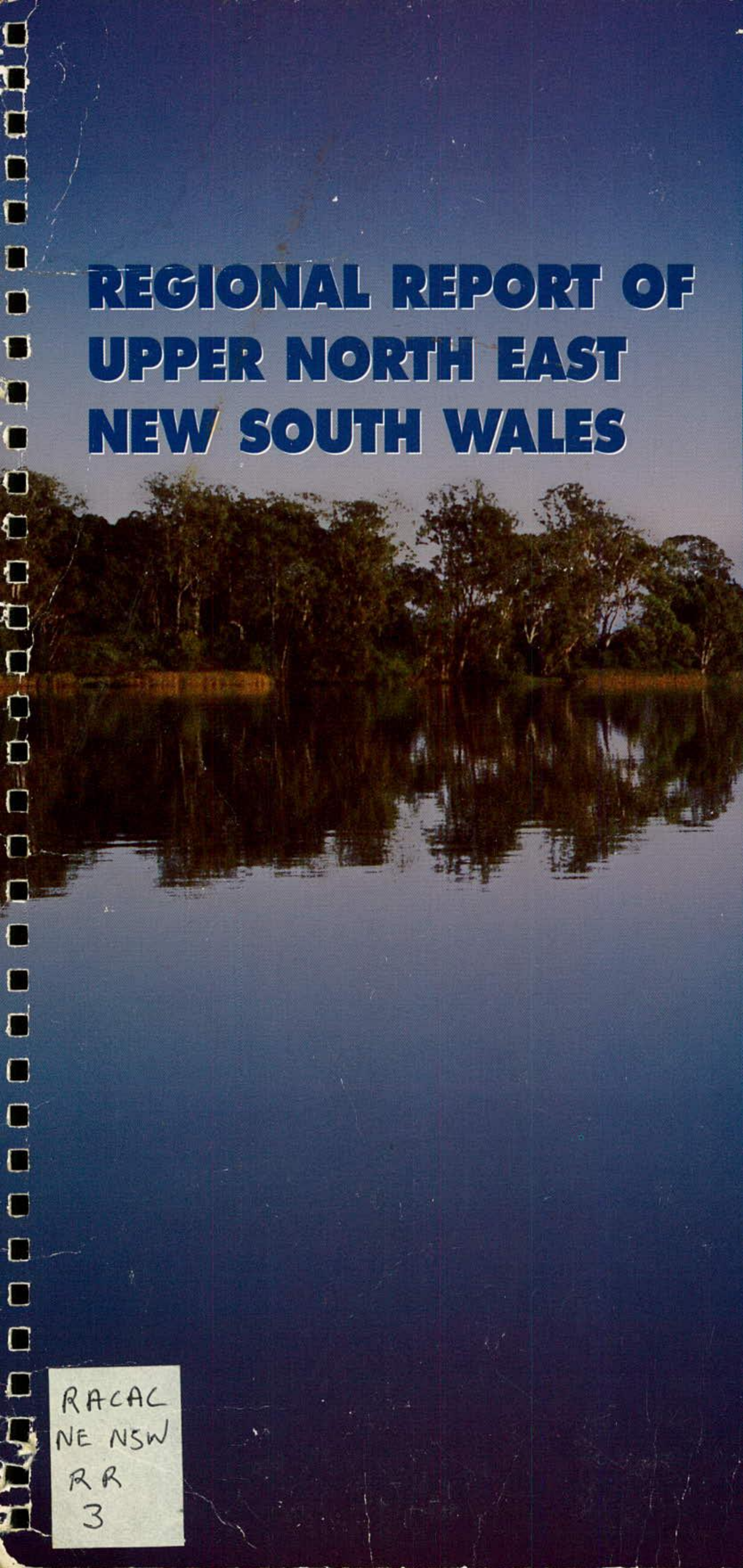
REGIONAL REPORT OF UPPER NORTH EAST NEW SOUTH WALES



3

Water attributes

Resource and Conservation Assessment Council

RACAC
N.E. NSW.
RR
3

REGIONAL REPORT OF UPPER NORTH EAST NEW SOUTH WALES

VOLUME 3
WATER ATTRIBUTES

A Report initiated by the Natural Resources Audit Council

Resource and Conservation Assessment Council

Sydney

ISBN
0 7310 7378 9
0 7310 7381 9 (volume 3)

cover photo: Clarence River, the largest coastal river in New South Wales.
Photo reproduced courtesy of Graham Sinden, Environment Protection Authority.

PREFACE

The Natural Resources Audit Council (NRAC) was established by the former NSW Government in 1993. Its brief was to conduct a series of regional 'audits' of public lands across the State, beginning with the Upper North East Region.

In 1995 the incoming Government fulfilled an election promise to dissolve NRAC while at the same time committing itself to publishing the findings to date of the first audit. It did this recognising not only the amount of work which had already gone into the task but also the value which that work may have to government and the community.

The Regional Report on the Upper North East has been a massive undertaking – of research, of coordination and of production. Its forty six chapters have been researched, written and reviewed with the involvement not only of the principal State Government agencies but also Commonwealth and local government, academic institutions, community groups, and individuals.

Although not an audit in any formal sense, the Report is an attempt to draw together sufficient information to give a detailed picture of the Region's public lands. It consists of six volumes:

Volume 1: Setting the scene
Volume 2: Physical attributes
Volume 3: Water attributes
Volume 4: Biodiversity attributes
Volume 5: Socio-economic attributes
Volume 6: Heritage, Aboriginal and social values

No similarly comprehensive report on public lands has previously been undertaken, and it was originally intended that this be an 'experimental first' in a series to be completed across New South Wales.

So as a first attempt to collate the attributes and values of the Upper North East Region, the Report cannot claim to be perfectly complete.

The unevenness between chapters reflects the unevenness in data quality and availability: some chapters raise as many questions as they answer. Yet this exercise in itself can be useful in identifying areas for further inquiry.

The Report is not intended to provide an assessment of the value of public lands or to make recommendations for management. It is meant to inform the community and decision-makers about the regional context. It will not provide a basis for decisions on allocation or management of individual parcels of land and will not replace the need for more detailed investigations and assessments when such decisions are being made.

The Regional Report documents a great deal of new and existing knowledge in an accessible format. It assists all the community – students, community groups, business and all levels of government – to understand the particular diversity of the Upper North East Region. It provides both a research tool and detailed background information to decision-making in New South Wales.

RIVERS AND CATCHMENTS

1.1 INTRODUCTION

A catchment, also called a drainage basin or watershed, consists of all land lying upstream from a specified point on a stream or river and enclosed by a topographic divide.

Catchments result when geological structures become subject to the dynamic processes of erosion and transportation of moving water over long periods of time. Each catchment is an ecologically and hydrologically integrated system (Dutton and Stewart, 1988) and is recognised as an important unit through which to manage natural resources.

The Upper North-East Audit Region includes catchments of the rivers which flow into the Pacific Ocean from Tweed Heads on the Queensland Border to just north of Coffs Harbour. Map 1a (Rivers and catchments of the Audit Region), shows the location of the Region, its rivers, catchments and towns. The Region includes four major river catchments, the Tweed, Brunswick, Richmond and Clarence, and several minor coastal catchments, such as Mooball, Cudgera, Cudgen, Belongil, Pine, Bonville, Woolgoolga, Corindi, Wooli, and Sandon (WC & IC 1966, 1968a, 1968b & 1970).

This chapter is intended to set the scene for the remaining chapters of this volume. (chapter 2: Coastal & marine zone, chapter 3: Groundwater, chapter 4: Hydrology, chapter 5: Water quality) and, therefore, only contains a brief overview of each of the major catchments and a few comments on the minor coastal catchments. A detailed description of the climate, geology, geomorphology and soils of the Upper North East Region is presented in volume 2, Physical attributes, and important water resources issues are considered in volume 5, chapter 6 Water resources values.

1.2 DESCRIPTION OF THE MAJOR CATCHMENTS

1.2.1 Tweed

The Tweed River Catchment covers an area of about 1110 square kilometres and has an average yearly discharge of about 540 000 Ml (table 1a).

The catchment has a symmetrical drainage pattern with the main stream being fed by only three major tributaries; the Rous, Oxley and Tweed Rivers. The Rous River rises in the Lamington Plateau area near Mount Merino and Mount Worendo in the McPherson Range (up to 1125 metres above sea level) and flows easterly, joining the Tweed River about eight kilometres downstream of Murwillumbah. Other tributaries of the Rous River, which drain sections of the McPherson Range, are Crystal and Dungay Creeks which rise near Springbrook and Mount Cougal respectively.

The Oxley River has its headwaters in the extreme western section of the catchment along the Tweed Range which extends from the Lamington Plateau to Loft's Pinnacle. The catchment boundary in this section follows precipitous cliffs and mountainous terrain at elevations of 900 to 1100 metres. Several creeks draining this region converge near the village of Tyalgum and flow in an easterly direction. The Oxley River joins the Tweed River about four kilometres upstream of Murwillumbah.

The Tweed River rises near Loft's Pinnacle in the south-western sector of the catchment at elevations of up to 900 metres and flows in a north-easterly direction, being joined first by Byrrill Creek and second by Doon Doon Creek about three kilometres upstream of Uki. The upper catchments of Doon Doon Creek and the Tweed River are characterised by mountainous terrain. Notable peaks in this area are Mount Burrell (Blue Nob) and Mount Mathieson. At Uki, the Tweed Arm is joined by Rolands and Smith's Creeks, both of which drain catchments of lower elevation than the other tributaries (WC & IC, 1968a).

Above Murwillumbah, the main streams and their tributaries flow through narrow alluvial flats. The upper and middle reaches of rivers are actively eroding wider and deeper valleys into the uplands. Below Murwillumbah, the Tweed occupies a broad open valley, flowing in a north-easterly direction and, finally, parallel to the coast, before breaking through the sandy coastline at Tweed Heads. In the lower reaches, abrupt changes, from rich alluvial flats and red clay loam to sandy heath and dune, produce marked contrasts within relatively small areas (WC & IC, 1968a).

The most outstanding topographic landmark in the Tweed Valley is Mount Warning, which is located in the centre of the Upper Tweed Catchment, midway between the Oxley and Upper Tweed Rivers. This mountain rises to an elevation of 1157 metres, the adjacent terrain falling away rapidly to about 60 metres above sea level in a distance of about three to five kilometres. Terrain of the Tweed River catchment is hilly to mountainous with land slopes in excess of eight degrees covering about 60% of the valley, whilst undulating to hilly areas, with slopes between three degrees and eight degrees, cover a further 20%. Areas of flat land, with slopes of less than three degrees, comprise only about 20 % of the catchment area. These flat areas are confined to the plain adjoining the lower reaches of the Tweed River and limited areas along the lower sections of the major tributaries (WC & IC, 1968a).

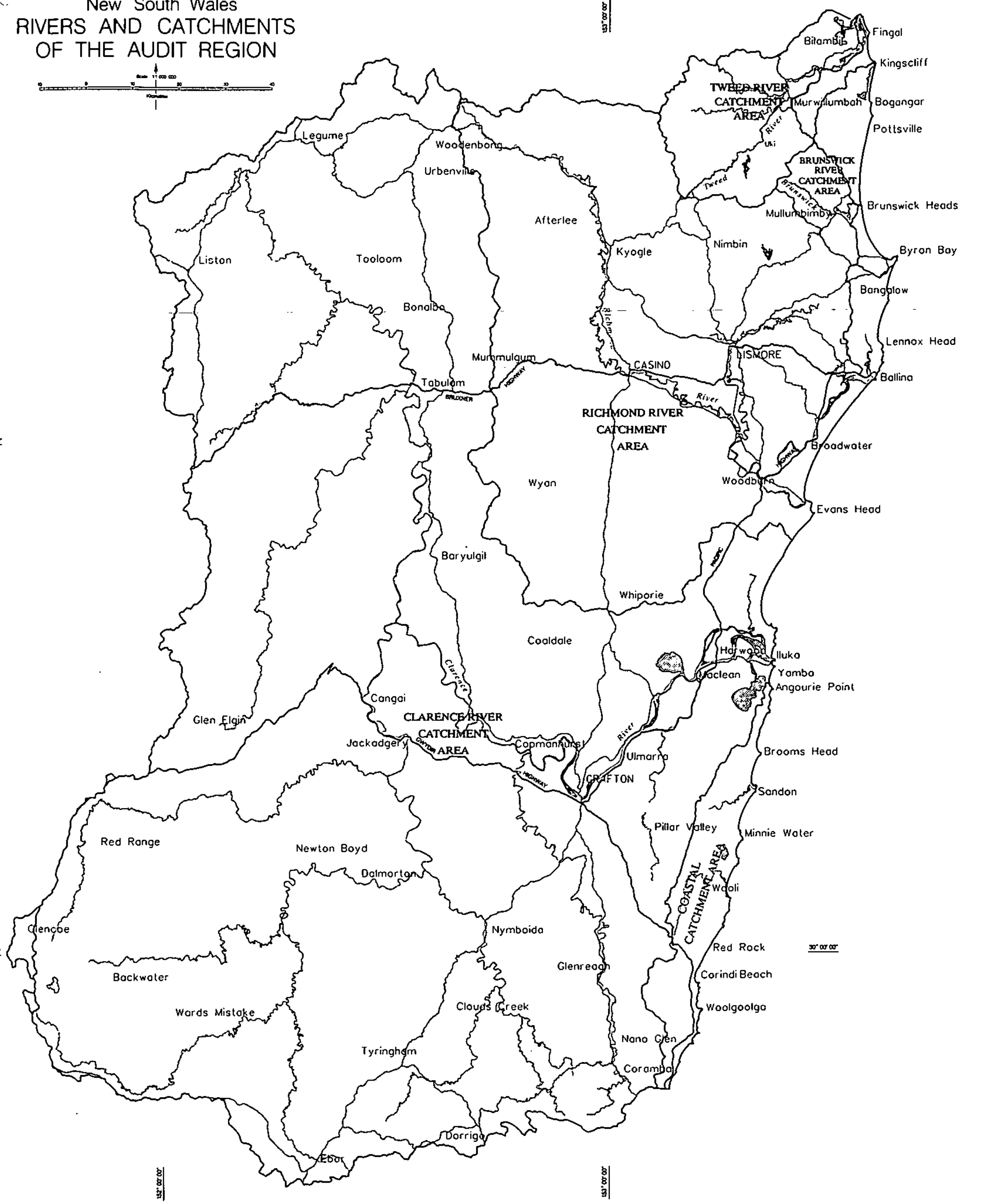
1.2.2 Brunswick

The Brunswick River Catchment covers an area of about 492 square kilometres and has an average yearly discharge of about 500 000 Ml (table 1a).

The main river has two large tributaries (Marshall's and Simpson's Creeks) which join at its mouth at Brunswick Heads. The Brunswick River drains a reasonably steep catchment (up to 600 metres) before entering the flat coastal area near Mullumbimby. Marshall's Creek commences at an elevation of about 420 metres and initially flows east, finally turning due south near the coast

Regional Audit of Upper North East New South Wales

RIVERS AND CATCHMENTS OF THE AUDIT REGION



Catchment Area .... TWEED RIVER

Highway ....

Main Road ....

River ....

RACAC

Published by the Resource and Conservation Assessment Council
Base map produced by the Land Information Centre,
Department of Conservation and Land Management January 1995
Data produced by the Land Information Centre Februrary 1995

TABLE 1A CHARACTERISTICS OF THE MAJOR CATCHMENTS (HILL AND HARRIS, 1991)						
Catchment	Area (sq km)	Length of river (km)	Average yearly discharge (X 103 Ml)	Average yearly runoff (mm)	Average yearly rainfall (mm)	Runoff as a percentage of rainfall
Tweed	1100	80	540	492	1650	30
Brunswick	492	23	246	500	1730	29
Richmond	6940	80	2390	344	1525	23
Clarence	22 660	394	5000	220	1070	21

before joining the Brunswick River. Simpson's Creek flows north, parallel to the coast, and drains the predominantly marshy coastal strip between Byron Bay and Brunswick Heads (WC & IC, 1968a).

