and G (Smith and Smith 1990).

Other significant plant species recorded on previous occasions, or likely to occur, in Berowra Creek catchment include *Eucalyptus camfieldii, Darwinia biflora, Lomandra brevis, Lomandra fluviatilis, Melaleuca deanei, Boronia fraseri, Gonocarpus salsoloides, Micromyrtus blakelyi, Eucalyptus leuhmanniana, Darwinia procera, Eucalyptus squamosa, Austromyrtus tenuifolia, Platysace clelandii, Ancistrachne maidenii, Genoplesium baueri, Leucopogon amplexicaulis, Caladenia tessellata, Darwinia grandiflora, Haloragis exalata, Kunzea rupestris, Persoonia nutans* and *Blechnum ambiguum.* It must be noted that none of the above threatened plant species were encountered during the ground truthing aspect of this study.

9.2 Terrestrial Fauna

9.2.1 Wildlife Habitats

The bushland within Berowra Creek catchment provides habitat for many of the common fauna occurring in the Hornsby region. Comparable with other bushland areas on Hawkesbury Sandstone, Berowra Creek catchment has poor mammal populations but high proportions of reptiles, birds and frogs. Smith and Smith (1990) recorded 28 mammal species (19 native species and 9 introduced species), 168 species of birds, 38 species of reptiles (1 tortoise, 23 lizards and 14 snakes) and 14 species of frogs.

The main wildlife habitat features of the catchment can be described in relation to the major vegetation classifications, topographic and drainage features. The following communities have been identified as important either because they support large fauna populations or because they are important for individual species of concern:

- Tall Open Forest: the mature trees provide food and shelter for arboreal fauna including possums, gliders and bats as well as roosts for predatory birds. Understorey habitat is grazed and foraged by such terrestrial mammals as Wallabies, Brown Antechinus and Bush Rats. Communities J, L, P and Q recorded the highest numbers of mammals in the catchment (Smith and Smith 1990).

- Low Open Woodland and Heath: Smith and Smith (1990) recorded the lowest numbers of mammals in these habitats, however, bird populations are greatest in these communities due to the nectar-rich flowers of species such as Heath Banksia (*Banksia ericifolia*), Silver Banksia (*B. marginata*), *B. oblongifolia* and *B. spinulosa.* Communities G and H (Smith and Smith 1990) provide the greatest habitat value for birds in the catchment.

- Riparian Vegetation: frogs and tadpoles inhabit immersed streambank vegetation and constitute a feeding resource for birds, reptiles, fish and mammals. Riparian vegetation also provides nesting sites for Water-rat (*Hydromys chryogaster*) and shelter for both terrestrial and semi-aquatic reptiles. Communities Q and V (Smith and Smith 1990) are particularly important as the seeds of the She-oaks are the principal food of the rare Glossy Black-Cockatoo.

Sufficient information is already available to formulate management plans for threatened fauna which may occur in the study area. However, consideration must be given to the particular habitat requirements for each species before correlating these requirements with the resources available within the catchment. Additional information which is valuable in the preparation of management plans for fauna includes existing and proposed land use, and proximity of habitat to disturbance.

9.2.2 Threatened Species

A review of the NPWS Wildlife Atlas database (5 July 1995) indicated nine species of threatened fauna (TSC Act 1996) which are likely to occur in the catchment, on the basis that they have been recorded locally and have habitat requirements consistent with those available in the study area. Two important species found within the catchment are:

- Broad-headed Snake (*Hoplocephalus bungaroides*) has not previously been recorded in the catchment but its occurrence is highly likely. It is most likely to occur in communities H and G (Smith and Smith 1990).

- Red-crowned Toadlet (*Pseudophryne australis*) is restricted to the sandstone areas around Sydney. The Red-crowned toadlet is widespread within Berowra Valley Bushland Park.

Other fauna species of importance include Powerful Owl (*Ninox strenua*), Masked Owl (*Tyto novaehollandiae*), Peregrine Falcon (*Falco peregrinus*), Koala (*Phascolarctos cinereus*), Tiger Quoll (*Dasyurus maculatus*), Turquoise Parrot (*Neophema pulchella*) and Glossy Black Cockatoo (*Calyptorhynchus lathami*).

The existing information relating to threatened fauna species is adequate for the preparation of management plans. All records on the NPWS database give a date and location. The probability of a given species still occurring in the vicinity of a previously recorded location is influenced by elapsed time, changes to land use, bushfire history and exposure to disturbance, predators and competitors.

9.3 Fauna of Catchment Creeks

- A long-term study of 19 stream catchments within the Berowra Creek catchment by volunteers found that some sites showed consistent levels of ecological health, whereas others showed highly variable quality, suggesting transient pollutant influence (Tuft and Coad 1996).

- AWT EnSight (1995) surveyed macroinvertebrates in several creeks draining into Berowra Creek, using rapid assessment techniques limited to one sampling period. They concluded that the macroinvertebrate communities of Berowra Creek are impoverished and that major pollution-sensitive fauna groups are apparently absent. The fauna was dominated by algal-grazing snails, indicating that primary productivity by benthic was high. They observed tadpoles only upstream of the STPs.

- AMBS (1996) surveyed six sites along the Boundary Road/Cherrybrook Road section of Berowra Creek to assess the site of a proposed constructed wetland. They sampled macroinvertebrates, physico-chemical variables and assessed riparian vegetation at two times. Macroinvertebrates were dominated by snails, worms and insect larvae from the midge family. Community composition was similar at the six sites sampled and analysis using the SIGNAL index indicated that habitats were severely polluted and/or severely degraded.

- AWT EnSight (1995) sampled fish in the freshwater sections of Berowra Creek, Waitara Creek, Tunks Creek and Calna Creek using electrofishing techniques. They recorded seven species of fish, mainly eels, gudgeons and Mosquitofish. Fish were scarce in Calna Creek upstream of the Hornsby Heights STP.

9.4 Seagrass

- West et al. (1985, based on aerial photographs 1977-78 and ground-truthing in 1981) reported seagrasses in Joe Crafts Bay and in patches stretching from Brittania Rock for about 1 km upstream.

- Seagrass health reported to be declining in patches growing in Calabash Bay and opposite Oaky Point (Silberschneider 1996)

- There is a report of the apparent loss of an unspecified size bed of Zostera, at least 10 years old, from within Calabash Bay (R. Campbell communication to EPA and HSC) in the two months prior to 26.4.96.

- The Ecology Lab (1993) recorded large, but patchy beds of Zostera adjacent to, and upstream of an area known as the Woolwash. Some of these beds ranged in size from 50 to 100 m in diameter.

- The Ecology Lab (this report) surveyed seagrass in Berowra Creek in April 1997. Appendix C records details of these observations. In summary, small, patchy seagrass beds were observed that were not recorded in West et al. (1985), and several large beds in the vicinity of the Woolwash were absent or had been replaced by mangroves. Seagrass beds were present in Calabash Bay (not recorded in West et al. 1985), but were small and patchy in nature. Previously recorded beds in Joe Crafts Bay were absent.

9.5 Benthic algae

No published information regarding the distribution and abundance of macroalgae was found. While verifying the distributions of other aquatic vegetation only very little macroalgae was observed. This appeared to be a filamentous green alga which was present on rocks (marking the mid to high tide level) near the ferry crossing. Anecdotal evidence suggests seasonal macroalgal blooms have occurred upstream of the Woolwash but these reports require confirmation.

AWT EnSight (1995) recorded 55 benthic algal taxa from eight sites during a study done in January 1995. The taxa consisted of 34 diatom species, 14 green algae species and 5 blue-green algae species. While the two sites downstream of the Hornsby STP showed the lowest diversity, they concluded that insufficient background data was available to make comparisons with indices of pollution based on diatoms from overseas studies.

9.6 Mangroves

- West et al. (1985) recorded the distribution of mangroves based on aerial photographs taken in 1977 and 1978 and supported by ground truthing in 1981. They found mangroves in Big, Friendly, Kulkah and Back bays and upper reaches within Marramarra Creek; Coba, Donnybrook, Kimmerikong, Bennets, Bujwa and Joe Crafts bays, Calabash and Sam's creeks, fringing most of the shoreline upstream of Mt Orient to beyond Crosslands, and within an unnamed bay between Bennets and Bujwa bays.

- Williams and Watford (1997) estimated changes in the abundance and distribution of mangroves over a fifty-year period by analysing aerial photographs from 1941 and 1992. Their results showed a substantial increase in mangrove area of 30% in that period. There was an estimated 149 ha of mangrove in the 1992 survey. The species recorded include grey (*Avicennia marina*) and river mangroves (*Aegiceras corniculatum*). Preliminary analyses of additional aerial photos from intervening years indicates that the increase in mangrove cover between 1941 and 1966 was only slight, but additional data from the 1970s is necessary to examine the more rapid change in the years between 1966 and 1982. Such information will allow the increase to be correlated with other variables that changed during that period in an attempt to gain a more detailed understanding of the cause or causes of the increase in area covered by mangroves.

- The Ecology Lab (this report) examined aerial photographs from 1995 (Source: Hornsby Shire Council), and verified observed differences from a 1995 survey (source: DLWC) and the 1977 map in West et al. (1985) by ground-truthing (April 1997). The following summarises differences between the 1977 and 1995 aerial photographs:

    1. Mangroves do not extend as far upstream past Crosslands as observed in 1985; large areas have been removed for recreational grounds at Crosslands.
    2. Mangroves now extend further into Calna Creek and Sam's Creek.
    3. Most of the foreshore between Sam's Creek and the Woolwash has scattered fringing mangroves along the steep, rocky shores unable to support the larger stands typical of that area.
    4. There is now an extensive mangrove forest, about 150 m x 50 m, about 600 m upstream of the Woolwash where seagrass previously colonised.
    5. Mangroves stretch for about 150 m up the small creek behind the Berowra Waters Marina.
    6. Increases in the cover of mangroves are apparent in Joe Crafts Bay, Bujwa Bay, Donnybrook Bay and Friendly Bay, particularly along the arms of these bays.
    7. There is now a dense mangrove forest within Peats Bight.
    8. Much of the foreshore of Berowra Creek, although rocky, has either scattered mangroves (i.e. a tree approximately every 5-10 m) usually only one tree deep along the more exposed fringes, or up to three trees deep in the smaller, more sheltered bays, such as those between Oaky Point and Berowra Point.
    9. Most of Marramarra Creek is now lined with mangroves.

9.7 Saltmarshes

- West et al. (1985, based on aerial photographs 1977-78 and ground truthing in 1981) reported saltmarshes in a small sections in Marramarra Creek, Kimmerikong Bay, Calabash Creek and the Crosslands, with a large area in the upper parts of Coba Creek.

- Analysis of aerial photographs showed a substantial decrease in saltmarsh area of 38% between 1941 and 1992 (Williams and Watford 1997). There was an estimated 13 ha of saltmarsh in the 1992 survey. It was recorded from Big Bay, Marramarra Creek, Kulkah Bay, Coba Creek, Donnybrook Bay, Peats Bight, Kimmerikong Bay, Bujwa Bay, Joe Crafts Creek, Calabash Creek and Crosslands, particularly within, and opposite, the mouth of Calna Creek. The native species recorded include *Sarcocornia quinqueflora*, *Sporobolus virginicus* and *Juncus kraussii*, and the introduced *Juncus acutis*.

- Analysis of aerial photographs from 1995, combined with ground-truthing in April 1997, located saltmarshes at Crosslands, Calna Creek, Calabash Creek, Joe Crafts Bay and Marramarra Creek. The species recorded include *Sarcocornia quinqueflora, Sporobolus virginicus, Juncus sp., Suaeda australis* and *Selliera radians*. An area of saltmarsh recorded by Watford and Williams (1997), on the right-hand side at Crosslands, was found by TEL to be a freshwater wetland, composed almost entirely of *Phragmites australis*.

9.8 Estuarine Fauna

9.8.1 Benthos

- Few studies of benthic fauna in Berowra Creek were found, although more information exists on the benthos of the Hawkesbury River (Jones et al. 1986, Jones 1987, The Ecology Lab 1988).

- Edwards (1995, unpublished student report) sampled benthos at Oaky Point and Calabash Bay in April and May 1995, using a hand-held corer. A total of 171 invertebrates were collected, consisting mainly of bivalves (mainly the Psammobiid *Soletellina alba*) and polychaete worms from the families *Capitellidae*, *Nephtyidae*, and *Nereididae*. All species were typical of estuarine habitats, and the low biomass and numbers of individuals recorded may reflect the small numbers of samples taken.

- Sessile organisms attached to hard structures associated with the Berowra Waters Marina were recorded by The Ecology Lab (1993). They recorded mussels (*Xenostrobius securis*) mainly on pontoons and barnacles (*Balanus variegatus*) mainly on pylons down to about 8 m depth. Oysters (*Saccostrea commercilais*) were recorded on rocky shores at various locations in the creek.

- AWT EnSight (1995) examined the fauna of soft sediments in the estuary at four locations and the invertebrate fauna of hard substrata.. Their sampling was done at one time only and was unreplicated, making it difficult to draw conclusions about the spatial and temporal variation in estuarine benthos. Their samples were taken only from shallow, sandy sediments, and do not reflect the communities that may be present in deeper water or in the muddy holes. They recorded polychaete worms (particularly abundant was the nephtyid, *Nephtys australiensis* and the nereid *Ceratonereis pseudoerythraeensis* (synonymised in 1985 as *Ceratonereis aquisetis*)), the isopod *Cymodetta* sp, barnacles, mussels (*Xeonstrobus securis)* and crabs.

9.8.2 Zooplankton

- AWT EnSight (1995) sampled zooplankton at four sites in January 1995. They found that diversity was generally low, recording 14 taxa that were mainly estuarine forms. The more common taxa were juvenile copepods and barnacle larvae.

9.8.3 Fish

- The Ecology Lab (1993) recorded abundant adult and juvenile bream (*Acanthopagrus australis*) around the Berowra Waters Marina, and also observed *luderick (Girella tricuspidata)*, silver batfish (*Monodactylus argentus*), flathead (*Platycephalus fuscus*) and fortesque (*Centropogon australis*) under pontoons and around pylons. Also, gill nets deployed around the marina collected estuarine perch (not Australian bass).