Land slopes in the Brunswick River Catchment are predominantly flat to undulating. About 40% of the catchment is flat, with land slopes less than three degrees, and a further 25% is undulating to hilly, with land slopes between three and eight degrees. The flat to undulating areas in the catchment extend from the coast to the foot-hills of the divide between the Tweed and Brunswick Catchments. The most extensive areas of flat land occur in the northern sector near Cudgen Lake and in the southern coastal section between Mullumbimby and Byron Bay. Hilly to steep areas in the catchment, with land slopes between eight and fifteen degrees, occupy about 20% of the catchment, whilst rugged or mountainous areas make up a further 15%. Mountainous areas in the Brunswick Catchment are confined to the central western boundary in the headwaters of the Brunswick River and Burringbar Creek (WC & IC, 1968a).

1.2.3 Richmond

The Richmond River Catchment covers an area of approximately 6 940 square kilometres and has an average yearly discharge of about 2 390 000 Ml (table 1a).

The main river has two large tributaries; the Wilsons River, which drains the north-eastern section of the catch-ment, and Bungawalbyn Creek, which drains the southern part of the catchment. The Richmond River rises in the McPherson Range near Mount Lindesay and flows in a southerly direction to Casino. Along its course, it is joined by a number of smaller tributaries, including Findon, Grady's, Lynchs, Fawcetts and Eden creeks. It flows south-easterly from Casino being joined firstly by the Wilsons River at Coraki and by Bungawalbin Creek five kilometres downstream of Coraki. In the lower catchment, the Richmond River flows in a north-easterly direction entering the South Pacific Ocean at Ballina. There are also several coastal streams (for example, Tuckean, Emigrant, North Creek) that drain directly into the estuarine section of the lower Richmond River (WC & IC, 1966).

The Wilsons River drains a steep and deeply dissected plateau extending from the main McPherson Range through Loft's Pinnacle and Mount Mathieson to near the coast at Byron Bay. The major tributaries, which form the Wilsons River, are Leycester, Goolmangar, Terania and Coopers Creeks.

Bungawalbin Creek rises near the southern extremity of the Richmond Range, its principal tributaries being Myall and Myrtle Creeks. About one fifth of the Richmond River Catchment can be classified as mountainous with land slopes in excess of fifteen degrees. The remainder of the catchment comprises roughly equal areas of undulating to steep country with slopes between three and fifteen degrees and flat country with slopes less than three degrees. In the lower catchment, much of the original vegetation has been entirely removed, particularly where soil and topography have favoured pastoral land use. On the slopes, the original forest cover has been thinned and replaced by grass to provide extensive areas for grazing. Vegetation of the rugged, infertile uplands of the ranges consists of regrowth forest, while the plateau north of Lismore supports a cover of dense forest and scrub (WC & IC, 1966).

1.2.4 Clarence

The Clarence River is the largest coastal river in New South Wales. Its catchment covers an area of about 22 660 square kilometres and has an average yearly discharge of about 420 000 Ml (table 1a).

The catchment is bounded to the west by the Great Escarpment and consists of undulating or hilly country. However, it does contain some high peaks, including the central and southern portions of the Bajimba, Capoompeta, and Ben Lomond Mountains, which all rise to, or exceed, 1500 metres. In places, the tablelands extend for some distance to the east of the divide before the country falls away into steep dissected valleys, leading to the Clarence River. The main tableland areas, characterised by undulating or flat country, are those between the Maryland and Boonoo Boonoo Rivers (elevation from 600 to 900 metres) east of Tenterfield (elevation mainly around 900 metres), and from the

The Upper Clarence Catchment.

Gibraltar Range to Ben Lomond (elevation 900 to 1200 metres). Many of the streams draining the New England Tablelands such as the Maryland, Cataract and Mann Rivers initially flow north or north-east roughly parallel to the Divide, before turning east to flow towards the coast (WC & IC, 1968b).

The southern boundary of the catchment is formed by an eastward spur of the Continental Divide and includes the Balblair and Doughboy Ranges, Chandler's Peak, Round Mountain and Mount Darkie, which all rise to greater than 1500 metres. Between Ben Lomond and Ebor , the plateau extends northward ranging between 900 and 1200 metres; however, elevations decrease to about 750 metres around Dorrigo. East of Ulong, the country is broken and deeply dissected by the headwaters of the Orara River and its tributaries. From Mount Darkie eastwards, the southern boundary is the crest of very steep escarpments facing southwards (WC & IC, 1968b).

The eastern boundary of the catchment consists of a relatively low range of hills. While some peaks are higher than 300 metres, they average around 180 metres. Land slopes along these hills (which are known in their northern section as The Coast Range) are mainly hilly to steep. The northern part of the eastern boundary is formed by the Richmond Range, sweeping first in a westerly direction from the coast and then northwards to join the McPherson Range near Woodenbong.

The McPherson Range and part of the Continental Divide constitute the northern boundary of the catchment. Running west from the coast, the Richmond Range is initially relatively low and traverses mainly undulating and hilly country to about 50 kilometres inland. From here, the McPherson Range rises as a narrow ridge from 300 metres in the south to over 500 metres in the north and is flanked by rugged slopes on both the eastern and western sides. The McPherson Range and the northern end of the Continental Divide are also high ridges, with rugged slopes on the southern side where the country falls away to the valleys of the northern tributaries of the Clarence River (WC & IC, 1968b).

The northern tributaries of the Upper Clarence River flow southwards and have generally widened their valleys in the soft sedimentary rocks, resulting in the development of considerable areas of arable land. Some of these streams, such as Koreelah and Tooloom Creeks, have also formed alluvial flood plains. Steep basalt capped ridges, between the valleys, support a dense vegetative cover. In contrast, open country with conspicuous sandstone hills and wide multiple terraced alluvial flats occur in the vicinity of Tabulam (WC & IC, 1968b).

The streams flowing east from the New England Tablelands, from the Maryland River in the north to the Sara River in the south, enter very rugged country after they leave the plateau margin. On their descent to the lowlands, they have become entrenched in deep valleys and gorges and the surrounding country is deeply dissected by their tributaries. The Guy Fawkes River and the Nymboida River, draining the south of the Clarence Catchment, also enter rugged dissected country after leaving the plateau along the southern boundary. In contrast, the Orara River is characterised by a broader and flatter valley and by the development of flood plains bordering the main stream. Rugged slopes exist to the west of the river as the country rises to the divide between the Orara and Nymboida systems; but, to the east, there is only one rugged area near Coffs Harbour and the remainder is either undulating or hilly (WC & IC, 1968b).

Below the western and southern plateaux, the Clarence River flows through rugged country as far as Copmanhurst, with only relatively narrow fingers of flatter land extending along the floors of the valleys of some of the streams. Downstream from Copmanhurst, where the Clarence River comes under tidal influence, the catchment opens out and there are large areas of alluvial flats and undulating country between Copmanhurst and the coast. Most of the intensive agriculture of the Clarence Valley is concentrated in this fertile area, which also includes the main centres of population (for example, the city of Grafton) (WC & IC, 1968b).

1.3 DESCRIPTION OF THE MINOR COASTAL CATCHMENTS

Between the Tweed River and the Queensland border, several minor creeks (for example, Cobaki, Bilambil) drain into extensive tidal areas in the lower reaches of the Tweed River near Tweed Heads. Between the Tweed and Richmond Rivers, there are several minor coastal catchments (Mooball, Cudgera, Cudgen, Belongil), which are characteristically low-lying and swampy. These catchments have been modified due to extensive drainage and reclaimation works which have been undertaken to permit agricultural and urban development (WC & IC, 1968a).

The narrow coastal strip north of Coffs Harbour to Woolgoolga also includes a series of small coastal streams draining the eastern fringe of the Dorrigo Plateau. The main streams are Pine, Bonville and Woolgoolga Creeks. To the north of Woolgoolga, the Corindi, Wooli and Sandon Rivers drain the land between the coastal range and the ocean. Due to the presence of sand barriers at the mouth of these coastal creeks, they seldom enter the sea directly, tending to run parallel to the coast before breaking through to the sea (WC & IC, 1970).

1.4 REFERENCES

Dutton, I. and Stewart, L. 1988. 'Total catchment management: An essential ingredient of coastal zone management', in *Proceedings of the 1988 Workshop on Coastal Zone Management,* ed. A.V. Arakel, Lismore, NSW.

Hill, L. and Harris, M. 1991. *Water Facts*, New South Wales Water Resources Council, Parramatta.

Water Conservation & Irrigation Commission (WC & IC) 1970. *Water Resources of the Bellinger and Nambucca Valleys including Woolgoolga Creek*, Water Conservation & Irrigation Commission, Sydney.

Water Conservation & Irrigation Commission (WC & IC) 1968a. *Water Resources of the Tweed and Brunswick Valleys*, Water Conservation & Irrigation Commission, Sydney.

Water Conservation & Irrigation Commission (WC & IC) 1968b. *Water Resources of the Clarence Valley*, Water Conservation & Irrigation Commission, Sydney.

Water Conservation & Irrigation Commission (WC & IC) 1966. *Water Resources of the Richmond Valley*, Water Conservation & Irrigation Commission, Sydney.

MAJOR CONTRIBUTORS

Author

Dr Bradley Eyre, Southern Cross University

Reviewer

Tom Grosskopf, NSW Environment Protection Authority

Other contributor

Max Scott, Department of Land and Water Conservation

2 CHAPTER

COASTAL AND MARINE ZONE

2.1 THE COASTAL ZONE

2.1.1 Introduction

The coastal environments of Australia are dynamic. Their form is the result of the complex interactions which occur between physical, ecological and human interactions in this environment (Resource Assessment Commission (RAC)1993). The coast of the Audit Region is no exception.

The natural forces which shape the coast are constantly at work, sometimes resulting in a great deal of change over a small period of time (see sections 2.2.4 Tides and 2.2.8 Coastal erosion). Within the estuaries and on the land, interactions occur within and between ecosystems, including impacts from humans. Human impact is felt through activities such as agriculture, sand mining and urban development.

The coast is the interface between the land and sea. However, 'The terms 'coastal zone' and 'coastal environment' encompass a broad range of concepts and, as might be expected, there are a great number of definitions' (House of Representative Standing Committee on Environment, Recreation and the Arts 1991, p. 3).

Several efforts have been made to define the coast or coastal zone. Recent discussions have determined that the definition will be influenced by what issues or matters are being investigated (Coastal Committee of NSW 1994; House of Representative Standing Committee on Environment, Recreation and the Arts 1991; RAC 1993b). The RAC (1993b, p. 7) used two definitions:

- existing local government administrative areas abutting the coast as a basis for examining the extent of human uses and activities;
- natural drainage basins abutting the coast for describing the extent of physical and biological resources.

The existing 1990 Coastal Policy for New South Wales defines the coastal zone as a section one kilometre inland from the open coast to the three nautical mile limit offshore which defines State waters. The Draft Revised Coastal Policy for NSW (Coastal Committee of NSW 1994) investigated five options for defining the coast. The final definition will probably include estuarine areas, so as to reflect the current Government's position on the coast. For the purposes of this chapter, the term 'coast' will be used broadly to include the coastal catchments of the Audit Region.

This chapter discusses some of the main projects on and investigations into the coastal environment of the Region as well as providing a description of the physical features that are characteristic of the coast. It links information presented in other chapters and provides an overview of the coast in the Audit Region.

2.1.2 Inquiries and investigations

The coastline of New South Wales and Australia has been the focus of many government reports and inquiries over the past five years. These include the NSW Standing Committee on State Development Inquiry (1991, 1992), the Commonwealth's RAC Coastal Zone Inquiry (1993b) and the review by the Coastal Committee of NSW of the Government's Coastal Policy (NSW Cabinet Office 1990). The Commonwealth Government (Zann 1995) has this year completed the first State of the Marine Environment Report for Australia (SOMER) and produced a Commonwealth Coastal Policy (DEST 1995).

Non-government groups also have interests in the state of the coastal environment. For example, the Surfrider Foundation of Australia (Legge Wilkinson 1993) has prepared a State of Our Surf report. The report provides information on the state of Australian surfing beaches, including 45 in the Audit Region. Appendix 2.1 lists the beaches in the Audit Region covered in the report.

The NSW Standing Committee on State Development Inquiry had the main task of reporting on the environmental and/or other implications of development in the coastal region of New South Wales. The Committee made recommendations to the Government designed to improve the planning and management process for the State's coast. The Government responded to the recommendations made by the Standing Committee by outlining the Government's initiatives with regard to the coast.

The RAC Inquiry recommended the establishment of a National Coastal Action Program which contains four elements: a set of nationally agreed coastal zone management objectives; arrangements for implementing and managing the program; greater community and industry involvement; and innovative management mechanisms. The final report was released in late 1993 (RAC 1993b). The Commonwealth responded to the RAC recommendations by launching a Commonwealth Coastal Policy in May 1995. The policy included 30 initiatives and budget of $53 million dollars (DEST 1995).

The NSW Coastal Policy was the first attempt by the New South Wales Government to address the problems and issues relating to the coast. In the late 1980s there was a perception that pressure for development along the New South Wales coast was growing and that development was occurring in an uncontrolled manner. As a result the policy was introduced in 1990 to provide a framework for making decisions about the planning and management of the State's coastline' (Coastal Committee of NSW 1994, p. 7). The 1990 Coastal Policy represents a 'whole of government' initiative and was a statement of direction for government departments and authorities that had a role in coastal zone management and planning. Since the release of the Coastal Policy, much work has been undertaken by government agencies and community expectations have changed. The current review of the Policy takes into account these changes.

The SOMER provides a scientific description of Australia's marine environment. It describes its uses and values; the issues and threats affecting it, and its management. The process of preparing the report resulted in many technical papers being prepared. Much of the information is on a State by State basis, however, some papers did focus on specific areas which included the Audit Region (Ashdown 1995; Macdonald & Phillip 1995; Schnierer et al. 1995).

2.1.3 Responsibilities along the coast

Coastal management is traditionally the responsibility of the State, out to the three nautical mile limit. The Commonwealth, however, does have jurisdiction over certain areas involving mainly natural and cultural heritage (Australian Heritage Commission Act 1975, World Heritage Properties Conservation Act 1983) and environmental protection (Environmental Protection (Sea Dumping) Act 1981, Whale Protection Act 1980) (NSW Standing Committee on State Development 1991).

The responsibility of the State Government begins at the three nautical mile limit and Crown land includes the land and the air to the Mean High Water Mark (MHWM), but does not include the water. However, the water is considered as a natural resource in this report. At the MHWM on the open coast, local government boundaries usually begin. Within estuaries, freehold title often abuts the MHWM. Volume 1, chapter 2 Public lands and natural resources, further discusses State Government agencies and local government responsibilities with regard to public lands in the Audit Region.

While some areas of the coast are developed, much has been conserved in national parks, nature reserves, historic sites and Aboriginal areas. However, the majority of land is public land (see volume 1, chapter 2 Public lands and natural resources). This land includes Crown land and reserved and dedicated land as well as those public lands mentioned above, such as national parks. The area of public land may only be narrow in places, but this land protects public access to the coastline. The Crown ownership of coastal lands also provides a buffer to private property from coastal erosion (see 2.2.8 Coastal erosion).

2.1.4 Physical features

The landscapes of the coast of the Audit Region are varied and include rugged headlands, long sandy beaches, wetlands, estuaries and broad river mouths. Chapters 3, 4 and 5 of volume 2 describe in detail the geology, geomorphology and soils of the Region, including the coast.