- The Ecology Lab (1993) collected 7,455 fish from 15 families using seine nets at five sites from near Sam's Creek to near Cunio Point. Nineteen species were collected of which 15 were of economic importance. The most abundant fishes were (in decreasing order): glass perchlet (*Ambassis jacksoniensis*), silver biddy (*Gerres subfasciatus*), gobies (family Gobiidae), flat-tailed mullet *(Liza argentea)*, trumpeter whiting (*Sillago maculata*), common toadfish (*Tetractenos hamiltoni*) and sandy sprat (*Hyperlophus vittatus*). The samples taken in Calabash Bay had the greatest numbers of fishes and the greatest diversity of fishes.

- AWT EnSight (1995) recorded 11 species of estuarine fish from four sites in the estuarine portion of Berowra Creek. The most common species were the goby *(Gobiopterus semivestita)*, the silverbelly, *(Gerres filamentosus)* and the southern Blue-Eye *(Pseudomugil signifer)*.

- In research currently underway, Booth and co-workers (unpublished data) have sampled juvenile fish in Berowra Creek from Sam's Creek to Oaky Point from September 1995 to the present at monthly intervals. To date they have collected abundance and length frequency data on 44 species. Dietary information has been collected on approximately 28 species, and detailed data have been obtained for smooth toadfish (*Tetractenos glaber*).

- Studies of the distribution and growth of juvenile mulloway in the Hawkesbury River found that the greatest numbers of individuals were caught at locations 20-50 km upstream of the mouth (Gray and McDonall 1993). One of the locations (No. 4) used in the study was Oaky Point, highlighting Berowra Creek as providing habitat for this commercially and recreationally important species.

- Studies of by-catch from prawn trawlers in the Hawkesbury River found that the lower estuary, 0-25 km from the mouth, thus including Berowra Creek, contained the highest total number of species, highest total number of commercial and recreational species and highest number of species of fish caught as by-catch (Gray et al. 1990).

- Fish kills have been recorded in Berowra Creek, but many occurrences have been anecdotal, or the cause of the kill has been unresolved. Although fish kills are often reported to EPA representatives, the fish kill database is maintained by NSW Fisheries. Recorded fish kills in the Berowra Creek system include:

* 27 January 1994 at Calabash Bay. Greater than 50 mullet, one yellow bream and one porcupine fish killed. No probable cause of death recorded. Record from NSW Fisheries fish kill database (J. Turpin). Examination of EPA water quality data taken in the vicinity during the same period indicates very low values for dissolved oxygen at the bottom of the creek (< 2 ppm). Chlorophyll-a levels were elevated well above ANZECC guidelines (> 30 µg/L).
* March 1997 in the upper reaches of Marramarra Creek. At least 2,000 mullet of uniform size found along a 1.5 to 2 km stretch of the creek. EPA tested dead fish and concluded probable cause of death was low oxygen levels in water. NSW National Parks and Wildlife record (G. Wallace).

9.8.4 Oysters

- Berowra Creek is an important element in the Hawkesbury River oyster industry as the primary area for the fattening of oysters to improve the quality of the meat; and providing the most consistent conditions for the final stages of growth pending their harvest for subsequent sale (Hornsby Shire Council 1993).

- Anecdotal information has indicated that oysters were once farmed further up the creek than is now the case. However, data from NSW Fisheries extending back to 1972 on the location and activities of oyster leases in Berowra Creek show no patterns with respect to activity and the relative position of the oyster leases in the creek. Furthermore, the leases located furthest upstream (in Kimmerikong Bay) are currently in production, although NSW Fisheries data do not allow direct comparisons between production of individual leases.

- EPA (1996) found that wild oysters from Berowra Creek generally had metal concentrations below National Food Authorities standard for human consumption. They found that there was a significant correlation between levels of zinc, copper and DDT in sediments and those in wild oysters.

9.8.5 Waterbirds

- Birds observed during the seagrass survey by The Ecology Lab in April 1997 include white-breasted sea eagles, cormorants, kingfishers, sea gulls, plovers, black ducks, chestnut teals and white-faced and mangrove herons.

- Berowra Creek is not considered by NPWS to be a key habitat area for waterbirds as it does not contain major mudflat areas. However, the mudflats of Kimmerikong and Big bays are popular feeding grounds for some bird species protected under Australian legislation (EPA 1992).

9.9 Other

Recher et al. (1993) looked at the impact of European settlement on the biota of the Hawkesbury-Nepean catchment, and for Berowra Waters in particular noted the following:

- water quality had deteriorated;
- tidal flushing was inadequate and high nutrient loads stimulated algal growth;
- storm surges were followed by dinoflagellate blooms;
- phytoplankton and suspended matter had greatly increased turbidity;

- dense growths of Enteromorpha, a green algae associated with increased nutrient levels and reduced salinity, were common along the high tide line in the cooler months; and
- it was likely that many species of fish and crabs had declined in abundance.

9.10 Summary of Ecological Processes

Ecological processes in Berowra Creek appear to be fundamentally similar to those in other estuaries along the NSW coast. However, the system has several unique attributes that contribute to making certain of these processes a concern to the community at large and the managers responsible for maintaining them. One important feature, that Berowra Creek flows not directly into the ocean, but into the Hawkesbury River, has important implications for the movement of water (and, in particular, the retention of water in the creek) and the ecological processes mediated by water movement, such as the recruitment of fish and invertebrates. Another important feature of Berowra Creek is the presence of deep holes, mainly in the middle section of the creek, that are sinks for fine sediments and have unique water quality characteristics. In the absence of anthropogenic inputs, such a system would be expected to be dynamic, as these physical features interact with ecological processes. It would be expected that, periodically, natural phytoplankton blooms would be 'trapped' in the mid-section of the creek due to the nature of water flushing in the system. It might also be expected that fish kills would occur naturally, although at some unknown frequency, due to the possibility that oxygen-depleted water from the deep holes would rise to the surface due to some force (perhaps an extraordinary wind or rainfall event) mixing the deep layers. Thus, while phytoplankton blooms and fish kills have directly observable and catastrophic effects on fish and plankton, they can be viewed as natural phenomenon probably exacerbated by anthropogenic causes. Human inputs into the system such as nutrients from sewage treatment plants and runoff from farms may increase the occurrences or duration of both phytoplankton blooms and fish kills. Anecdotal accounts hold that these events are more frequent now than in the past, but quantitative data is lacking to confirm that view.

However, adequate information is available to indicate that, in general, water quality in the creek system is poor, and frequently fails to meet standards considered to be minimal to ensure ecological health.

For other elements of the ecological system in the creek, a lack of data linking water quality and fauna hampers the identification of the ecological effects of poor water quality. For groups such as zooplankton and estuarine benthos observations of reduced abundance and diversity are difficult to attribute directly to poor water quality in the absence of longer-term, quantitative data on the natural variations in these parameters. The expected pattern for benthic fauna, for instance, is for small estuarine systems to have smaller abundances and less diversity of aquatic plants and animals compared to larger, fully marine systems. Ecological processes controlling the abundance and diversity of the benthos such as the pattern of replenishment of benthic fauna after a significant flood event have been documented for the adjacent Hawkesbury River (Jones et al. 1986, Jones 1987). The controlling factor in such replenishment is water exchange with the ocean, the major source of benthic larval propagules. Because the Berowra Creek system has restricted flushing and is not directly linked with the ocean, a pattern of slower replenishment after a significant event would be expected, resulting in fewer species present than in the adjacent Hawkesbury River. But the data are not available to distinguish this natural process from the hypothesis that the benthos in Berowra Creek are impoverished due to the effects of sewage or other human influence.