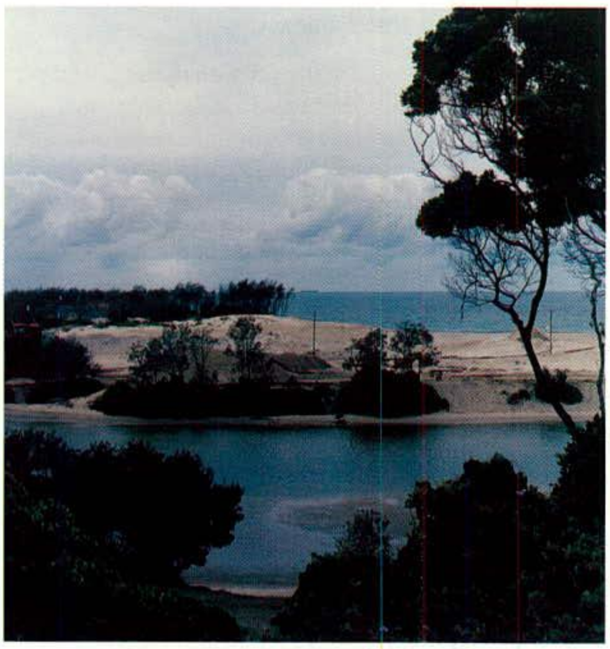
The complexity of the coastal area in terms of geomorphology is reflected by the hinterland topography (see volume 2 ,chapter 4 Geomorphology). Where bedrock impinges on the coast, the coast is relatively narrow and simple. But in the case of the river valleys, the influence of the coast penetrates further inland and the mix of fluvial, estuarine and marine processes result in landform diversity and complexity. The same chapter also discusses the coastal outline, bays and headlands and barrier estuaries.

The soils of the coast vary in relation to the terrain (see volume 2, chapter 5 Soils). Of particular concern in the Audit Region is the presence of acid sulphate soils. These soils have been found in all coastal floodplains and small coastal inlets. Acid sulphate soils are those containing pyrite. Exposure of these soils to the air (by drainage or other earthworks) leads to the formation of sulphuric acid and a lowering of the soil's pH (EPA 1993, p. 144). Acid sulphate soils can have an impact on agriculture and urban environments. They may lead to fish kills, poor plant growth and corrosion of metal and concrete structures (see also volume 4, chapter 1 Biodversity). Details of acid sulphate soil process and the risk mapping which has been undertaken with Natural Resource Audit Council (NRAC) funding can be found in volume 2, chapter 5 Soils (see box on acid sulphate soil risk mapping).

The physical appearance of the coast has been changed by natural and human activity. The most recent human activities which have affected the coast are agriculture, urban and associated development and to a lesser extent heavy mineral sand mining. Rehabilitation techniques have enabled the heavy minerals industry to reinstate or stabilise existing topography and features (see volume 5, chapter 5 Mineral resources). Little sand mining is undertaken now. One present day site is at the southern side of Cudgen Creek near Kingscliff.

Agricultural activity has resulted in the clearing of native vegetation and the introduction of domesticated animals. Urban development has also seen the clearing of vegetation as well as the construction of roads, railways and other service infrastructure (see volume 5, chapter 2 Infrastructure).

The climate of the coastal areas of the Audit Region attracts people to the Region. During summer the coast of the Audit Region experiences warm, humid conditions and higher rainfall averages. During winter and early spring, June to September, the average rainfall and



G. Hicks Department of Urban Affairs and Planning

Sand Mining Operations at Kingscliff.

humidity decrease. The coast tends to have less variability in temperature through the year, compared to non-coastal areas. The coast also tends to receive more rain annually than the non-coastal areas of the Audit Region. From January to April, tropical cyclones drifting down from northern Australia, may affect the Region.

The Enhanced Greenhouse Effect may affect the coastal area of the Audit Region and Australia in the coming decades. Sea level rise could have a significant effect on coastal ecosystems and coastal development (DASET 1991). It is still not possible to accurately predict the changes likely to occur including the magnitude of change. Some changes may include increased sea level, increased storminess and rainfall and a general increase in the variability of climatic factors (RAC 1993a). The CSIRO concludes that Greenhouse induced climate change has the potential to:

- intensify the east coast lows which form off the New South Wales coast and this in turn could exacerbate the associated storm surge which can cause extensive flooding and damage along the coast (CSIRO 1994);
- produce warmer sea surface temperatures which in turn may increase the possibility of tropical cyclones moving further southward, becoming more intense or, perhaps, increasing in number (CSIRO 1992a). Therefore the coast of the Audit Region, which is rarely affected by cyclones, may see an increase in the number affecting the area;
- increase sea levels between 0.1 metres (low scenario) to 0.3 metres (high scenario) by the year 2030. Allowances need to be made for other changes in climatic factors such as storm peaks, river discharge, temperature, precipitation, evaporation and waves, all of which can locally effect sea levels (CSIRO 1992b).

For further details on climate, see volume 2, chapter 1 Climate.

2.1.5 Coastal land uses

Along the coast there are many, often competing, land use pressures. The area also contains diverse ecosystems. With the combination of these factors, the need for proper management of the coast becomes evident. This is reflected in the number of past Government inquiries (Commonwealth and State) into coastal issues, as previously mentioned.

Continued population growth and development on the coast has led to deterioration in both estuarine and marine water quality, clearing, loss of remnant vegetation, habitat modification and fragmentation and the introduction of feral animals. These all impact on biodiversity and genetic diversity. The coast contains several rich ecosystems associated with landscape features including, wetlands, estuaries, flood plains, beaches, rocky shores and the ocean and contain a variety of fauna and flora (see volume 4, chapter 9 Coastal and marine ecology).

Certain species move between different ecosystems. For example, migratory birds will spend part of the year breeding in the Audit Region before flying north. Other species can move between the marine and estuarine environments. To date there has been no systematic inventory of Australian coastal fauna (RAC 1993a). However, the instigation of several projects through RACAC funding will help in identifying the flora and fauna of the coastal areas of the Audit Region.

Many areas on the coast are listed as National Estate sites because of their natural values. The Iluka Nature Reserve is the one site on the coast of the Audit Region which is inscribed on the World Heritage List (see volume 6, chapter 1 Heritage values).

ESTUARINE INVENTORIES

In 1985, the NSW Department of Agriculture and Fisheries prepared *An Estuarine Inventory for New South Wales, Australia*. It covers 20 estuaries and lagoons in the Audit Region and aims to provide a fisheries oriented inventory of the estuaries to assist in estuarine management. Information in the inventory includes: location (map reference and local government area); estuary type; entrance status; estuarine based fisheries production; and sewage disposal sites.

A survey of fish communities in northern New South Wales Estuaries has been done as part of the NRAC Audit of the Upper North East Region (see Project Summary of NRAC Project S12 – *Fish Communities in Northern NSW Estuaries* at the end of volume 4).

NSW Public Works (1992) has prepared the Estuary Inventory of New South Wales. Seventeen estuaries in the Audit Region are documented. The fact sheet for each estuary presents a synoptic assessment of the principal characteristics and issues relating to estuary management. Information includes estuary characteristics, special attributes and management issues. These sheets are contained in appendix 2.2.

2.1.6 Population and development

History has played a major role in the present day configuration of land uses in the Audit Region (see volume 1, chapter 4 Non-indigenous history). The location of present day settlements, land cleared for agriculture and, more importantly, the land retained as public land has mainly been because of past land and natural resource use decisions.

The population growth experienced in north east New South Wales and south east Queensland is detailed in publications by both the Department of Planning (1994) and RAC (1993a) and in the Draft Revised Coastal Policy (Coastal Committee of NSW 1994) (see volume 5, chapter 1 Demographic profile).

The scenic values (volume 6, chapter 1 Heritage values) and mild climate (volume 2, chapter 1 Climate) of the

COASTAL LANDS PROTECTION SCHEME

The NSW Coastal Lands Protection Scheme, introduced in the early 1970s, identifies important coastal land for protection by appropriate land use zones and lands with special values for acquisition by the New South Wales Government. Important coastal landscapes acquired include headlands, dune systems and hinterland around lagoons and coastal lakes. Acquisitions only occur on a voluntary basis and therefore this is a long-term program.

Over $32 million has been expended acquiring over 13 350 hectares of scenic land in New South Wales. Present funding allocation is $2 million per year. In the majority of cases the land is added to an existing national park or Crown land reserve. The Scheme is administered by the Department of Urban Affairs and Planning.

In the Audit Region the Scheme has been used to purchase land adjoining national parks. This land has then been incorporated into the parks under the ownership and management of the National Parks and Wildlife Service. Examples in the Audit Region are Yuraygir and Broadwater National Parks.

Region, amongst other things, have acted to attract a large proportion of the population involved in intra- and inter-State migration in New South Wales. A 1991 survey by the Department of Conservation and Land Management confirmed that of the lower, mid and far north coast local government areas, the north coast was preferred because of perceptions of pleasant climate and scenic, unpolluted beaches (Pitt 1991). The same study also found a visual background of dune vegetation and trees further raised the appreciation of the scenic coastline. 'The large scale growth of population in the coastal belt in the past decade was a result of natural decentralisation in that it occurred with little, or no, prompting by government policies or initiatives' (NSW Standing Committee on State Development 1991, p. 31).

This rapid increase in population has resulted in particular socio-economic conditions in the area and places pressure on available land, not only for urban development, but also on land for conservation and recreational purposes. It is also important to note that some centres may experience a doubling in population during peak holiday periods. This has generally been the case in the Audit Region. There have in the past two decades been increasing numbers of holiday-makers enjoying the national parks and State forests further inland. This is due in part to the increasing ownership of recreational vehicles, better roads and an increasing community awareness and appreciation of the natural environment (see volume 5, chapter 10 Tourism and recreation resources).

Past development along the coast has generally been dispersed. This is evident in many of the older settlements along the coast of the Audit Region such as from Kingscliff to Pottsville and Evans Head, where ribbon development has occurred. A coastal urban planning strategy (Department of Planning 1995) has been prepared for the North Coast to direct future development into areas of least environmental sensitivity with the strategy's main aim being the efficient and sustainable management of growth. The strategy is for use by both State government agencies and local councils (see volume 5, chapter 1 Demographic profile). The strategy will also provide those agencies with responsibility for infrastructure with a framework for where future demands will be. Chapter 2 in volume 5 looks at the provision of infrastructure on public lands in the Audit Region.

2.1.7 Aboriginal people and Torres Strait Islanders and the coast

The coast is important to Aboriginal people not only as a past and present resource for food but also as a source of material for shelter, clothing, tools and weapons and objects for trade and ceremonial use. Their habitation of

BEACHES OF THE AUDIT REGION

The Surf Environment Analysis Study Program was initiated by NSW Public Works Department in 1979, with the aim of acquiring surf environment and beach usage data for selected New South Wales beaches. Environmental data was collected on wave climate, wind, temperature, cloud and rain levels. In the Audit Region, data was collected for New Brighton, Red Rock, Corindi, Arrawarra, Woolgoolga, Sandy and North Sapphire Beaches. The collection period ranged from a few months to seven years. These reports (NSW Public Works 1991, 1992) are contained in the bibliography to this volume.

Beaches of The New South Wales Coast (Short 1993) is a guide to all beaches in New South Wales including all those in the Audit Region. The elements addressed in the report include:

- a safety rating for each beach (1 is safest, 10 least safe);
- nature and condition of the beach including dominant swell direction, rips, beach state and wave height;
- presence of Surf Life Saving Club and/or lifeguards;
- facilities including parking, toilets, caravan parks/camping, boat ramps, picnic areas and lighthouses.

The suitability of each beach for bathing, surfing and fishing is also reported. The report describes the geology and evolution of the New South Wales coast, the coastal processes which impact on the beaches of New South Wales, general beach types and beach hazards.

the coast has resulted in social, economic, spiritual and cultural ties with the area and there are numerous sacred sites and sites of significance for Aboriginal people on the coast of the Audit Region. In southern Australia (in comparison to northern Australia), where the physical and cultural effects of European settlement have been much more pronounced, Aboriginal use of the coastal zone resources is more limited' (RAC 1993a, p. 64).

Volume 1, chapter 3 Indigenous history discusses the history of Aborigines in the Audit Region and volume 6, chapter 5 Aboriginal values and chapter 6 Aboriginal sites of significance, specifically discusses Aboriginal values of the Audit Region, including those along the coast.

2.2 THE MARINE ZONE

This section will look at the main physical characteristics and processes which occur in the area of the Audit Region from the MHWM to the three nautical mile limit. It can generally be said that there is lack of data on most of the processes in this area. Often data are only collected on a project by project basis. It should also be noted that the processes mentioned in this section do not act independently, but often react together. For ease of presentation the processes have been separated.

2.2.1 Bathymetry

Bathymetry is the measurement of the depths of water and describes the topography under the ocean. 'Water depth influences the patterns of tides, tidal and other currents, the distribution of intertidal flats, the extent to which the sea floor and overlaying water are affected by light, the areas safe for navigation and areas that may be of interest for recreational diving' (LCC-Land Conservation Council 1993, p. 27).

The Northern New South Wales coast is dominated by a relatively steep nearshore zone which includes several islands and reefs. Because of its steepness and depth tides and tidal currents are relatively small, while breaker wave height is relatively large (Short A., Coastal Studies Unit, University of Sydney, pers. comm., March 1995).

2.2.2 Marine sediments

Generally, inshore marine sediments are coarse in comparison to those sediments found on the middle and outer shelves. Marine processes, acting on sediments contributed over a long period to the inner continental shelf, have produced a well-rounded, quartz-rich sand with usually less than 10 per cent rock and felspar grains' (Chapman et al. 1982, p. 36). This sediment includes shell fragments.

In estuaries sediments are less weathered and more angular. However this fluvial sand rarely occurs as the dominant sediment type in open-ocean environments (Chapman et al 1982). Detailed seabed information has not been collected for the marine areas of the Audit Region. Detailed studies are undertaken for specific projects. For example, the sediments of Yamba have been studied and mapped (NSW Public Works 1994). It was found that very fine sands and muds are carried to sea during the flooding of the Clarence River and that the composition of nearshore sands suggests northerly longshore transport of sands from the river entrance.

SURVEY DATA

Historical bathymetrical survey data exist for New South Wales, dating back to early European occupancy. The accuracy of these data is questionable and there are problems with comparing data (Chapman et al. 1982). These historical data are available from the microfiche library of NSW Public Works and from the Royal Australian Navy Hydrographic Branch.

NSW Public Works has undertaken several different types of coastal surveys in the Audit Region. These include hydrosurveys, which comprise bathymetric surveys and sediment-type mapping of the seabed within approximately 10 kilometres of the shoreline. Public Works considers the quality of data for these surveys as good. Below are details on the sections of the Audit Region covered by hydrosurvey.

Section of coast	Survey year
Hastings Point to Byron Bay	1978
Cape Byron to Evans Head	1982
Woody Head to Angourie Head	1982
Minnie Water to Station Creek	1985

2.2.3 Currents

The dominant offshore oceanographic feature which affects the Audit Region is the EAC-East Australian Current. The EAC consists of large anti-clockwise eddies which flow north to south on the landward side (west side) and flow to the north on the outer edge (eastern side) (Chapman et al. 1982). The EAC is of high temperature and high salinity relative to adjacent waters and is nutrient-poor. This current has its origins in the Coral Sea and flows south along the east coast of Australia, sometimes at rates of up to 2.5 metres per second. Between 31 degrees and 33 degrees South, just south of the Audit Region, the current turns eastwards and meanders towards New Zealand (Mulhearn 1987). The southern boundary of the current is described as the Tasman Front.

The EAC exists because the warm surface water of the Coral Sea is less dense than that of the Tasman Sea and as a result there is a height differential between these major water bodies, with the Coral Sea being higher by some tens of centimetres. The current flows down this gradient and is given extra impetus by the earth's rotation. The EAC is considered to be highly variable both spatially and temporally (Hamon 1965).

HYDROGRAPHIC AND BATHYMETRIC MAPS

Maps Aus 813 and 814 cover the Audit Region at a scale 1:150 000. These maps provide water depth data in fathoms (1 fathom equals six feet or approximately 1.83 metres). Map Aus 220 provides more detailed information on the depth of water around the Tweed, Brunswick, Richmond, Clarence and Wooli Wooli River entrances. This map is at 1:12 500 and provides water depth information in metres.

The National Bathymetric Map Series 1:250 000 covers 2.3 million square kilometres of the Australian Continental Shelf. The following maps cover the Audit Region (Coffs Harbour SH56-11, Maclean SH56-07 and Tweed Heads SH56-03). All maps are available from the Map Sales section of the Department of Land and Water Conservation.

In the Audit Region, the EAC is very close to the shore, often crossing onto the continental shelf. The current has a 'strong effect on the distribution of bottom sediments' along this stretch of the coastline (Cresswell 1987). The permanent loss of sediment from coastal processes to sinks offshore due to ocean currents has been reported at Byron Bay (NSW Public Works 1991a).

The EAC can diverge or separate and move out to sea in several places. Within the Audit Region, Point Danger, Fingal Head and Cape Byron have been identified as prominent headlands where this deflection occurs (Cresswell 1987; NSW Public Works 1991b). These deflections of the current appear to trigger clockwise circulations in the coastal embayments between the headlands (NSW Public Works 1991b). In the area between the coast and the diverging current, it is common to find nutrient rich waters that have upwelled from depths greater than 200 metres. This water can be up to five degrees celsius cooler than the surrounding water mass and carries large amounts of phytoplankton (Cresswell 1987).

The Department of Defence studied the EAC off northern New South Wales in November 1982 and in May 1983 (Mulhearn, 1986). Though the studies were undertaken to assist in the use of submarines, two point of interest are that:

- the front of the EAC could move in an east-west direction at speeds of order 10 to 20 kilometres per day. This movement during the surveys was not related to wind stress;
- the front's structure can be affected by the outflows from rivers in the Audit Region.

Currents found closer to the shore are affected to some degree by the EAC as well as the existing land mass, bathymetry and prevailing winds. It is generally accepted that there is a northerly littoral current along the northern New South Wales coast which, with a decline in long term sediment supply, the dominant south east wave direction and long beaches, can result in substantial beach and dune erosion, particularly in embayments between Cape Byron and Point Danger (PWD 1982; PWD 1983; NSW Public Works 1991c; Roy & Crawford 1977; Short, A., Coastal Studies Unit, University of Sydney, pers. comm., March 1995).

However, it is also thought that in some cases, the inner edges of eddies can exhibit a north-south flow and the 'longshore drift is discontinuous and poorly developed and that direction of longshore drift varies seasonally' (Pisanu & Gale 1994, p. 26). It is the littoral current which transports sand, as littoral/longshore drift, along the coast. Section 2.2.8 discusses coastal erosion and littoral drift in more detail. Average littoral current velocity at Brunswick Heads has been measured at 0.6 metres per second, with peak velocities up to 1.3 metres per second. These figures are similar to those recorded at the Gold Coast (Manly Hydraulics Laboratory (MHL) 1987).

Chapman et al (1982) discusses tidal and wind- and wave-induced currents. Significant wave-driven current circulations have been identified by local fishermen near Yamba Point. These include a large anti-clockwise current generated within the embayment between Yamba Point and the Clarence River entrance' (NSW Public Works 1994, p. 41). For the majority of the Audit Region, however, little information is known about these currents.

Currents produced by local winds can result in either upwelling or downwelling of the water. When southerly winds are blowing, water piles up on the coast pushing the surface water down and out along the continental shelf. This is downwelling and often results in the water being warmer on the coast. The opposite (upwelling) occurs when northerly winds blow during summer, pushing coastal water out to sea. Colder water from the continental shelf then flows to the coast to infill the depression (Short 1993). The effect on nutrient levels from upwelling is discussed in section 2.2.7 Water quality.

2.2.4 Tides

Tides are the regular rise and fall of sea level in response to the gravitational pull of the sun and moon. The tides along the New South Wales coast are considered to be relatively uniform and are semi-diurnal, having two tides of unequal height per day (NSW Public Works 1994).

2.2.4.1 Tidal range

Average tidal range for New South Wales is less than two metres and varies from less than one metre on neap tides to 1.6 metre on spring tides (Chapman et al., 1982; Short 1993). Table 2a shows the tidal ranges for each of the major rivers in the Audit Region and demonstrates the uniformity between them.

Figures 2a to 2d contained in appendix 2.3, show the level of typical neap and spring tides for each of the main rivers in the Audit Region.

2.2.4.2 Tidal velocities and discharges

The Environment Protection Authority (EPA 1992a) found that tidal velocities at the mouths of all rivers in the region from Point Danger to the Clarence River, were at least 1.5 metres per second and the velocities at the Clarence and Richmond Rivers were as much as 2.5 metres per second. The tidal range contracts substantially through the entrance and lower estuaries of rivers. This is normal behaviour at a river entrance and reflects the friction effects of entrance losses, shallow water, and aquatic vegetation. Figures 2e to 2h in appendix 2.4 show the tidal comparison at different sites along each of the four main rivers in the Audit Region.

Table 2b shows the tidal velocity and discharge data for the four main rivers in the Audit Region. The maximum discharge from the rivers is quite different and is relative to the size of the river.

2.2.4.3 Tidal influence

The range of tidal influence varies for each of the major river systems in the Audit Region. For the Tweed River, the tidal influence extends approximately 30 kilometres into the Tweed system, just beyond Murwillumbah (Acer Wargon Chapman 1994). The north arm of the Brunswick River has a tidal length of five kilometres; the south arm a tidal length of 15 kilometres. The tidal limit of the Richmond River is approximately 90 kilometres from the ocean (NSW Public Works 1994). The Clarence River is tidal to Copmanhurst, a distance from the ocean of approximately 100 kilometres (PWD 1984).

2.2.4.4 Elevated ocean levels/storm surge

Tides which are either larger or smaller than those predicted are termed tidal anomalies. These occur randomly and can be caused by particular meteorological and oceanographic conditions. The atmospheric pressure over the Tasman Sea is on average 1013 hectopascals (measure of pressure) and when the pressure varies, tidal anomalies can occur. The main concern with tidal anomalies is when elevated ocean levels or storm surges occur. Information on elevated ocean levels assists planners and engineers in managing the coast.

Elevated ocean levels can be caused by intense tropical and east coast cyclones and, with high astronomical tides, there is the potential for flooding of low-lying areas, increased flooding of coastal streams and coastal erosion. Severe east coast cyclones can generate wave heights comparable to tropical cyclones and these occur more

TABLE 2A TIDAL RANGES FOR THE FOUR MAIN RIVERS IN THE AUDIT REGION

Location	Maximum Range (m)	Mean Range (m)	Mean Neap Range (m)	Mean Spring Range (m)
Tweed River Entrance	1.8	0.9	0.6	1.2
Brunswick River Entrance	1.9	1.0	0.7	1.3
Richmond River Entrance	1.9	0.9	0.7	1.2
Clarence River Entrance	1.8	0.9	0.7	1.2

Source: NSW Public Works MHL 1995

TABLE 2B TIDAL VELOCITIES AND DISCHARGES FOR THE FOUR MAIN RIVERS OF THE AUDIT REGION

Location	Tweed R. Entrance	Brunswick R. Entrance	Richmond R. Entrance	Clarence R. Entrance
Date	17/2/88	26/7/94	3/11/94	16,17/3/84
Tide Range				
Flood (m)	1.02	1.07	1.54	1.26
Ebb (m)	1.55	1.01	1.50	1.34
Maximum Velocity				
Flood (m/s)	1.10	0.99	1.21	1.22
Ebb (m/s)	1.29	0.91	1.40	2.14
Maximum Discharge				
Flood (m3/s)	>700	120.5	1641	2800
Ebb (m3/s)	800	102.5	1354	3600

Source: Public Works MHL 1995

frequently than tropical cyclones. Tropical cyclones generally occur in summer, while east coast cyclones can occur any time during the year.

For example, in March 1990, the aftermath of cyclone Hilda produced an intense low pressure system which resulted in a storm surge in the Audit Region. The average peak surge measured between Tweed Heads and Yamba was approximately 0.5 metres. A trend which has been identified is that when cyclones track into the Tasman Sea, the north coast experiences surges 0.2 metres higher than the south coast of the State (MHL 1991).

Public Works Department (1985) investigated all storms likely to have caused significant variation in predicted water levels between 1880 and 1980. This study concluded that the peak storm period on the north coast is in February and March, due to the incidence of tropical cyclones. A second study, covering the period 1980 to 1985 (PWD 1986), concluded the months from August to December are significantly less stormy than the remainder of the year. The north coast can also have long periods without any significant storm activity. For these two studies, the north coast comprised the area from Tweed Heads to Smokey Cape.

OIL SPILLS

The EPA has prepared coastal resource atlases for oil spills for the areas Point Danger to the Clarence River (EPA 1992a) and Clarence River to Smoky Cape (EPA 1992b). These atlases take into account the influence of tides on possible oil spills in the region and summarise information about environmentally sensitive areas. The atlases include:

- an analysis of the resources at risk by category, from extremely sensitive to low sensitivity;
- recommendations to minimise the impact of a spill in these areas;
- an assessment of the threat from oil spills;
- a review of resources in relation to oil-spill countermeasures; and
- a discussion on the effects of oil and dispersants on the flora and fauna of off-shore islands and headland rock platforms.

Those areas identified as extremely sensitive include areas which are feeding or roosting grounds for waders and seabirds protected under international treaties. Also included are mangrove and saltmarsh areas, which are extremely sensitive to repeat oil spills. The highly sensitive areas are those which include oyster leases, birds not protected by treaties, seagrasses, corals and marine mammals.

OCEAN TIDE MEASUREMENT PROGRAM

Manly Hydraulics Laboratory (MHL) is collecting ocean tide level data in the Audit Region at four recording stations, located at Tweed Heads, Brunswick Heads, Ballina and Yamba.

The program supports a number of Government programs associated with coastal and estuary management, ports and marine facilities and waterways and fishing facilities. Local Government and other organisations both in Australia and overseas have access to the data collected. The data can be used to predict ocean tide levels and potential impacts along the coast and in estuaries. There are also historical records available for an additional eighteen sites in the Region. The MHL (1994a) produces an annual summary of the results of ocean tide measurements and catalogues all ocean tide data collected in New South Wales by Public Works.

2.2.5 Wave climate

Wave climate is described as the range of wave conditions experienced at a particular location, including seasonal variation in the size, character and direction of waves (Short 1993). Knowledge of the wave climate is a key element in many aspects of coastal and marine matters in regard to tourism and recreational pursuits, possible sustainable energy generation, disposal of wastes via outfalls, commercial shipping, recreational boating, foreshore protection, and coastal land management' (LCC 1993, p. 31). The wave climate of an area shapes the coastline and is responsible, mainly, for the transportation of sediments on- and off-shore and parallel to the beach.

Though no similar study has been done for the Audit Region it could be expected that a similar wave climate exists in the Sydney region. A study of 20 years of wave data for Sydney (Short & Trenaman 1992) determined that the annual wave climate was energetic and variable. Also noted was the distinct seasonality of the wave climate. The largest average monthly wave heights were recorded in the months of February-March and June. However, it was found extreme waves (greater than 4 metres) and/or low swell may occur in any month.

There are five sources generating waves on the New South Wales coast. Table 2c lists the sources, where they originate and the impact on wave climate.

Three of these sources are cyclones including tropical cyclones, east coast cyclones and mid-latitude cyclones. Tropical cyclones occur more often in the Audit Region than in other areas along the New South Wales coast and may occur two or three times a year between December and April. East coast cyclones produce the biggest waves in the Audit Region and can occur any time during the year. Though these cyclones are twice as frequent as tropical cyclones, they also experience a moderate degree of variability in frequency and storm intensity (Short & Trenaman 1992). On average three or four will form each year. Mid-latitude cyclones have the greatest influence on the New South Wales coast. The swell travels from cyclones located south of Tasmania. Ninety-five percent of the waves over 2.5 metres in height are produced by these cyclones (Short 1993).

Anticyclonic pressure systems over inland Australia produce an easterly flow of air (low to moderate anticyclonic winds) onto the New South Wales coast and produce waves usually less than 1.5 metres. As a high pressure system moves over the coast, the chance of sea and land breezes increases (Short 1993).

A typical wave on the New South Wales coast will have an average wave height of 1.6 metres and an average wave period (time between two crests) of ten seconds (Short 1993). Swell in the Audit Region is predominantly from the southeast to east, while storm wave conditions are predominantly from the south to east quadrant (NSW Public Works 1994) (see volume 2, chapter 1 Climate).

2.2.6 Salinity and temperature

A few studies have been done in the Audit Region on the salinity and temperature of the marine environment. One study was undertaken offshore at Yamba between September 1989 and March 1990 (see appendix 2.6, figure 2j water temperature and figure 2k salinity levels). There are two studies on salinity which cover the Tasman and Coral Seas and include the coastal area of the Audit Region. Given the area covered by these studies, the information is on a broad scale. Subsequent reports have been prepared by the CSIRO Division of Fisheries and Oceanography (Edwards 1979; Rochford 1977).

Mean annual surface salinity of the Tasman Sea is 35.5 parts per thousand (NSW Public Works 1994). Rochford (1977) defines low salinity as that less than 35.4 parts per thousand and reported that low salinity water seasonally appears off the New South Wales coast. A pathway of low salinity water which is augmented by local river discharges, runs along the coastal margin of the Audit Region. The water spreads southward predominantly in the period December to April. The influence of the East Australian Current can increase salinity levels (NSW Public Works 1994).

Sea surface temperature is under the same influences as salinity (Landsberg 1984). Mean summer and winter

WAVE CLIMATE PROGRAM

The data collected in the Wave Climate Program by NSW Public Works, is necessary in the design, construction and performance monitoring of projects undertaken by government agencies. The Manly Hydraulics Laboratory (1994b) prepares annual summaries of wave climate information the data which is accessible through a computer database. The network incorporates seven Waverider Buoys located off the coast from Eden to Byron Bay.

The only commissioned site in the Audit Region is at Byron Bay. Another site is located just south of the Audit Region at Coffs Harbour. Other data exist for four sites around Tweed Heads. However, this data capture was project specific and the sites were only commissioned during a eighteen month period, ending late 1989. No other buoys have been installed in the Audit Region due to the high cost to commission and maintain sites. Nevertheless, 'The NSW Waverider system is in fact one of the longest running and most comprehensive wave recording systems in the world' (Short 1993, p. 23).

Figure 2i in appendix 2.5, illustrates the daily and storm wave frequency and direction at both Byron Bay and Coffs Harbour.

TABLE 2C WAVE GENERATING SOURCES AND WAVE CHARACTERISTICS ON NEW SOUTH WALES COAST

Source	Location	Wave Height (metres)	Wave period (seconds)	Wave Direction
Low Pressure:				
Tropical cyclones*	Southern Coral Sea	2-3	9-10	NE
East coast cyclones	Central Tasman Sea	2-4	10-12	E
Mid-latitude cyclones	Southern Tasman Sea	1-3	10-14	SE
High Pressure:				
Anticyclonic pressure systems	Southern Coral – Central Tasman Seas	0.5-1.5	9-10	E
Sea breeze*	NSW coast	0.5-1.5	6-9	NE

* summer only
Source: Short & Trenaman 1992; Short 1993

temperatures are 23 degrees Celsius and 19 degrees Celsius (NSW Public Works 1994). The sea surface temperature peaks late summer (January-March) (Edwards 1979). The EAC has considerable influence on the temperature of the sea and the current can produce eddies, upwellings and downwellings, resulting in temperature change. Cooler water is not as high in the water column as warm water and so water flows from the warmer areas to fill in the cooler areas. Another source of temperature change has been identified as the El Nino oscillations (see volume 2, chapter 1 Climate) which produces pulses of relatively warmer and cooler water every few years (Short 1993).

2.2.7 Water quality

Little information has been collected on the water quality of coastal waters in the Audit Region. This is mainly due to the cost associated with undertaking such work. There have been a few site-specific studies carried out on water quality, such as the recent EIS, Tweed River Entrance Bypassing Project (Acer Wargon Chapman 1994).

Effluent discharged from sewerage treatment plants (STPs) and runoff from urban and rural land can adversely affect coastal water quality (Macdonald & Phillip 1995). Ocean disposal of effluent from STPs must be licensed and plants are required to meet effluent quality conditions set annually by the EPA (Macdonald & Phillip 1995). This requires plant operators, usually local councils, to monitor the effluent being discharged. The regional EPA office at Grafton is provided with this information and it can be accessed on request.

However, this information and the data collected does not cover the water quality of the receiving waters or ambient levels present (Keats, J., EPA, pers. comm., October 1994). In the Audit Region there is only one STP discharging effluent directly into the ocean. Other STPs discharge into rivers, wetlands and onto land (see volume 5, chapter 2 Infrastructure).