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Appendix A
Rainfall Analysis

Table A1 Duration Between 0 mm of Rainfall

0 mm	Summer	Autumn	Winter	Spring	All Data
Average	3.86	3.86	4.36	3.89	2.87
Standard Deviation	4.23	4.93	5.76	4.65	4.28
Mode	1	1	1	1	1
Min	1	1	1	1	1
Max	27	48	41	43	122
10 percentile	1	1	1	1	1
50 percentile	2	2	2	2	1
90 percentile	9	9	11	8	7
Data Points	572	930	804	880	5628

Table A2 Duration Between 10 mm of Rainfall

10 mm	Summer	Autumn	Winter	Spring	All Data
Average	9.64	11.49	10.31	10.90	16.56
Standard Deviation	10.52	15.96	14.17	13.29	23.11
Mode	1	1	1	1	1
Min	1	1	1	1	1
Max	42	75	72	68	196
10 percentile	1	13	1	1	1
50 percentile	6	7	4	6	7
90 percentile	26.2	14	27.1	31.1	45
Data Points	139	192	180	180	968

Table A3 Duration Between 20 mm of Rainfall

20 mm	Summer	Autumn	Winter	Spring	All Data
Average	12.64	15.83	10.86	14.07	33.67
Standard Deviation	13.90	19.83	14.98	16.28	46.31
Mode	1	1	1	1	1
Min	1	1	1	1	1
Max	52	78	70	61	324
10 percentile	1	1	1	1	1
50 percentile	7	7	5	6	14
90 percentile	33	45.6	36.3	41.2	96
Data Points	55	88	78	59	473

Table A4 Duration Between 30 mm of Rainfall

30 mm	Summer	Autumn	Winter	Spring	All Data
Average	13.83	14.18	11.91	18.65	54.32
Standard Deviation	15.74	16.36	15.86	23.12	69.52
Mode	1	1	1	1	1
Min	1	1	1	1	1
Max	52	62	69	71	366
10 percentile	1	1	1	1	1
50 percentile	5.5	6.5	6	7	27
90 percentile	35.8	39.2	37.4	57.5	155.6
Data Points	24	40	47	26	292

Table A5 Duration Between 50 mm of Rainfall

50 mm	Summer	Autumn	Winter	Spring	All Data
Average	10.50	11.57	10.78	4.25	129.80
Standard Deviation	11.39	11.28	14.49	6.50	150.09
Mode	#N/A	1	1	1	1
Min	1	1	1	1	1
Max	26	35	45	14	583
10 percentile	1.6	1	1	1	1
50 percentile	7.5	9	4	1	67
90 percentile	21.8	26.2	34.7	10.1	350.4
Data Points	4	14	18	4	119

Appendix B
Tabulated Tidal Constituents for Sites in Berowra Creek

Table B1a Analysis of Tidal Observations - Crosslands

Time of Analysis	1310: 14-04-97
Station Location	*
Station Name	Berowra Creek, Crosslands
Station Latitude	033 Deg 50 Min South
Station Longitude	151 Deg 15 Min East
Datum	Australian Height Datum
Analysis Period Start Time	1900: 26-05-95
Analysis Period Finish Time	1200: 28-09-95
Mid Point Time	0300: 28-07-95
Period Of Analysis	124 days 18 hrs
Local Time Zone Name	Eastern Standard Time
Local Time Factor	GMT +10.00 Hrs
Time Meridian	-10.08 Hrs

* N.B. No station input file.. Inference ratios and latitude/longitude values obtained from station input file for Middle Head Cobblers Bay i.e. LEVEL$CAN:SYDIN.DAT

Table B1b List of Harmonic Constituents

No.	Name	Frequency (cyc/hr)	Period (day,hr)	Mean Amplitude (metres)	G-Phase (deg)	Local Amplitude (metres)	Local Phase (deg)
1	Z0			0.262413		0.262413	
2	MM	0.001512	27d,13h	0.051595	350.6	0.051595	119.7
3	MSF	0.002821	14d,18h	0.054924	14.62	0.054924	357.33
4	ALP1	0.034396	29.07h	0.000492	14.4	0.000421	96.69
5	2Q1	0.035706	28.01h	0.006740	41.66	0.005777	337.65
6	Q1	0.037218	26.87h	0.025662	71.01	0.021876	136.25
7	O1	0.038730	25.82h	0.104746	103.06	0.088566	297.61
8	NO1	0.040268	24.83h	0.013161	227.34	0.006025	188.45
9*	P1	0.041552	24.07h	0.039974	133.7	-1	0.040434
10	K1	0.041780	23.93h	0.144230	140.88	0.130205	235.33
11	J1	0.043292	23.10h	0.011	213.14	0.009803	74.09
12	OO1	0.044830	22.31h	0.014552	202.24	0.006176	10.63
13	UPS1	0.046343	21.58h	0.001702	31.07	0.000849	328.13
14	EPS2	0.076177	13.13h	0.006440	311.83	0.006964	126.32
15	MU2	0.077689	12.87h	0.031247	329.52	0.032662	273.04
16	N2	0.078999	12.66h	0.102203	256.12	0.105709	53.02
17	M2	0.080511	12.42h	0.531072	268.94	0.548480	195.14
18	L2	0.082023	12.19h	0.030152	290.4	0.036329	165.73
19	S2	0.083333	12.00h	0.099662	300.31	0.099479	210.37
20**	K2	0.083561	11.97h	0.028610	287.17	-2	0.022267
21	ETA2	0.085073	11.75h	0.005025	142.56	0.003805	275.21
22	MO3	0.119242	8.39h	0.017382	248.24	0.015179	9
23	M3	0.120767	8.28h	0.005951	169.14	0.006242	238.51
24	MK3	0.122292	8.18h	0.024457	342.3	0.022803	2.96

25	SK3	0.125114	7.99h	0.002114	145.78	0.001905	150.29
26	MN4	0.159510	6.27h	0.024291	113.89	0.025947	197
27	M4	0.161022	6.21h	0.060082	129.18	0.064086	341.59
28	SN4	0.162332	6.16h	0.012136	195.38	0.012529	262.34
29	MS4	0.163844	6.10h	0.025565	177.46	0.026354	13.73
30	S4	0.166666	6.00h	0.002996	303.65	0.002985	123.77
31	2MK5	0.202803	4.93h	0.008759	106.52	0.008434	53.38
32	2SK5	0.208447	4.80h	0.001371	27.28	0.001233	301.85
33	2MN6	0.240022	4.17h	0.004891	213.78	0.005395	223.08
34	M6	0.241534	4.14h	0.009937	222.35	0.010947	0.97
35	2MS6	0.244356	4.09h	0.006369	283.33	0.006780	45.8
36	2SM6	0.247178	4.05h	0.000822	86.03	0.000846	192.36
37	3MK7	0.283314	3.53h	0.002715	269.3	0.002700	142.37
38	M8	0.322045	3.11h	0.003992	76.1	0.004542	140.92
39	M10	0.402557	2.48h	0.000659	20.21	0.000774	11.23

Key: * P1 is inferred from K1
** K2 is inferred from S2

After inference, RMS (Residual Error) = 0.10271

Table B1c Tidal Planes in Metres Above Zero of Local Gauge Values

High High Water (Solstices Springs)	HHW (SS)	1.242
Mean High Water Springs	MHWS	0.893
Mean High Water	MHW	0.793
Mean High Water Neaps	MHWN	0.694
Mean Sea Level	MSL	0.262
Mean Low Water Neaps	MLWN	-0.169
Mean Low Water	MLW	-0.269
Mean Low Water Springs	MLWS	-0.368
Indian Spring Low Water	ISLW	-0.617

Table B1d Tidal Ranges in Metres

Mean Spring Range	(MHWS - MLWS)	1.261
Mean Neap Range	(MHWN - MLWN)	0.863
Mean Range	(MHW - MLW)	1.062
Range	(HHW (SS) - ISLW)	1.859

Table B2a Analysis of Tidal Observations - Berowra Marina

Time of Analysis	1309: 14-04-97
Station Location	*
Station Name	Berowra Creek, Berowra Marina
Station Latitude	033 Deg 50 Min South
Station Longitude	151 Deg 15 Min East
Datum	Australian Height Datum
Analysis Period Start Time	1900: 26-05-95
Analysis Period Finish Time	1300: 28-09-95
Mid Point Time	0400: 28-07-95
Period Of Analysis	124 days 19 hrs
Local Time Zone Name	Eastern Standard Time
Local Time Factor	GMT +10.00 Hrs
Time Meridian	-10.08 Hrs

* N.B. No station input file.. Inference ratios and latitude/longitude values obtained from station input file for Middle Head Cobblers Bay i.e. LEVEL$CAN:SYDIN.DAT

Table B2b List of Harmonic Constituents

No.	Name	Frequency (cyc/hr)	Period (day,hr)	Mean Amplitude (metres)	G-Phase (deg)	Local Amplitude (metres)	Local Phase (deg)
1	Z0			0.179356		0.179356	
2	MM	0.001512	27d,13h	0.045254	345.15	0.045254	113.7
3	MSF	0.002821	14d,18h	0.034436	1.21	0.034436	342.89
4	ALP1	0.034396	29.07h	0.001521	58.34	0.001300	128.24
5	2Q1	0.035706	28.01h	0.006209	14.26	0.005321	297.42
6	Q1	0.037218	26.87h	0.025546	62.21	0.021777	114.02
7	O1	0.038730	25.82h	0.100782	95.1	0.085214	275.71
8	NO1	0.040268	24.83h	0.007747	181.41	0.003546	128.01
9*	P1	0.041552	24.07h	0.042737	127.05	-1	0.043228
10	K1	0.041780	23.93h	0.154198	134.23	0.139203	213.64
11	J1	0.043292	23.10h	0.012486	207.05	0.011128	52.42
12	OO1	0.044830	22.31h	0.014942	177.42	0.006341	329.68
13	UPS1	0.046343	21.58h	0.002681	332.2	0.001338	252.6
14	EPS2	0.076177	13.13h	0.007517	271.05	0.008129	58.12
15	MU2	0.077689	12.87h	0.031946	293.85	0.033392	209.42
16	N2	0.078999	12.66h	0.116829	246.51	0.120836	14.96
17	M2	0.080511	12.42h	0.580665	260.17	0.599699	157.39
18	L2	0.082023	12.19h	0.026337	273.05	0.031732	118.85
19	S2	0.083333	12.00h	0.126457	289.85	0.126224	169.91
20**	K2	0.083561	11.97h	0.036302	276.71	-2	0.028254
21	ETA2	0.085073	11.75h	0.000754	96.05	0.000571	198.06
22	MO3	0.119242	8.39h	0.013894	179.36	0.012132	257.19
23	M3	0.120767	8.28h	0.004414	45.1	0.004629	70.99
24	MK3	0.122292	8.18h	0.010234	253.56	0.009542	230.2

25	SK3	0.125114	7.99h	0.004690	211.43	0.004226	170.9
26	MN4	0.159510	6.27h	0.005672	46.48	0.006059	72.14
27	M4	0.161022	6.21h	0.009615	68.22	0.010255	222.66
28	SN4	0.162332	6.16h	0.002326	104.59	0.002401	113.1
29	MS4	0.163844	6.10h	0.006120	76.17	0.006309	213.45
30	S4	0.166666	6.00h	0.000609	99.15	0.000607	219.27
31	2MK5	0.202803	4.93h	0.006408	320.11	0.006170	193.97
32	2SK5	0.208447	4.80h	0.001826	353.45	0.001642	192.99
33	2MN6	0.240022	4.17h	0.007759	99.89	0.008560	22.78
34	M6	0.241534	4.14h	0.013230	119.33	0.014574	171
35	2MS6	0.244356	4.09h	0.007303	164.82	0.007776	199.33
36	2SM6	0.247178	4.05h	0.000690	161.16	0.000710	178.51
37	3MK7	0.283314	3.53h	0.001657	65.99	0.001648	197.08
38	M8	0.322045	3.11h	0.000968	112.45	0.001101	61.34
39	M10	0.402557	2.48h	0.00116	354.18	0.001363	200.3

Key: * P1 is inferred from K1
** K2 is inferred from S2

After inference, RMS (Residual Error) = 0.10672

Table B2c Tidal Planes in Metres Above Zero of Local Gauge Values

High High Water (Solstices Springs)	HHW (SS)	1.243
Mean High Water Springs	MHWS	0.886
Mean High Water	MHW	0.760
Mean High Water Neaps	MHWN	0.634
Mean Sea Level	MSL	0.179
Mean Low Water Neaps	MLWN	-0.275
Mean Low Water	MLW	-0.401
Mean Low Water Springs	MLWS	-0.528
Indian Spring Low Water	ISLW	-0.783

Table B2d Tidal Ranges in Metres

Mean Spring Range	(MHWS - MLWS)	1.414
Mean Neap Range	(MHWN - MLWN)	0.908
Mean Range	(MHW - MLW)	1.161
Range	(HHW (SS) - ISLW)	2.026

Table B3a Analysis of Tidal Observations - Oaky Point

Time of Analysis	1309: 14-04-97
Station Location	*
Station Name	Berowra Creek, Oaky Point
Station Latitude	033 Deg 50 Min South
Station Longitude	151 Deg 15 Min East
Datum	Australian Height Datum
Analysis Period Start Time	1900: 26-05-95
Analysis Period Finish Time	1000: 28-09-95
Mid Point Time	0200: 28-07-95
Period Of Analysis	124 days 16 hrs
Local Time Zone Name	Eastern Standard Time
Local Time Factor	GMT +10.00 Hrs
Time Meridian	-10.08 Hrs

* N.B. No station input file.. Inference ratios and latitude/longitude values obtained from station input file for Middle Head Cobblers Bay i.e. LEVEL$CAN:SYDIN.DAT