Upwelling

'Upwelling is a process of enrichment of surface waters whereby deeper waters are carried to the surface and transported away from the upwelling centre by compensatory currents', (Rochford 1972). Little research has been done on upwelling in the Audit Region. However, Rochford (1972) studied the upwelling process at Evans Head between July 1966 and June 1969. The main conclusions of this study were that:

- upwelling commonly occurs in the spring and early summer (July – December);
- upwelling is confined to approximately the inner six kilometres of coastal waters with the centre of the upwelling travelling north to south at around 1.2 kilometres per day;
- peak concentrations of nitrates during the upwelling never exceeds five microgram-atom per litre (a measure of concentration). However, this concentration is some ten times the level at other times of the year;
- the upwelling water originates at around 150 metres over the continental slope and local winds are not important in its genesis;
- high nitrate discharges from the two closest rivers, the Richmond and Clarence, had negligible effect on the nitrate economy of the coastal waters.

It is possible the upwelling, described by Rochford, may be due to the EAC impinging on the headlands along the north coast (Short A., Coastal Studies Unit, University of Sydney, pers. comm., March 1995).

Ocean upwelling can cause algal blooms, particularly during summer months. These blooms include red tides (Macdonald & Phillip 1995). Red tides are, 'A reddish discolouration of coastal surface waters due to concentrations of certain toxin-producing dinoflagellates (microscopic planktonic organisms) and often cause major fish kills and paralytic shellfish poisoning' (Zann 1995, p. 109).

Inorganic phosphate, organic phosphorus and nitrate in Australian waters have been investigated (Kirkwood 1967) but because of the scale of information it is difficult to determine the values for the Audit Region. However, this type of information is important for marine biologists, ecologists and geologists.

NOAA SATELLITE IMAGERY

Twice daily, CSIRO monitors sea surface temperature in the Tasman Sea, using data collected from the United States NOAA Satellite. This information is accessible through CSIRO, Hobart. In New South Wales, the Manly Hydraulics Laboratory in Sydney maintains an archive of weekly readings for the period from November 1988. This information is available for the Audit Region. The information assists in the identification of current, warm and cold-centred eddies, upwellings and plumes from river mouths.

2.2.8 Coastal erosion

Coastal erosion is a process that affects most areas of the Audit Region. Sources of change in the rate of coastal erosion have been identified to be both natural and human induced. Natural sources include tropical cyclones, high seas, bathymetry and off-shore sinks, while human sources can include, the building of groynes and other structures, deforestation of dunes, on-and off-shore mining and the dredging of estuaries.

Several reviews of historical records on erosion for the Audit Region have shown that for the last 40 to 100 years, the coastline has eroded up to one metre per year. The exceptions to this in the Audit Region are where breakwaters have been built around river mouths, such as at the Brunswick, Wooli and Tweed Rivers. Here shoreline accretion has occurred (Roy & Crawford 1977). This is due to the breakwaters interfering with the northward littoral drift and sand building up against the breakwaters.

Table 2d shows the volume of sand estimated to be passing four points in the Audit Region (Acer Wagon Chapman 1994; Chapman et al. 1982; NSW Public Works 1992). The movement of sand past the Tweed coast has been determined to be higher than any other location on the New South Wales coast (NSW Public Works 1991c).

Off-shore sediment loss has been documented at both Point Danger and Byron Bay, where sand is lost from the littoral drift to off-shore sinks. At Byron Bay this loss is attributed to the movement on shore of anti-cyclonic eddies which originate from the EAC (see section 2.2.3 Currents). It is estimated that the average loss of sand from the coast at Byron Bay is 26 000 cubic metres per year (Chapman et al. 1982).

Sand migration into estuaries can also occur. This had been shown on the Tweed River where the dredging of sand has caused the estuary to become a sink. It is estimated that for the Tweed the average loss of sand from littoral drift to estuarine sinks is between 30 000-36 000 cubic metres per year (Acer Wagner Chapman 1994; Druery & Curedale 1979).

The rivers of the Audit Region flow through drowned river valleys behind the coastal barriers and terrestrial sediment infills to create estuaries. Therefore, little or no sediment from coastal rivers and estuaries reaches the open coast. Though terrestrial mud and fine sands are carried out during flood periods, this material is deposited beyond capture by the littoral drift. Therefore, fluvial sands do not supply sand in any great quantity for coastal deposition or transportation in littoral currents (Chapman et al. 1982; Roy & Crawford 1977).

From a major cyclonic storm in 1974, which involved high seas with extreme astronomical tides (Chapman et al. 1982), the incident of erosion was found to be most severe on the north coast at the following locations:

- beaches facing south to south-easterly, due to exposure;
- toward the northern end of the beach, also due to exposure;
- pocket, bay-head beaches except those facing north;
- sheltered beaches, due to changes in normal wave conditions;
- near river, estuary and lagoon inlets;
- at other weak points in the beach and dunal system such as access tracks, drainage lines, stormwater, culverts, blowouts, washouts etc. However, sand-mined areas were not necessarily more vulnerable (Chapman et al. 1982, p. 115 – 21).

Coastal dunes are also susceptible to erosion events. Like beaches, dunes lose sand and then are usually restructured with sand at a later date. The foredunes behind the beach

TABLE 2D AVERAGE ANNUAL NET LITTORAL DRIFT ESTIMATES

Area	Cubic metres per annum
Letitia Spit	500 000
Letitia Spit – Tweed River	360-480 000
Hastings Point	180-200 000
Brunswick Heads	100-150 000
Cape Byron	15 000

* summer only
Source: Short & Trenaman 1992; Short 1993

TWEED STUDIES

The Tweed River has been the focus of several major studies, due in part to sand by-passing, dredging effects and structural changes to the mouth of the river. The Tweed River Dynamic Study (Druery & Curedale 1979) commenced in 1976 with the aim of defining the impact of large scale dredging upon the Tweed estuary. Earlier dredging had marked effects on the tidal levels and flows in the estuary. The study involved hydrographic surveys, river and flood gauging, sediment sampling, salinity and temperature measurements. It also investigated geology and estuarine behaviour.

The aim of the Tweed Entrance Feasibility Study (Apelt & Stone 1991) was to identify the feasibility of various options to improve conditions at the mouth of the river. Components of the study included various technical, environmental, social and economic aspects of the project and many technical reports were produced. The project area extended from Point Danger in the north to Cudgen Headland in the south.

The construction of breakwaters at the Tweed River entrance in the 1960s, to improve navigability, interrupted the littoral drift. This has been identified as a principal factor governing erosion and the pattern of sand deposition on beaches further north.

A project was recently approved (Acer Wargon Chapman 1994) which involved a proposal to dredge 2.5 million cubic metres of sand from the Tweed River entrance bar and, by the use of a sand by-pass system, nourish the southern beaches of the Gold Coast. The project will also assist in establishing and maintaining an improved navigable entrance to the Tweed River as the level of safety when crossing the entrance has decreased over recent years. The dredging is also purported to improve the flushing of the lower estuary and therefore improve water quality. The project is for two stages the first involving the current dredging and nourishment of the beaches north of the Tweed River (which has been approved) and Stage 2, future permanent dredging and nourishment work (requiring an EIS to be prepared).

EROSION STUDIES

A number of studies have been commissioned by NSW Public Works to investigate coastal processes in the Audit Region. The first study, focusing on the area between Byron Bay and Hastings Point (Gordon, Lord & Nolan 1978), had the objective of gaining an understanding of the coastal processes governing erosion. The report covers geology and geomorphology, economic considerations, climatological and oceanographic factors, coastal processes and management options and recommendations.

Similar studies have been undertaken for Dreamtime Beach, Bogangar Beach and the coastline from Iluka to Angourie Head and Minnie Water to Station Creek.

PHOTOGRAMMETRIC & GEODIMETER SURVEYS

NSW Public Works undertakes photogrammetric and geodimeter surveys of the New South Wales coast. Photogrammetric surveys comprise analyses of historical aerial photography to determine past shoreline behaviour. That is whether beaches are receding, accreting or are stable. Geodimeter surveys comprise ground surveys of shore profiles and/or shoreline features such as erosion escarpments and high water marks. Table 2e details the sections of the Audit Region covered by these surveys.

provide a barrier to erosion and these dunes are also a source of sand for the beach system. Vegetation on these dunes bind and stabilise the sand and reduce the loss of sand from the system via wind or water erosion. 'In Australia the breakdown of frontal dunes or foredunes, reducing their effectiveness as erosional buffers and creating landward moving sand drift, has been concomitant with human (notably European) settlement' (Chapman et al. 1982, p. 140). Development on frontal dunes results in the loss of this sand from the beach system and loss of vegetation allows for sand to drift inland, also being lost from the system.

TABLE 2E PHOTOGRAMMETRIC AND GEODIMETER SURVEYS IN THE AUDIT REGION

Section of Coast	Survey Type	Survey Period	Quality of Data
Letitia Spit	photogrammetric	1962-88	excellent
Dreamtime Beach	photogrammetric	1944-77	good
Bogangar Beach	photogrammetric	1947-83	good
Byron Bay-Main Beach	geodimeter	1990	excellent
Byron Bay Main & Clarkes Beaches	photogrammetric	198792	excellent
Tallow Beach	photogrammetric	1947-81	good
Seven Mile Beach	photogrammetric	1947-91	excellent
Lighthouse Beach	photogrammetric	1947-91	excellent
South Ballina Beach	photogrammetric	1947-91	excellent
Woody Bay	photogrammetric	1942-90	excellent
Yamba Main Beach	photogrammetric	1942-91	excellent
Pippi Beach	photogrammetric	1942-82	good
Barri Beach	photogrammetric	1958-82	good
Angourie Bay	photogrammetric	1942-82	good
Brooms Head	photogrammetric	1942-80	poor
Wooli Beach	photogrammetric	1942-88	good
Woolgoolga Beach	photogrammetric	1943-86	excellent
Green Bluff	photogrammetric	1943-88	excellent

Source: NSW Public Works

REFERENCES

Acer Wargon Chapman 1994. *Tweed River Entrance Sand Bypassing Project: Environmental Impact Statement Impact Assessment Study*, NSW Public Works and Queensland Department of Environment and Heritage. Public Works report no. 94100, Sydney.

Apelt, C.J. & Stone, D.M. 1991. *Tweed Entrance Feasibility Study-Review of Investigations*, NSW Public Works, Sydney.

Ashdown, C. 1995. 'Solitary Island Marine Reserve', *The State of the Marine Environment Report for Australia: Technical Annexes 1 and 2*, Great Barrier Reef Marine Park Authority for the Department of the Environment, Sport and Territories and the Ocean Rescue 2000 Program, Townsville.

Chapman, D.M., Geary, M., Roy, P.S. & Thom, B.G. 1982. *Coastal Evolution and Coastal Erosion in New South Wales*, Coastal Council of NSW, Sydney.

Coastal Committee of NSW 1994. *Draft Revised Coastal Policy for NSW*, Coastal Committee of NSW, Sydney.

Cresswell, G. 1987. *The East Australian Current*, CSIRO Marine Laboratories Information Sheet No. 3, June, Sydney.

CSIRO 1992a. *Regional Impact of the Enhanced Greenhouse Effect on New South Wales: Annual Report 1990-91*, prepared for NSW Government, Climate Impact Group, Division of Atmospheric Research, Sydney.

CSIRO 1992b. *Regional Impact of the Enhanced Greenhouse Effect on New South Wales: Annual Report 1991-92*, prepared for NSW Government, Climate Impact Group, Division of Atmospheric Research, Sydney.

CSIRO 1994. *Regional Impact of the Enhanced Greenhouse Effect on New South Wales: Annual Report* 1992-93, prepared for NSW Government, Climate Impact Group, Division of Atmospheric Research, Sydney.

Department of the Arts, Sport, the Environment, & Territories (DASET) 1991. *Australian National Report th the United Nations Conference on Environment and Development,* prepared for the Australian Government, Australian Government Publishing Service, Canberra.

Department of the Environment, Sport and Territories 1995. *Living on the Coast – The Commonwealth Coastal Policy*, Department of Environment Sport and Territories, Canberra.

Department of Planning 1994. *North Coast Population and Development Monitor Issue No. 15,* Department of Planning, Sydney.

Department of Planning 1995. *North Coast Urban Planning Strategy,* Department of Planning, Sydney.

Druery, B.M. & Curedale, J.W. 1979. *Tweed River Dynamics Study*, Report No. PWD 78009, NSW Public Works, Sydney.

Edwards, R.J. 1979. *Tasman and Coral Sea Ten Year Mean Temperature and Salinity Fields, 1967-1976*, CSIRO Division of Fisheries and Oceanography, Report No. 88, Sydney.

Environment Protection Authority 1992a. *Coastal Resource Atlas for Oil Spills from Point Danger to the Clarence River*, Environment Protection Authority NSW, Sydney.

Environment Protection Authority 1992b. *Coastal Resources Atlas for Oil Spills from the Clarence River to Smoky Cape*, Environment Protection Authority NSW, Sydney.

Environment Protection Authority 1993. *New South Wales State of the Environment 1993,* Environment Protection Authority NSW, Chatswood.

Gordon, A.D., Lord, B.D., & Nolan, M.W. 1978. *Byron Bay-Hastings Point Erosion Study*, Report No. PWD 78026, Public Works Department of NSW, Sydney.

Hamon, B.V. 1965. 'The East Australian Current 1960-1964', *Deep-Sea Research*, vol 12, pp. 889-921.

House of Representative Standing Committee on Environment, Recreation and the Arts 1991. *The Injured Coastline: Protection of the Coastal Environment*, Australian Government Publishing Service, Canberra.

Kirkwood, L.F. 1967. *Inorganic Phosphate, Organic Phosphorous, and Nitrate in Australian Waters*, CSIRO Division of Fisheries and Oceanography, Technical Paper No. 25, Melbourne.

Legge Wilkinson M. 1993. *State of Our Surf.* 1993 Report. Surfrider Foundation Australia, Newcastle.

Land Conservation Council, 1993. *Marine and Coastal Special Report: Descriptive Report*, Land Conservation Council, Melbourne.

Landsberg, H.E. 1984. *Climates of the Oceans*, World Survey of Climatology, vol 15, ed. van Loon, Elsevier Scientific Publishing, Amsterdam.

Macdonald, R., & Phillip, N. 1995. 'Issues in New South Wales' marine environment', *The State of the Marine Environment Report for Australia: Technical Annexes 1 and 2*, Great

Manly Hydraulics Laboratory 1987, *Brunswick Heads Outfall Investigation,* Report No. 580, PWD Report No. 86043, Public Works Department NSW, Sydney.

Manly Hydraulics Laboratory 1991, *Storm Surge Monitored along the New South Wales Coast March-April 1990*, Report No. MHL591, Public Works, Sydney.

Manly Hydraulics Laboratory 1994a, *NSW Ocean Tide Levels – Annual Summary 1993/94*, Report No. MHL658, NSW Public Works, Sydney.

Manly Hydraulics Laboratory 1994b, *New South Wales Wave Climate, Annual Summary 1993/94*, Report No. MHL695, NSW Public Works, Sydney.

Manly Hydraulics Laboratory 1994c, *New South Wales Estuary and River Water Levels Annual Summary 1992/93*, Report MHL659, PWD Report No. 93069, NSW Public Works, Sydney.

Mulhearn P. J. 1987, 'The Tasman Front: A Study Using Satellite Infrared Imagery', *Journal of Physical Oceanography* vol 17.

NSW Cabinet Office 1990, *The NSW Coast: Government Policy*, New South Wales Government, Sydney.

NSW Department of Agriculture and Fisheries 1985, *An Estuarine Inventory for New South Wales, Australia*, NSW Department of Agriculture, Division of Fisheries. Sydney.

NSW Public Works 1991a, *Reviving the Tweed Feasibility Study-Nearshore Oceanographic Data*, Report No. 3.1.2, NSW Public Works, Sydney.

NSW Public Works 1991b, *Reviving the Tweed Feasibility Study-Ocean Currents*, Report No. 3.1.3, NSW Public Works, Sydney.

NSW Public Works 1991c, *Reviving the Tweed Feasibility Study*, Technical Reports Coastal Processes Appraisal Report No. 3.1.10, NSW Public Works, Sydney.

NSW Public Works 1992, *Estuary Inventory of New South Wales*, Internal report, NSW Public Works, Sydney.