Table B3b List of Harmonic Constituents

No.	Name	Frequency (cyc/hr)	Period (day,hr)	Mean Amplitude (metres)	G-Phase (deg)	Local Amplitude (metres)	Local Phase (deg)
1	Z0			0.198634		0.198634	
2	MM	0.001512	27d,13h	0.045136	345.19	0.045136	114.84
3	MSF	0.002821	14d,18h	0.033114	1.45	0.033114	345.17
4	ALP1	0.034396	29.07h	0.001702	72.79	0.001454	167.44
5	2Q1	0.035706	28.01h	0.005684	14.93	0.004871	323.81
6	Q1	0.037218	26.87h	0.025083	62.63	0.021382	141.25
7	O1	0.038730	25.82h	0.100173	94.81	0.084700	303.31
8	NO1	0.040268	24.83h	0.008902	180.53	0.004075	156.15
9*	P1	0.041552	24.07h	0.042501	126.78	-1	0.042990
10	K1	0.041780	23.93h	0.153347	133.96	0.138436	243.46
11	J1	0.043292	23.10h	0.012380	206.05	0.011034	82.6
12	OO1	0.044830	22.31h	0.015095	179.8	0.006407	4.33
13	UPS1	0.046343	21.58h	0.002111	309.94	0.001053	263.7
14	EPS2	0.076177	13.13h	0.007259	266.61	0.007849	108.47
15	MU2	0.077689	12.87h	0.031153	292.7	0.032564	264.21
16	N2	0.078999	12.66h	0.115928	245.8	0.119904	71.16
17	M2	0.080511	12.42h	0.575885	259.42	0.594762	214.62
18	L2	0.082023	12.19h	0.026050	273.42	0.031387	178.29
19	S2	0.083333	12.00h	0.125449	289.13	0.125218	229.2
20**	K2	0.083561	11.97h	0.036012	275.99	-2	0.028029
21	ETA2	0.085073	11.75h	0.000895	70.06	0.000678	233.35
22	MO3	0.119242	8.39h	0.013255	177.97	0.011575	341.67
23	M3	0.120767	8.28h	0.003918	50.82	0.004109	163.68
24	MK3	0.122292	8.18h	0.009756	256.18	0.009096	320.87

25	SK3	0.125114	7.99h	0.004547	207.14	0.004097	256.71
26	MN4	0.159510	6.27h	0.005852	50.56	0.006252	191.11
27	M4	0.161022	6.21h	0.010096	73.75	0.010769	344.15
28	SN4	0.162332	6.16h	0.002115	97.14	0.002183	222.57
29	MS4	0.163844	6.10h	0.006157	82.42	0.006347	337.69
30	S4	0.166666	6.00h	0.000667	92.02	0.000665	332.16
31	2MK5	0.202803	4.93h	0.005966	315.28	0.005744	335.18
32	2SK5	0.208447	4.80h	0.001413	356.25	0.001271	345.88
33	2MN6	0.240022	4.17h	0.007417	95.47	0.008182	191.22
34	M6	0.241534	4.14h	0.012150	116.39	0.013384	341.98
35	2MS6	0.244356	4.09h	0.006780	162.9	0.007218	13.36
36	2SM6	0.247178	4.05h	0.000694	179.45	0.000715	14.78
37	3MK7	0.283314	3.53h	0.001598	59.74	0.001589	34.83
38	M8	0.322045	3.11h	0.000912	104.67	0.001038	285.46
39	M10	0.402557	2.48h	0.001179	354.52	0.001386	130.51

Key: * P1 is inferred from K1
** K2 is inferred from S2

After inference, RMS (Residual Error) = 0.10479

Table B3c Tidal Planes in Metres Above Zero of Local Gauge Values

High High Water (Solstices Springs)	HHW (SS)	1.255
Mean High Water Springs	MHWS	0.9
Mean High Water	MHW	0.775
Mean High Water Neaps	MHWN	0.649
Mean Sea Level	MSL	0.199
Mean Low Water Neaps	MLWN	-0.252
Mean Low Water	MLW	-0.377
Mean Low Water Springs	MLWS	-0.503
Indian Spring Low Water	ISLW	-0.756

Table B3d Tidal Ranges in Metres

Mean Spring Range	(MHWS - MLWS)	1.403
Mean Neap Range	(MHWN - MLWN)	0.901
Mean Range	(MHW - MLW)	1.152
Range	(HHW (SS) - ISLW)	2.011

Table B4a Analysis of Tidal Observations - Berowra Point

Time of Analysis	1308: 14-04-97
Station Location	*
Station Name	Berowra Creek, Berowra Point
Station Latitude	033 Deg 50 Min South
Station Longitude	151 Deg 15 Min East
Datum	Australian Height Datum
Analysis Period Start Time	1900: 26-05-95
Analysis Period Finish Time	1000: 28-09-95
Mid Point Time	0200: 28-07-95
Period Of Analysis	124 days 16 hrs
Local Time Zone Name	Eastern Standard Time
Local Time Factor	GMT +10.00 Hrs
Time Meridian	-10.08 Hrs

* N.B. No station input file.. Inference ratios and latitude/longitude values obtained from station input file for Middle Head Cobblers Bay i.e. LEVEL$CAN:SYDIN.DAT

Table B4b List of Harmonic Constituents

No.	Name	Frequency (cyc/hr)	Period (day,hr)	Mean Amplitude (metres)	G-Phase (deg)	Local Amplitude (metres)	Local Phase (deg)
1	Z0			0.130663		0.130663	
2	MM	0.001512	27d,13h	0.044426	342.62	0.044426	112.27
3	MSF	0.002821	14d,18h	0.032714	1.02	0.032714	344.74
4	ALP1	0.034396	29.07h	0.001510	75.35	0.001290	169.99
5	2Q1	0.035706	28.01h	0.005790	13.11	0.004962	321.99
6	Q1	0.037218	26.87h	0.02467	61.48	0.021030	140.1
7	O1	0.038730	25.82h	0.098706	93.61	0.083460	302.12
8	NO1	0.040268	24.83h	0.007994	178.19	0.003659	153.8
9*	P1	0.041552	24.07h	0.04231	125.48	-1	0.042796
10	K1	0.041780	23.93h	0.152655	132.66	0.137811	242.16
11	J1	0.043292	23.10h	0.01221	204.04	0.010882	80.59
12	OO1	0.044830	22.31h	0.014447	182.64	0.006132	7.17
13	UPS1	0.046343	21.58h	0.002009	323.32	0.001002	277.08
14	EPS2	0.076177	13.13h	0.006589	261.41	0.007125	103.27
15	MU2	0.077689	12.87h	0.028416	286.88	0.029703	258.39
16	N2	0.078999	12.66h	0.113220	242.97	0.117104	68.32
17	M2	0.080511	12.42h	0.560741	257.16	0.579121	212.36
18	L2	0.082023	12.19h	0.024358	274.59	0.029348	179.46
19	S2	0.083333	12.00h	0.121673	285.46	0.121448	225.52
20**	K2	0.083561	11.97h	0.034928	272.32	-2	0.027185
21	ETA2	0.085073	11.75h	0.000630	67.95	0.000477	231.24
22	MO3	0.119242	8.39h	0.010580	177.5	0.009239	341.2
23	M3	0.120767	8.28h	0.003338	48.57	0.003501	161.43
24	MK3	0.122292	8.18h	0.007225	255.91	0.006736	320.61

25	SK3	0.125114	7.99h	0.004392	200.34	0.003957	249.91
26	MN4	0.159510	6.27h	0.004372	65.2	0.004670	205.75
27	M4	0.161022	6.21h	0.008361	100.61	0.008919	11.01
28	SN4	0.162332	6.16h	0.000663	110.72	0.000684	236.14
29	MS4	0.163844	6.10h	0.003557	96.69	0.003667	351.96
30	S4	0.166666	6.00h	0.000204	95.65	0.000203	335.79
31	2MK5	0.202803	4.93h	0.004689	318.26	0.004515	338.15
32	2SK5	0.208447	4.80h	0.001097	333.84	0.000986	323.48
33	2MN6	0.240022	4.17h	0.006595	91.13	0.007275	186.88
34	M6	0.241534	4.14h	0.010506	115.54	0.011574	341.13
35	2MS6	0.244356	4.09h	0.006228	158.39	0.006631	8.85
36	2SM6	0.247178	4.05h	0.000569	160.68	0.000586	356.01
37	3MK7	0.283314	3.53h	0.000998	40.13	0.000993	15.23
38	M8	0.322045	3.11h	0.000682	51.78	0.000776	232.57
39	M10	0.402557	2.48h	0.000574	338.51	0.000674	114.5

Key: * P1 is inferred from K1
** K2 is inferred from S2

After inference, RMS (Residual Error) = 0.10312

Table B4c Tidal Planes in Metres Above Zero of Local Gauge Values

High High Water (Solstices Springs)	HHW (SS)	1.165
Mean High Water Springs	MHWS	0.813
Mean High Water	MHW	0.691
Mean High Water Neaps	MHWN	0.570
Mean Sea Level	MSL	0.131
Mean Low Water Neaps	MLWN	-0.308
Mean Low Water	MLW	-0.430
Mean Low Water Springs	MLWS	-0.552
Indian Spring Low Water	ISLW	-0.803

Table B4d Tidal Ranges in Metres

Mean Spring Range	(MHWS - MLWS)	1.365
Mean Neap Range	(MHWN - MLWN)	0.878
Mean Range	(MHW - MLW)	1.121
Range	(HHW (SS) - ISLW)	1.968

Appendix C
Aquatic and Terrestrial Vegetation Information

Table C1 Plant Community Descriptions

Community Description	Vegetation Units			Structure			Dominant Species		Habitat
	Benson and Howell (1994)			Strata			Overstorey		
Tall Open Forest	10ag	9	L	Trees: Sm. Trees: Shrubs: Ground Layer:	20-35 6-15 1.5-4 0.3-1.5	20-60 5-40 10-70 20-70	Eucalyptus pilularis Angophora costata Eucalyptus piperita Eucalyptus gummifera Syncarpia glomulifera Allocasuarina torulosa	Pultenaea flexilis Persoonia pinifolia Xanthorrhoea arborea Pteridium esculentum Dodonaea triquetra	Occurs in gullies and sheltered Hawkesbury Sandstone slopes. Greatest development on protected steep, south-facing slopes.
Tall Open Forest	10ag	-	J	Trees: Sm. Trees: Shrubs: Ground layer:	40 10 5 1	40 10 10 90	Eucalyptus saligna Eucalyptus pilularis Angophora floribunda	Cinnamomum camphora* Ligustrum sinense* Ligustrum lucidum* Culcita dubia*	Occurs in two sites only in the Berowra Valley Bushland Park: south-eastern slopes of Joes Mountain and Boundary Road at the southern most tip of the Park.
Tall Open Forest	10ag	-	P	Trees: Sm. Trees: Shrubs: Ground layer:	35-40 5-15 0.5-3	30-50 20-60 70-90	Eucalyptus pilularis Angophora floribunda Eucalyptus saligna	Glochidion ferdinandi Ligustrum sinense* Acacia floribunda Culcita dubia	Restricted to alluvial flats beside Berowra Creek just south of Crosslands.
Open Forest	10ag	9	A	Trees: Sm. Trees Shrubs: Ground layer:	12-20 5-8 2-4 0.5-1.5	10-50 5-15 5-60 30-90	Eucalyptus piperita Angophora costata Eucalyptus gummifera Eucalyptus punctata	Dillwynia retorta Platysace linearifolia Pteridum esculentum Lomandra longifolia Entolasia stricta Caustis flexuosa	Most extensive community in Berowra Valley Bushland Park. Occupies sheltered slopes and gullies of the Hawkesbury Soil Landscape Unit.

Open Forest	9h	7	Q	Trees: Sm. Trees: Shrubs: Ground layer:	20-30 10-18 2-8 0.2-1	10-50 10-80 10-80 5-60	Angophora floribunda Allocasuarina torulosa Eucalyptus piperita Eucalyptus punctata	Acmena smithii Acacia ulcifolia Persoonia linearis Dodonaea triquetra Glochidion ferdinandi	On dry soils from Narrabeen geology and colluvial soils on Hawkesbury Sandstone footslopes, above estuarine conditions. The aspect is commonly dry and exposed. Common adjacent to the tidal reaches of Berowra Creek in the north of Berowra Valley Bushland Park.
Open Forest	10ar	-	B	Trees: Sm. Trees: Shrubs: Ground layer:	10-14 2-4 0.5-1	30-50 50-80 10-40	Eucalyptus piperita Angophora bakeri	Dillwynia retorta Lomandra glauca Entolasia stricta Tetratheca thymifolia	Occurs only on one ridge-top with a north-east aspect near Cherrybrook.
Low Open Forest	10ar	11	-	Trees: Sm. Trees: Shrubs: Ground layer:	5-15 7-9 2-4 1-2	10-30 20-50 10-50 30-50	Eucalyptus racemosa Eucalyptus gummifera Eucalyptus sieberi Eucalyptus eximia	Banksia serrata Xylomelum pyriforme Lambertia formosa Banksia marginata Banksia spinulosa	Plateau surface on yellow earth soils with a clay sub-soil often containing iron-stone Mittagong formation. Occurs on the flatter, higher ridge tops of Bujwa Ridge, Kimmerikong Ridge and Wedgwood Ridge.
Closed Forest	10ag	1	O	Trees: Sm. Trees: Shrubs: Ground layer:	15-35 4-10 4-10 0.5-1.5	0-10 20-80 20-80 20-50	Eucalyptus piperita Angophora costata Tristaniopsis laurina Ceratopetalum apetalum	Ligustrum lucidum* Sticherus flabellatus Culcita dubia Lomandra longifolia Pteridum esculentum	Found in deep sheltered gullies along the narrow strip of Hawkesbury Sandstone adjacent to the major watercourses, eg Joe Crafts Creek, Bujwa Creek, Kimmerikong Creek and Muogamarra Creek. Usually found below Community 9.