NSW Public Works Clarence River Data Compilation Study, NSW Public Works, Sydney. (in press.)

NSW Standing Committee on State Development 1991, *Coastal Planning and Management in New South Wales: A Framework for the Future*, Vol 1, Report no. 4, NSW Legislative Council, Sydney.

NSW Standing Committee on State Development 1992, *Coastal Planning and Management in New South Wales: The Process for the Future*, Vol 2, Report no. 8, NSW Legislative Council, Sydney.

Patterson Consultants 1993. *Lower Clarence River Floodplain Management Study*, Maclean Shire Council, Sydney.

Pisanu, P.C. & Gale, S.J. 1994. *Geomorphological Analysis of the Upper North East of New South Wales*, Department of Mineral Resources, Sydney.

Pitt, M.W. 1991, *Tourism and Coastal Land Management: A Survey of Visitors on the North Coast of New South Wales*, Economic Papers, Department of Conservation & Land Management, Sydney.

Public Works Department NSW 1982. Cape Byron to Ballina data collection exercise 17/2/82 – 25/2/82, Internal report, Public Works Department NSW, Sydney. (unpub.)

Public Works Department NSW 1983. *Coastal Erosion Report Tweed Shire*, Report No. PWD 83009, Public Works Department NSW, Sydney.

Public Works Department NSW 1984. *Yamba Waters: A Summary of the Yamba Waters Coastal Engineering Study*, Public Works Department NSW, Sydney.

Public Works Department NSW 1985. *Elevated Ocean Levels-Storms Affecting the NSW Coast 1880-1980*, Report No. 85041, Public Works Department NSW, Sydney.

Public Works Department NSW 1986. *Elevated Ocean Levels-Storms Affecting the NSW Coast 1980-1985*, Report No. 86026, Public Works Department NSW, Sydney.

Resource Assessment Commission 1993a. *Coastal Zone Inquiry-Resources and Uses of the Coastal Zone*, Information Paper No. 3. Australian Government Publishing Service, Canberra.

Resource Assessment Commission 1993b. *Coastal Zone Inquiry-Final Report,* Australian Government Publishing Service, Canberra.

Rochford, D.J. 1972. *Nutrient Enrichment of East Australian Coastal Waters-I Evans Head Upwelling*, CSIRO Division of Fisheries and Oceanography Technical Paper No. 33, CSIRO, Melbourne.

Rochford, D.J. 1977. *The Surface Salinity Regime of the Tasman and Coral Seas*, CSIRO Division of Fisheries and Oceanography, Report No. 84, CSIRO Sydney.

Roy, P.S., & Crawford, E.A. 1977. *Significance of sediment distribution in major coastal rivers, Northern NSW*, 3rd Australian Conference on Coastal and Ocean Engineering, Melbourne.

Short, A. 1993. *Beaches of the New South Wales Coast: A Guide to their Nature, Characteristics Surf and Safety*, Australian Beach Safety and Management Program, Sydney.

Short, A. and Trenaman N.L. 1992, 'Wave climate of Sydney region, an energetic and highly variable ocean wave regime', *Australian Journal of Freshwater and Marine Research*, vol 43, p. 765-791.

Zann, L. 1995. *The State of the Marine Environment Report for Australia*, Great Barrier Reef Marine Park Authority for the Department of the Environment, Sport and Territories and the Ocean Rescue 2000 Program, Townsville.

GLOSSARY

astronomical tides – tide regime which includes two high tides and two low tides per day and there is a once-daily inequality in tide range arising from the superimposition of the diurnal constituents (Chapman et al. 1982).

dinoflagellates – a group of single-celled algae.

ebb tide – the outflow of water from rivers and estuaries from the falling tide.

Enhanced Greenhouse Effect – increases in the earth's atmospheric temperature as a result of increasing levels of gases (such as carbon dioxide, methane and nitrous oxide) in the atmosphere due to human activity (RAC 1993b).

flood tide – the inflow of water into rivers and estuaries caused by a rising tide.

groynes – breakwater.

littoral zone – an area of the coastline in which sediment movement by wave, current and action is prevalent; also the environment between the HWM and the LWM.

littoral drift processes – wave, current and wind processes that facilitate the transport of sediments (mainly sand) along a coastal shcreline.

neap tides – tides with the smallest range in a monthly cycle. Neap tides cccur when the sun and moon lie at right angles relative to the earth.

spring tides – tides with the greatest range in a monthly cycle, which occur when the sun, moon and earth are in alignment. Spring tides are also called king tides and are highest around Christmas and New Year (Short 1993).

storm surge – the increase in coastal water levels caused by barometric and wind setup effects of storms. Barometric setup refers to the increase in coastal water levels associated with the lower atmospheric pressures characteristic of storms. Wind setup refers to the increase in coastal water levels caused by an onshore wind driving water shorewards and piling up on the coast.

tidal currents – as tides flood then ebb, tidal currents are generated. These depend on the tidal range and geometry of the water body.

tidal range – the difference between successive high water and low water levels. Tidal range is maximum during spring tides and minimum during neap tides.

wave setup – increase in coastal water levels caused by an onshore wind driving water shorewards and piling up on the coast.

ACRONYMS

AGPS – Australian Government Publishing Service

CSIRO – Commonwealth Scientific and Industrial Research Organisation

DASET – Department of the Arts, Sport, the Environment & Territories (Commonwealth)

DEST – Department of Sport, the Environment and Territories (Commonwealth)

EAC – East Australian Current

EIS – environmental impact statement

EPA – Environment Protection Authority (NSW)

hPa – hectopascal, measure of pressure

HWM – high water mark

LCC – Land Conservation Council (Victoria)

LWM – low water mark

MHL – Manly Hydraulics Laboratory (consultative unit within NSW Public Works)

MHWM – mean high water mark

NOAA – National Oceanic and Atmospheric Administration (USA)

NRAC – Natural Resources Audit Council

PWD – Public Works Department NSW

RAC – Resource Assessment Commission (Commonwealth)

SOMER – State of the Marine Environment Report (Australia)

STP – sewerage treatment plant

m/s – metres per second

m3/s – cubic metres per second

MAJOR CONTRIBUTORS

Author

Susan Harrison, secondee to NRAC Secretariat, Department of Urban Affairs and Planning.

Reviewers

Dr Andrew D. Short, Director, Coastal Studies Unit, University of Sydney (external reviewer).

Peter Haskins, NSW Public Works.

Manly Hydraulics Laboratory.

Other contributors

Peter Haskins, NSW Public Works.

Staff from the Manly Hydraulics Laboratory.

3 CHAPTER

GROUNDWATER

Tables

Figures

3.1 INTRODUCTION

Groundwater is water that occupies pores, cavities, cracks and other spaces in the crustal rocks. It includes water precipitated from the atmosphere which has percolated through the soil; water that has risen from deep magmatic sources, liberated during igneous activity and fossil water retained in sedimentary rocks since their formation (Whittow 1984).

Groundwater is an extremely important natural resource making up more than 98% of the earth's useable water. It plays a crucial role in the global hydrological cycle and is an important source of water for cities and rural towns. The very existence of many isolated communities and rural properties depends on the availability of good groundwater. Many features of our landscape, such as wetlands and lakes, are directly linked to the groundwater underneath.

In the Upper North East Region, groundwater plays a particularly important role for many communities and ecosystems during the dry spring to mid-summer period when availability of surface water is limited.

Aquifers in the Audit Region can be classified into five broad categories on the basis of geology and similarity of groundwater characteristics (see figure 3b):

- Unconsolidated sediments - beach and dune sands
- Unconsolidated sediments - valley alluvium
- Tertiary basalts
- Porous rock (Clarence-Moreton Basin)
- Fractured rock - Beenleigh Block, granites, New England metasediments)

With the exception of valley alluvium, which is specific to each river basin, these aquifer systems are regional units. As such, they will be considered separately in a regional context and not on a catchment basis as is conventionally done with surface waters.

However, to be consistent with other chapters in the volume, where possible groundwater will be placed in a 'catchment context' by highlighting specific information relevant only to individual catchments. Valley alluvium will be considered on a catchment basis. Each of the five aquifer systems will be summarised under the following sub-headings:

- Geology
- Hydrogeology
- Aquifer attributes
  - bore yields
  - area
  - permeability/porosity
  - saturated thickness
  - hydrochemistry (quality)
  - recharge estimates
  - usage
  - management approach to resource allocation
  - sustainable yield
- Potential contamination sources
- Significance of public lands

The management approach and volumes indicated as yield (either safe or sustainable) should be used for planning purposes only as they may not be the preferred option for groundwater allocation. This will be a matter for the State's water manager and the community to negotiate at some future date.

This chapter relies heavily on information contained in the report, *Upper North Coast Groundwater Resource Study for the Natural Resources Audit Council.* (McKibbin 1995). NRAC provided funds to assist in this study by the Department of Land and Water Conservation.

An executive summary and data quality statement for this project (S15 Groundwater Resource Study) are presented at the end of this volume.

3.2 BACKGROUND

The global hydrological cycle, of which groundwater is an integral part, is the circulation of moisture (water) from the sea to the atmosphere, to the land, and back again to the sea (see figure 3a).

Although this implies that the hydrological cycle begins and finishes with water from the ocean, the cycle actually has no beginning or ending. Water evaporates from the surface of the ocean and moves through the atmosphere as weather. When atmospheric conditions are suitable, water vapour condenses and forms droplets which fall to the sea or land as precipitation (rain, snow, ice). This precipitation will either runoff into creeks and rivers, evaporate from the surface of vegetation and soil, or infiltrate into the soil profile where it clings to soil particles and becomes soil moisture. Excess soil moisture percolates under the force of gravity to the water table, where it becomes groundwater which flows through aquifers until it discharges as a spring or in a lake or river, or in the ocean. Evaporation from terrestrial water bodies and the ocean, and transpiration from vegetation (collectively termed evapo-transpiration) continues the hydrological cycle (McKibbin 1995).

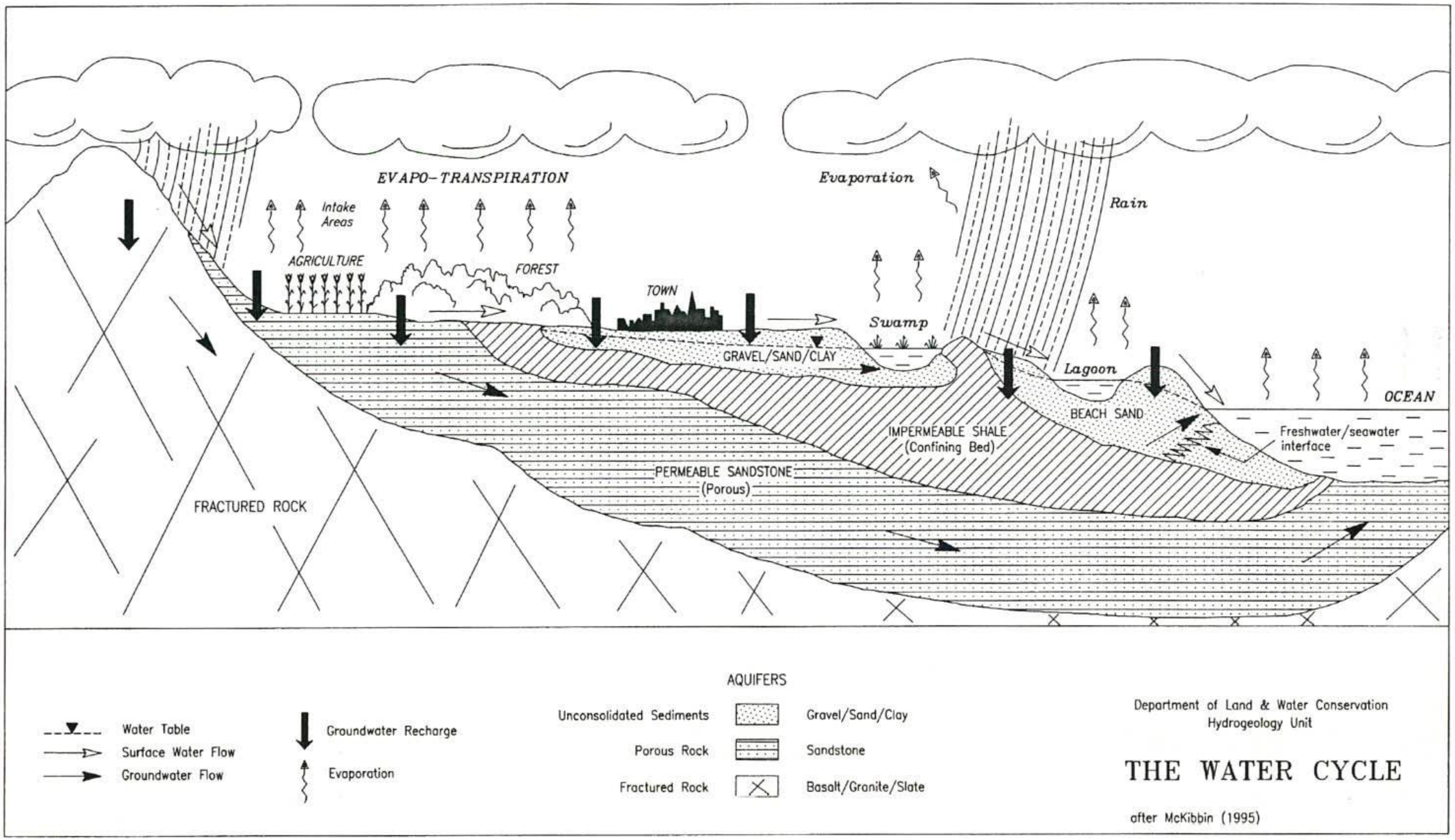


Figure 3a The water cycle

3.3 DESCRIPTION OF AQUIFER SYSTEMS

3.3.1 Beach and dune sands

Beach and sand dune deposits extend almost the entire length of the Audit Region coastline. Extensive deposits are found north of Yamba in the Clarence River catchment, and between Ballina and Evans Head and on Tuckean Island in the Richmond River catchment (see figure 3b). They average two to five kilometres in width, but broaden out to almost 15 kilometres in the mouths of major rivers, and have a maximum thickness of about 50 metres.

The beach and dune sands are mostly fine to medium grained (ie. diameter 0.12 to 0.5mm) and consist of quartz with minor volcanic and metamorphic rock fragments and heavy minerals such as zircon, rutile, ilmenite, magnetite and monazite. In places a dark carbonaceous cemented layer is found interbedded with the sands beds, which can result in a localised perched water table (Coffey Partners International Pty. Ltd. 1989). The sandbeds are usually underlain by estuarine clays and silts and flanked by either estuarine sediments, bedrock, estuaries, or tidal creeks and the ocean. Characteristics of the beach and sand dune aquifer system are summarised in table 3a.

The sandy nature of the beach and dune sands gives them good porosity, permeability and recharge potential. Bore yields are commonly around 0.5 to 5.0 L/s with a maximum of 34 L/s recorded. Groundwater quality is generally good with low total dissolved salts (median 177 mg/L) and hardness (42 mg/L), but water quality problems occur in some areas with the presence of iron or hydrogen sulphide or colour. Dominant use of the groundwater is for domestic supplies (homes, caravan and camping areas) and stock watering. Other uses include four licensed irrigation bores, and town water supply bores at Woodburn (see figure 3c). The water tables are generally shallow which is expressed by the numerous freshwater wetlands, lakes and lagoons found behind the frontal dunes.

The beach and dune sands aquifer system is particularly vulnerable to contamination because of the shallow depth of water tables and permeable soils. The most likely contamination sources include saltwater intrusion, septic systems, landfill sites, effluent disposal, agricultural fertiliser and sand mining.

TABLE 3A SUMMARY OF BEACH AND DUNE SANDS AQUIFER SYSTEM CHARACTERISTICS

Geology	Recent deposits of sands occurring along dune heathland plains and beach ridges. Consists of fine to medium grained sands with some weakly cemented carbonaceous horizons. Thickness of sediments rarely exceeds 40 metres.	
Hydrogeology	Medium to high permeability, unconfined or semi-unconfined aquifer with a shallow water table.	
Bore yields	Maximum 34 L/s, most commonly 0.5 - 5.0 L/s	
Volume of water in storage	Area of aquifer:	631km2
	Estimated saturated thickness:	15m
	Porosity:	30%
	Estimate:	2 840 950 ML
Hydrochemistry	Total dissolved salts	177 mg/L
	pH	6
	Hardness	42 mg/L
	SAR	2.6
Recharge – discharge	Average annual rainfall:	1 458 mm
	Proportion of rainfall infiltration:	20%
	Estimate:	184 093 ML/yr
Usage	Number of water supply bores:	202
	Estimate of use:	3 000 ML/yr
Management approach to resource allocation	Safe yield	
Yield (per year)	184 000 ML	
Potential contamination sources	Saltwater intrusion; septic systems; landfill sites land effluent disposal; sand mining; agricultural fertilisers.	
Significance of public lands	Total area of public lands overlying groundwater resource: 314 km2 representing 50% of the surface extent of the aquifer.	

Source: McKibbin 1995; Groundwater Technology pers. comm., 1995

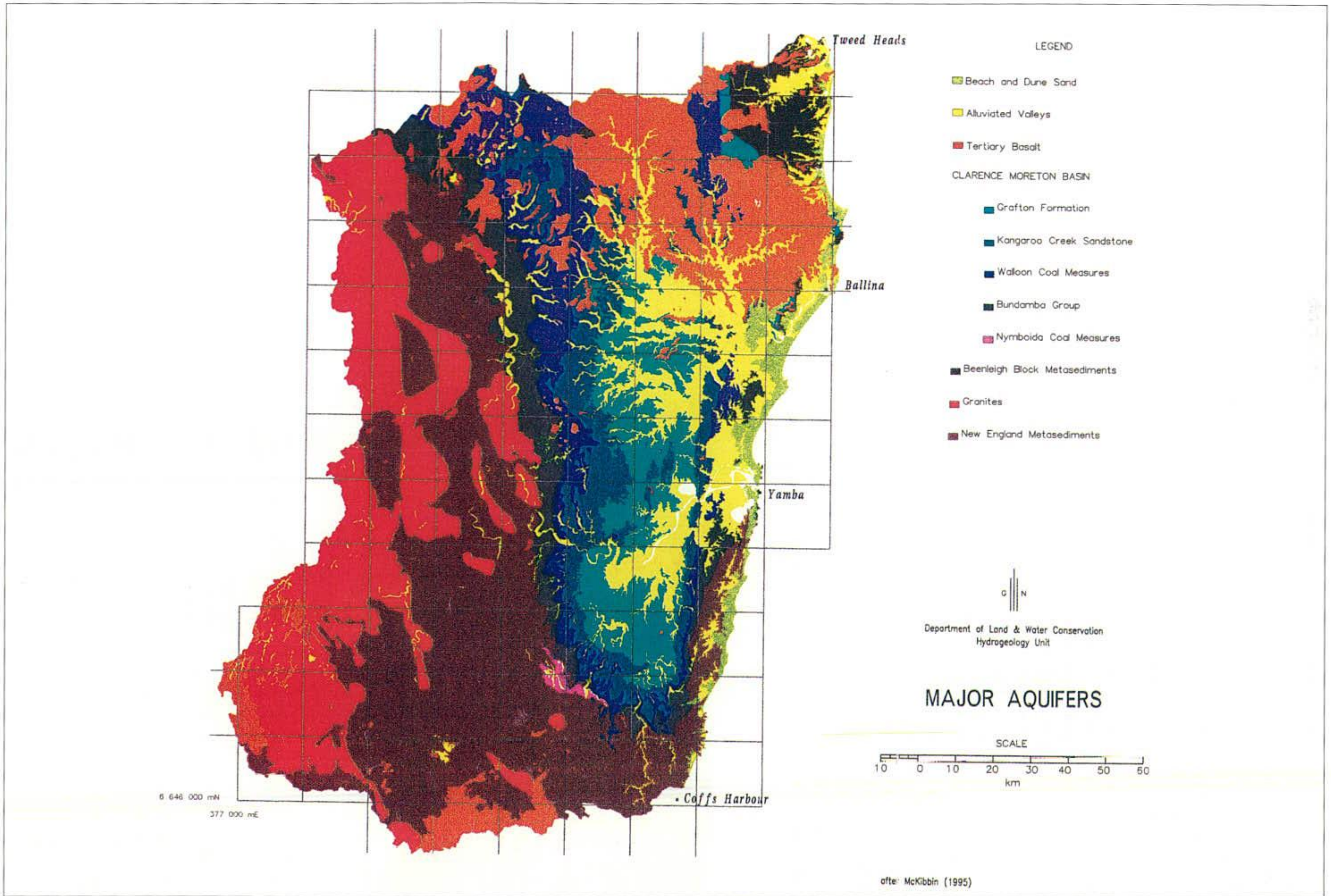


Figure 3b Major aquifers

There is little information available on possible saltwater intrusion and impacts on wetlands and vegetation communities, due to groundwater abstraction in the Audit Region. However, the very small current usage relative to safe yield suggests that impacts will be minimal or negligible. Approximately 10% of the beach and dune sand aquifer has been mined for mineral sands. Potential impacts from sand mining include mobilisation of iron, loss of permeability, groundwater contamination from disturbed organic material, tailings water from the wet plant, and saltwater intrusion. The hydrogeological impacts of sand mining are yet to be fully evaluated. With increasing consideration being given to alternative forms of sewage effluent disposal in the Audit Region (for example: Sinclair Knight & Partners 1986; Sinclair Knight & Partners 1987; Public Works Department 1988), exfiltration and land effluent disposal are future potential groundwater contamination sources. Urban and recreational development of these sensitive areas is probably the greatest potential impact. Fertilisers, pesticides, landfill leachate and septic discharge are also potential contamination sources with a number of current and disused landfill sites and numerous septic systems within the beach and sand dune aquifer system. However, there have been no studies undertaken to evaluate their potential impact on groundwater quality.

3.3.2 Unconsolidated sediment – valley alluvium

Characteristics of each of the valley alluvium aquifer systems (Tweed, Brunswick, Richmond, Clarence) are summarised in tables 3b, 3c, 3d and 3e. Valley alluvium between 7 and 10 metres thick occurs in the upper reaches of the Tweed, Brunswick, Richmond and Clarence Rivers, the thickness increases up to 25 to 35 metres in the downstream limits of the rivers where they grade into estuarine sediments (see figure 3b). The Quaternary fluviatile and estuarine alluvium consists of cobbles, gravels, sands, silts and muds.

The best potential of areas for large supply of low salinity groundwater are upstream of Murwillumbah in the Tweed, on the main arm of the Brunswick River and Mullumbimby Creek upstream of Mullumbimby, and upstream and south of Casino in the Richmond. Bore yields commonly range from 0.5 to 1.5 L/s with a maximum of 30 L/s recorded for Richmond River alluvium. Groundwater quality is good to fair with median

TABLE 3B SUMMARY OF TWEED RIVER ALLUVIUM AQUIFER SYSTEM CHARACTERISTICS

Geology	Quaternary fluviatile and estuarine alluvium consisting of cobbles, gravels, sands, silt and muds, that range in thickness up to a maximum of 35 metres.	
Hydrogeology	Generally of medium permeability shallow water tables and unconfined to semi-confined groundwater conditions.	
Bore yields	Maximum 15 L/s (estimate) with most common supplies of 1.0 - 1.5 L/s.	
Volume of water in storage	Area of aquifer:	147 km2
	Estimated saturated thickness:	15m
	Porosity:	10%
	Estimate:	222 000 ML
	Low salinity:	44 000ML
	High salinity:	178 000 ML
Hydrochemistry	Total dissolved salts:	110 mg/L
	pH:	7
	Hardness:	60 mg/L
	SAR:	1.3
Recharge – discharge	Average annual rainfall:	1 687 mm
	Proportion of rainfall infiltration:	2%
	Estimate:	4 986 ML/yr
Usage	Number of water supply bores:	12
	Estimate of use:	108 ML/yr
Management approach to resource allocation	Safe yield	
Yield (per year)	4960 ML	
Potential contamination sources	Acid sulphate soils, urban runoff, petrol stations, septic systems, cattle tick dip sites, and excessive fertiliser and pesticide/herbicide application.	
Significance of public lands	Total area of public lands overlying groundwater 6.6km2 representing 4.5% of the surface extent of the aquifer.	

Source: McKibbin 1995; Groundwater Technology pers. comm., 1995

total dissolved salts concentrations ranging from 110 mg/L in the Tweed to 594 mg/L in the Richmond and median hardness concentrations ranging from 60 mg/L in the Tweed to 266 mg/L in the Richmond. Lower total dissolved salts (70 mg/L) and hardness (5 mg/L) values have been reported for the Brunswick, but are based on only one sample. Dominant use of valley alluvium groundwater is for domestic supplies and stock watering. There are also 25 licensed irrigation bores installed (see figure 3c).

The most likely contamination sources include acid sulphate soils, urban runoff, petrol stations, septic systems, cattle tick dip sites, and fertiliser and pesticide/herbicide application. The Richmond River catchment has been highlighted as an area that has the potential for pesticide contamination in unconfined aquifers (Knight 1993).

However, this work was based on crop use and inferred chemical application linked with a pesticide root zone model (Finlayson 1989), and very little field verification of groundwater contamination from pesticides/herbicides in the Audit Region has been carried out. Preliminary work in the Richmond River catchment (McKee & Eyre, in press) suggests that contaminated groundwater in valley alluvium aquifers (i.e. from fertiliser leaching, septic systems) may be a significant contributor to elevated nutrient levels in the river during low flow conditions. Further work on nutrient contamination in groundwater is currently being undertaken by the Centre for Coastal Management.

Probably the biggest threat to groundwater quality in valley alluvium aquifers is contamination from acid sulphate soils disturbed by rural and urban development. Acid sulphate soils and their impact in the Tweed, Richmond and Clarence catchments are the subject of numerous recent and continuing studies (for example Lin & Melville 1993; Sammut et al. 1993; White et al. 1993; Ferguson & Eyre 1995) and are discussed further in volume 2, chapter 5, Soils.

TABLE 3C SUMMARY OF BRUNSWICK RIVER ALLUVIUM AQUIFER SYSTEM CHARACTERISTICS

Geology	Quaternary fluviatile and estuarine alluvium consisting of gravels, sands, silt and muds that range in thickness to 15 metres.	
Hydrogeology	Generally of medium permeability, shallow water tables and unconfined groundwater conditions.	
Bore yields	Maximum 10 L/s (estimate) with most common yields of 0.7 L/s.	
Volume of water in storage	Area of aquifer:	114.8km2
	Estimated saturated thickness:	5m
	Porosity:	10%
	Estimate:	57 500 ML
	Low salinity:	46 000 ML
	High salinity:	11 500 ML
Hydrochemistry	Total dissolved salts:	70 mg/L
	pH:	6
	Hardness:	5 mg/L
	SAR:	2.9
Recharge – discharge	Average annual rainfall:	1700mm
	Proportion of rainfall infiltration:	2%
	Estimate:	3 906 ML/yr
Usage	Number of water supply bores:	25
	Estimate of use:	230 ML/yr
Management approach to resource allocation	Safe yield	
Yield (per year)	3 900 ML	
Potential contamination sources	Acid sulphate soils, urban runoff, petrol stations, septic systems, cattle tick dip sites, and excessive fertiliser and pesticide/herbicide application.	
Significance of public lands	Total area of public lands overlying groundwater resource: 5.2 km2 representing 4.5% of the surface extent of the aquifer.	

Source: McKibbin 1995; Groundwater Technology pers. comm., 1995

TABLE 3D SUMMARY OF RICHMOND RIVER ALLUVIUM AQUIFER SYSTEM CHARACTERISTICS

Geology	Quaternary fluviatile and estuarine alluvium consisting of gravels, sands, silts and muds that range in thickness to 50 metres.	
Hydrogeology	Medium to high permeability: shallow water tables (5m) and unconfined to semi-confined groundwater conditions.	
Bore yields	Maximum 30 L/s (estimate) with most common range 0.5 - 1.0 L/s.	
Volume of water in storage	Area of aquifer:	1705 km2
	Estimated saturated thickness:	25 m
	Porosity:	10%
	Estimate:	426 400 ML
	Low salinity:	255 800 ML
	High salinity:	170 600 ML
Hydrochemistry	Total dissolved salts:	594 mg/L
	pH:	7
	Hardness:	266 mg/L
	SAR:	3.4
Recharge – discharge	Average annual rainfall:	1 108 mm
	Proportion of rainfall infiltration:	2%
	Estimate:	37 800 ML/yr
Usage	Number of water supply bores:	373
	Estimate of use:	4 180 ML/yr
Management approach to resource allocation	Safe yield	
Yield (per year)	37 800 ML	
Potential contamination sources	Acid sulphate soils, urban runoff, petrol stations, septic systems, cattle tick dip sites, and excessive fertiliser and pesticide/herbicide application.	
Significance of public lands	Total area of public lands overlying groundwater resource: 150 km2 representing 9.0% of the surface extent of the aquifer.	

Source: McKibbin 1995; Groundwater Technology pers. comm., 1995

TABLE 3E SUMMARY OF CLARENCE RIVER ALLUVIUM AQUIFER SYSTEM CHARACTERISTICS

Geology	Quaternary fluviatile and estuarine alluvium consisting of gravels, sards silts and muds that range in thickness to 25 metres.	
Hydrogeology	Generally of medium permeability, shallow water tables and mostly unconfined groundwater conditions.	
Bore yields	Maximum 20 L/s (estimate) with most common yields of 0.5 - 3 L/s.	
Volume of water in storage	Area of aquifer:	1 376km2
	Estimated saturated thickness:	15m
	Porosity:	10%
	Estimate:	207 000 ML
	Low salinity:	62 000 ML
	High salinity:	145 000 ML
Hydrochemistry	Total dissolved salts:	544 mg/L
	pH:	7.0
	Hardness:	220 mg/L
	SAR:	2.8
Recharge – discharge	Average annual rainfall:	1074mm (Grafton)
	Proportion of rainfall infiltration:	2%
	Estimate:	29 565 ML/yr
Usage	Number of water supply bores:	44
	Estimate of use:	1 500 ML/yr
Management approach to resource allocation	Safe yield	
Yield (per year)	29 560 ML	
Potential contamination sources	Acid sulphate soils, urban runoff, petrol stations, septic systems, cattle tick dip sites and excessive fertiliser and pesticide/herbicide application.	
Significance of public lands	Total area of public lands overlying groundwater resource: 93 km2 representing 7.0% of the surface extent of the aquifer.	

Source: McKibbin 1995; Groundwater Technology pers. comm., 1995

3.3.3 Tertiary basalts

Tertiary basalts in the Audit Region occur in three distinct provinces

1. the Lamington Volcanics in the northern part of the study area, which are the most extensive and mainly consists of rhyolite and basalt;
2. the Ebor-Dorrigo volcanic province in the southern part of the study area, which is dominantly basalt but also includes thin tuffaceous layers, breccia lenses and rhyolite flows, and
3. minor plateau basalt in the south-west of the study area (see figure 3b).

Characteristics of the Tertiary Basalt aquifer systems are summarised in table 3f.

The Tertiary Basalts are one of, if not the most important aquifer systems of the Audit Region. They are very reliable aquifer systems with bore yields ranging from 0.5 to 15 L/s with a maximum of 30 L/s recorded. Groundwater quality is generally good with low median total dissolved salts concentrations of 169 mg/L and median hardness concentrations of 56 mg/L. Permeability is generally high due to consistent secondary porosity features (joints, fractures), primary features (vesicular zones), and weathering profiles between individual volcanic layers. Groundwater discharges from basalt aquifers feed numerous springs, maintain some wetlands, and provide baseflow in streams that drain basaltic terrain. It is the most developed regional aquifer with 670 stock and domestic bores, 52 licensed irrigation bores, and 8 municipal bores (see figure 3c).

The Cudgen and Alstonville Plateaux have the potential to become stressed due to significant groundwater development for irrigation (Ross & McKibbin 1992). To address resource allocation and protect groundwater from over extraction, an interim aquifer management plan was introduced for the Alstonville Plateau in July 1989. Currently, the entitlement ceiling for the plateau is 20 700 megalitres per year which is well above the current level of issued entitlements for the whole plateau. However, there are some individual catchments south of Alstonville where entitlements are almost fully allocated.