Closed Forest	4a	22	V	Trees: Sm. Trees Shrubs: Ground layer:	12-18 3-10 0.2-2	40-80 0-10 60-90	Casuarina glauca Avicennia marina Aegiceras corniculatum	Sporobolus virginicus Phragmites australis Samolus repens Stenotaphrum secundatum	Occurs on saline alluvial flats beside the tidal reaches of Berowra Creek, mostly above the limit on tidal inundation.
Woodland	10ar	13	D, E, F	Trees: Sm. Trees: Shrubs: Ground layer:	8-18 4-6 1-2 0.3-1.0	10-50 5-40 10-60 10-50	Eucalyptus racemosa Eucalyptus punctata Eucalyptus gummifera Eucalyptus eximia	Leptospermum attenuatum Banksia serrata Phylotta phylicoides Dillwynia retorta Xanthorrhoea media	Occurs on steep slopes and ridgetops and also on narrow crests and hillocks. Usually with a dry, exposed aspect. Very widespread, most common on north- and west- facing slopes above water.
Low Open Woodland	10ar	15	C, G	Trees: Sm. Trees: Shrubs: Ground layer:	8-12 3-6 1-2 0.3-1	10-50 5-30 5-80 10-70	Eucalyptus gummifera Eucalyptus haemastoma Eucalyptus oblonga Eucalyptus eximia	Banksia serrata Hakea sp Pultenaea elliptica Dillwynia retorta Lambertia formosa	Occurs on shallower soils in flat or gently sloping areas, often with impeded drainage, on Hawkesbury Sandstone.
Closed Scrub/Scrub Heath	21g	17	-	Trees: Sm. Trees: Shrubs: Ground layer:	6-10 1-4 1-4 0.5-1.5	0-10 10-20 20-60 50-70	Eucalyptus gummifera Eucalyptus haemastoma Eucalyptus oblonga	Banksia oblongifolia Hakea teretifolia Banksia ericifolia Petrophile pulchella Angophora hispida	Low slope areas on ridges, hillsides and sandstone benches with impeded drainage and thin skeletal soils on ridge tops.
Rock Platform Heath	21g	18	H	Trees: Sm. Trees: Shrubs: Ground layer:	5 2 2 0.5	1 60 20 20-40	Eucalyptus gummifera Eucalyptus punctata	Banksia ericifolia Angophora hispida Banksia oblongifolia Baeckea brevifolia Epacris microphylla Kunzea capitata	Occurs on high exposed rocky areas, usually benches or shelves with a few joints. This community is found scattered throughout the study area on ridgetops but more common in the north.

Sedgeland/ Swamp	21g	21	I	Trees: Sm. Trees: Shrubs: Ground layer:	 1-2 0.4	 5 70	Banksia oblongifolia Banksia ericifolia Hakea teretifolia	Sprengelia incarnata Callistemon citrinus Schoenus brevifolius Baeckea imbricata Drosera spathulata Dampiera stricta	Occurs on poorly drained Hawkesbury Sandstone soils subject to prolonged waterlogging.
Tall Open Scrub - Mangrove	4a	19	W	Trees: Sm. Trees: Shrubs: Ground layer:	6-10 2-4 2-4	50-80 10-50 10-50	Avicennia marina	Aegiceras corniculatum	Occurs on saline alluvial soils in the upper tidal reaches of watercourses and mudflats subject to tidal inundation.
Saltmarsh	4a	20	Y	Trees: Sm. Trees: Shrubs: Ground layer:	 1	 90	Juncuss krausii Sarcocornia quinqueflora Sporobolus virginicus Samolus repens		Occurs on saline alluvial flats in sites subject to tidal inundation but slightly higher ground and hence less frequent inundation than Community W.

* Introduced Species

Table C2 Guide to Equivalent Vegetation Map Classifications

Benson and Howell (1994)	Benson (1985)	Smith and Smith (1990)
10ag	1 9	A L
10ar	11 13 15	D E F G C
9h	7	Q
21g	17 18 21	H I
4a	19 20	V W Y Z

Observations of Seagrasses by The Ecology Lab, April, 1997

A ground-truthing survey of seagrass by The Ecology Lab in April, 1997. We observed seagrasses at the following locations (rights and lefts set looking upstream):

- Section A, Crosslands to Berowra Waters Marina

Crosslands - a very patchy bed about 150 m long x 30 m wide, in dense clusters of shoots up to 50 cm long, GPS (taken roughly at the centre of the bed) 33o 37.755 S & 151o 06.751 E; not recorded in 1985 (West et al.)

Between Sam's and Calna Creeks - the bed on the right hand side was about 100 m x 20 m, in dense clusters of shoots up to 30 cm long, GPS 33o 37.479 S & 151o 07.234 E. - the bed on the left was about 230 m x 10 m, not as dense as the beds on the right but the shoots were about the same length - small, scattered beds about 1 m x 1 m on the right hand side; none of these were recorded in 1985 (West et al.)

Opposite to, and near the mouth of, Sam's Creek, and down to the next bay on the right - scattered beds about 4 m x 0.5 m, GPS 33o 37.388 S & 151o 07.433 E; not recorded in 1985 (West et al.)

About 350 m downstream of Sam's Creek - on the right, in front of a large unnamed bay, was a very patchy bed that was about 100 m x 15 m, GPS 33o 36.941 S & 151o 07.277 E; recorded by West et al.

300 m further downstream - on the right, a very patchy bed that was about 100 m x 6 m, with shoots generally less than 30 cm; not recorded in 1985 (West et al.)

200 m further downstream - on the left-hand bend below "Brittania Rock", was a very patchy bed about 80 m x 10 m, with shoots generally less than 40 cm, GPS 33o 36.623 S & 151o 07.429 E; recorded by West et al.

Noticeably absent from this survey compared to the 1985 survey, are three large beds between The Woolwash and the unnamed bay below Mt Orient. One of these beds, formerly about 100 m x 50 m, appears to have been smothered by sediment and now supports a significant mangrove stand of some 150 m x 50 m. The second large bed was adjacent to the first, but was about 400 m x 30 m, and the third was about 100 m x 70 m.

- Section B, Berowra Waters to Coba Point

Calabash Creek (none recorded by West et al., 1985). The creek was comprised of four arms. The first, on the left, ran N-S and was less than 6 m wide, with the occasional bed of seagrass about 2 m x 1 m, fringing the pneumatophores of the mangroves. The second arm was a broad bay running E-W, about 100 m across at its widest point. There were about 15-20 patchy beds within the bay, and most were about 2 m x 0.5 m, or 3 m x 1 m. GPS 33o 35.378 S & 151o 06. 506 E. The third arm also ran E-W, but was about 6 m wide. There was a bed about 10 m x 1 m fringing the pneumatophores about half-way along the arm, GPS 33o 35.328 S & 151o 06.422 E. The fourth arm was about 30 m wide at the mouth, but was generally less than 10 m wide for most of its length. There were about 5 small beds, roughly 2 m x 1 m, about half way up the arm, GPS 33o 35.057 S & 151o 06.435 E.

Joe Crafts Bay - one small bed in the left arm of the bay, about 3 m x 2 m; the two large beds recorded in 1985, 125 m x 50 m and 100 m x 50 m, were not present in this survey.

- Section C, Coba Point to upper Marramarra Creek

Within Marramarra Creek, there was a small bed about 3 m x 1 m, with shoots up to 60 cm long, GPS 33o 31.132 S & 151o 06.541 E. This bed was not recorded in West et al. (1985).