The most likely Tertiary Basalt aquifer contamination sources include urban runoff, petrol stations, rural residential septic systems, cattle tick dip sites, and

TABLE 3F SUMMARY OF TERTIARY BASALTS AQUIFER SYSTEM CHARACTERISTICS

Geology	Tertiary basalt and related volcanic strata. The thickness of the basalt profile varies but often exceeds 200 metres.	
Hydrogeology	Groundwater occurs in joints and fractures as well as vesicular layers and inter-layered palaeosol and sediments. Conditions vary from unconfined to confined. Generally medium permeability.	
Bore yields	Up to 30 L/s but most commonly yields range from 0.5 – 15 L/s. Supplies from excavations range from 15 L/s, but may be seasonally affected.	
Volume of water in storage	Area of aquifer:	3 961 km2
	Estimated saturated thickness:	60 m
	Porosity:	3%
	Estimate:	7 130 000 ML
Hydrochemistry	Total dissolved salts:	169 mg/L
	pH:	7.0
	Hardness:	56 mg/L
	SAR:	1.4
Recharge – discharge	Average annual rainfall:	1 867 mm
	Proportion of rainfall infiltration:	10%
	Estimate:	740 000 ML/yr
Usage	Number of water supply bores:	724
	Estimate of use:	8 800 ML/yr
Management approach to resource allocation	Safe yield	
Yield (per year)	797 000 ML	
Potential contamination sources	Urban runoff, petrol stations, rural residential septic systems, cattle tick dip sites, and excessive fertiliser and pesticide/herbicide application.	
Significance of public lands	Total area of public lands overlying groundwater resource: 898 km2 representing 23.0% of the surface extent of the aquifer.	

Source: McKibbin 1995; Groundwater Technology pers. comm., 1995

excessive fertiliser and pesticide/herbicide application. Basalt plateaux in the Audit Region are favoured rural residential development areas which, combined with current rapid population growth, will increase the potential threat of groundwater contamination from septic systems. However, there has been very little work undertaken to assess Tertiary Basalt aquifer contamination sources (McKibbin 1995).

3.3.4 Porous sedimentary rocks (Clarence-Moreton Basin)

The Clarence Moreton Basin is an elongated structural basin, extending nearly the full length of the Audit Region (see figure 3b). The oldest rocks of the basin are the Nymboida Coal Measures which crop out in relatively small areas in the south and south-east of the study area. The Nymboida Coal measures are overlain by early to mid-Jurassic sandstones, siltstones and pebble conglomerates of the Bundamba Group. The Jurassic rocks include the Walloon Coal Measures that occur towards the centre of the basin and are overlain by the Kangaroo Creek Sandstone. The Grafton Formation is the youngest formation of the Clarence-Moreton Basin. Characteristics of the aquifer systems of the Clarence-Moreton Basin are summarised in tables 3g, 3h, 3i, and 3j.

The resource potential of the Clarence-Moreton Basin is not well known as there are only limited exploration bores. Bore yields are commonly around 0.3 to 0.5 L/s, with high yields of 10 L/s or more possible from the Kangaroo Creek Sandstone. Water quality is fair with median total dissolved salts concentrations ranging from 513 mg/L in the Kangaroo Creek Sandstone to 1125 mg/L in the Grafton Formation, and median hardness concentrations ranging from 138 mg/L in the Walloon Coal Measures to 500 mg/L in the Grafton Formation. The Kangaroo Creek Sandstone is the most favourable formation for groundwater and may contain some very permeable zones that could be a significant source of water supply. Dominant use of the groundwater is for domestic supplies and stock watering. There is one licensed irrigation bore in the Kangaroo Creek Sandstone and three licensed bores in the Walloon Coal Measures (see figure 3c).

Of the aquifers in the Audit Region, the Clarence-Moreton Basin aquifers are probably the least vulnerable to contamination, due to the depth of the water tables and often low permeability of the soil profiles. The most likely aquifer contamination sources are excessive fertiliser and pesticide/herbicide application (McKibbin 1995).

TABLE 3G SUMMARY OF CLARENCE – MORETON BASIN GRAFTON FORMATION AQUIFER SYSTEM CHARACTERISTICS

Geology	Consists of interbedded sandstone, siltstone and claystone and minor coal; Late Jurassic and early Cretaceous Age.	
Hydrogeology	Groundwater occurs in porous horizons as well as joints and bedding planes fractures. Conditions are mostly confined. Low permeability.	
Bore yields	Most commonly around 0.3 L/s, but may range to about 1.5 L/s	
Volume of water in storage	Area of aquifer:	2 103 km2
	Estimated saturated thickness:	50 m
	Porosity:	2%
	Estimate:	2 104 000 ML
Hydrochemistry	Total dissolved salts:	1 125 mg/L
	pH:	7.0
	Hardness:	500 mg/L
	SAR:	5
Recharge – discharge	Average annual rainfall:	1 074 mm
	Proportion of rainfall infiltration:	0.5% (5.37mm/year)
	Estimate:	11 300 ML/yr
Usage	Number of water supply bores:	104
	Estimate of use:	1 000 ML/yr
Management approach to resource allocation	Sustainable yield	
Yield (per year)	28 100 ML	
Potential contamination	Excessive fertiliser and pesticide/herbicide application.	
Significance of public lands	Total area of public lands overlying groundwater resource: 542 km2 representing 26.0% of the surface extent of the aquifer.	

Source: McKibbin 1995 & Groundwater Technology pers. comm., 1995

TABLE 3H SUMMARY OF CLARENCE-MORETON BASIN KANGAROO CREEK SANDSTONE AQUIFER SYSTEM CHARACTERISTICS

Geology	Consists of Middle to Late Jurassic quartz sandstone with minor conglomerate horizons. Bedding thickness varies and contains high angle cross bedding facies. Thickness of the formation ranges from 200 - 500 m.	
Hydrogeology	Groundwater occurs in porous layers and joints/bedding planes fracture systems. Conditions are mostly confined.	
Bore yields	Recorded supplies mostly about 0.4 L/s. Aquifer has potential for high yields possibly 10 L/s, or more.	
Volume of water in storage	Area of aquifer:	1 971 km2
	Estimated saturated thickness:	200m
	Porosity:	5%
	Estimate:	19 710 000 ML
Hydrochemistry	Total dissolved salts:	513 mg/L
	pH:	7.0
	Hardness:	315 mg/L
	SAR:	1.8
Recharge – discharge	Average annual rainfall:	1 074 mm
	Proportion of rainfall infiltration:	5% (53mm/year)
	Estimate:	105 890 ML/yr
Usage	Number of water supply bores:	67
	Estimate of use:	650 ML/yr
Management approach to resource allocation	Sustainable yield	
Yield (per year)	263 600 ML	
Potential contamination sources	Excessive fertiliser and pesticide/herbicide application.	
Significance of public lands	Total area of public lands overlying groundwater resource: 744 km2 representing 38.0% of the surface extent of the aquifer.	

Source: McKibbin 1995; Groundwater Technology pers. comm., 1995

TABLE 3I SUMMARY OF CLARENCE-MORETON BASIN WALLOON COAL MEASURES SANDSTONE AQUIFER SYSTEM CHARACTERISTICS

Geology	Consists of terrestrial Middle to Late Jurassic grey claystone, lithic sandstone, coal and minor volcanics at base. The unit has a maximum thickness of about 600 m.	
Hydrogeology	Groundwater mostly occurs in joints, bedding planes fractures and in porous sequences of the coarse grained rocks. Conditions are mostly confined. Low to medium permeability.	
Bore yields	Most commonly around 0.5 L/s ranging to 5.0 L/s.	
Volume of water in storage	Area of aquifer:	2 152 km2
	Estimated saturated thickness:	100 m
	Porosity:	2%
	Estimate:	4 304 000 ML
Hydrochemistry	Total dissolved salts:	750 mg/L
	pH:	8.0
	Hardness:	138 mg/L
	SAR:	9.2
Recharge – discharge	Average annual rainfall:	1 074 mm
	Proportion of rainfall infiltration:	0.5% (5.37 mm/year)
	Estimate:	11 560 ML/yr
Usage	Number of water supply bores:	53
	Estimate of use:	700 ML/yr
Management approach to resource allocation	Sustainable yield	
Yield (per year)	46 000 ML	
Potential contamination sources	Excessive fertiliser and pesticide/herbicide application.	
Significance of public lands	Total area of public lands overlying groundwater resource: 566 km2 representing 26% of the surface extent of the aquifer.	

Source: McKibbin 1995; Groundwater Technology pers. comm., 1995.

TABLE 3J SUMMARY OF CLARENCE-MORETON BASIN BUNDAMBA GROUP AQUIFER SYSTEM CHARACTERISTICS

Geology	Consists of terrestrial Early Jurassic to Late Triassic polymictic and quartz conglomerate, quartz-lithic and lithic sandstone and carbonaceous siltstone. Maximum thickness is about 600 m.	
Hydrogeology	Groundwater occurs in both porous and joint/fracture systems and conditions are mostly confined. Generally low permeability.	
Bore yields	Mostly less than 0.5 L/s, ranging to 2.5 L/s. Some potential for larger yields with greater depths of intersection of formation.	
Volume of water in storage	Area of aquifer:	1 774 km2
	Estimated saturated thickness:	100 m
	Porosity:	5% (some units higher)
	Estimate:	8 872 000 ML
Hydrochemistry	Total dissolved salts:	866 mg/L
	pH:	8.0
	Hardness:	436 mg/L
	SAR:	2.0
Recharge – discharge	Average annual rainfall:	1 074 mm
	Proportion of rainfall infiltration:	5% (53.7mm/year)
	Estimate:	95 000 ML/yr
Usage	Number of water supply bores:	15
	Estimate of use:	150 ML per yr
Management approach to resource allocation	Sustainable yield	
Yield (per year)	166 000 ML	
Potential contamination sources	Excessive fertiliser and pesticide/herbicide application.	
Significance of public lands	Total area of public lands overlying groundwater resource: 590 km2 representing 33.0% of the surface extent of the aquifer.	

Source: McKibbin 1995; Groundwater Technology pers. comm., 1995

3.3.5. Fractured rock

Fractured rock aquifer systems have been sub-divided on a geographical basis into

1. the New England Fold Belt in the southern and western areas;
2. the Beenleigh Block in the far north east; and
3. granitic rocks of the Audit Region (see figure 3b).

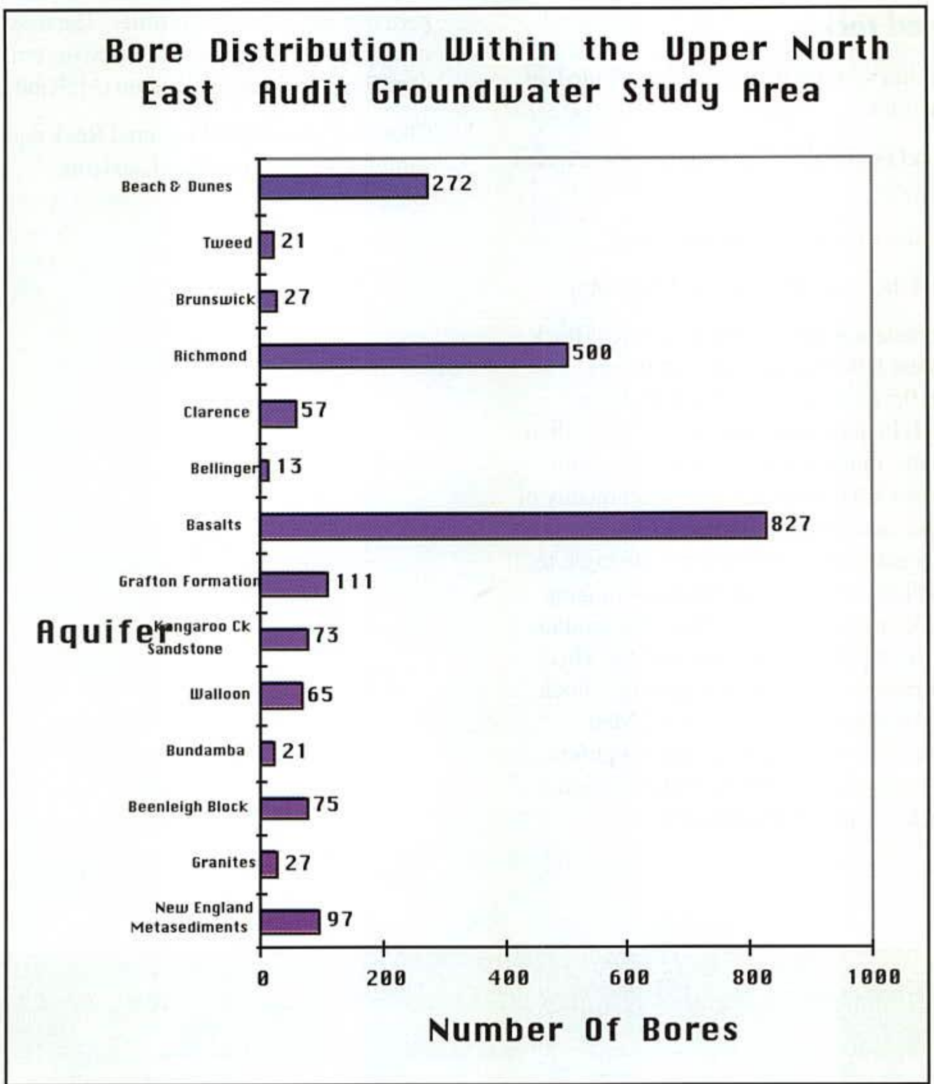
Bore yields in the metasediments of the Beenleigh Block and the New England Fold Belt aquifer systems are commonly around 0.5 L/s but range up to 5.0 L/s. In contrast, bore yields in the granite aquifers are lower than in the metasediments, ranging from 0.2 to 0.4 L/s, with supplies of more than 1.0 L/s rare. Groundwater quality of all the fractured rock aquifers is good with median total dissolved salts concentrations ranging from 108 mg/L to 312 mg/L, and median hardness concentrations ranging from 36 mg/L to 135 mg/L. Dominant use of the groundwater is for domestic supplies and stock watering. There are four licensed irrigation bores in the Beenleigh Block metasediments and seven in the New England Metasediments (see figure 3c). The Fractured Rock aquifers have a low to moderate vulnerability to contamination, due to the depth of the water tables and the low permeability of the soil profiles. The most likely aquifer contamination sources are excessive fertiliser and pesticide/herbicide application (McKibbin 1995).

Characteristics of the Fractured Rock aquifer systems are summarised in tables 3k, 3l, and 3m.

TABLE 3K SUMMARY OF BEENLEIGH BLOCK METASEDIMENTS AQUIFER SYSTEM CHARACTERISTICS

Geology	Consists of strongly folded and deformed Silurian greywacke, slate, phyllite and quartzite. Also known as the Neranleigh-Fernvale Group.	
Hydrogeology	Groundwater only occurs as secondary porosity ie. in joints, fractures and fissures and weathered zones along these features. Conditions range from unconfined to semi-confined. Generally low permeability.	
Bore yields	Most common around 0.5 L/s with occasional supplies to 5.0 L/s.	
Volume of water in storage	Area of aquifer:	597 km2
	Estimated saturated thickness:	50 m
	Porosity:	1%
	Estimate:	300 000 ML
Hydrochemistry	Total dissolved salts:	122 mg/L
	pH:	6.0
	Hardness:	36 mg/L
	SAR:	1.3
Recharge - discharge	Average annual rainfall:	1 680 mm
	Proportion of rainfall infiltration:	1% (16.8 mm/year)
	Estimate:	10 000 ML/yr
Usage	Number of water supply bores:	64
	Estimate of use:	700 ML per yr
Management approach to resource allocation	Sustainable yield	
Yield (per year)	10 000 ML	
Potential contamination sources	Excessive fertiliser and pesticide/herbicide application.	
Significance of public lands	Total area of public lands overlying groundwater resource: 55 km2 representing 9.0% of the surface extent of the aquifer.	

Source: McKibbin 1995; Groundwater Technology pers. comm., 1995.



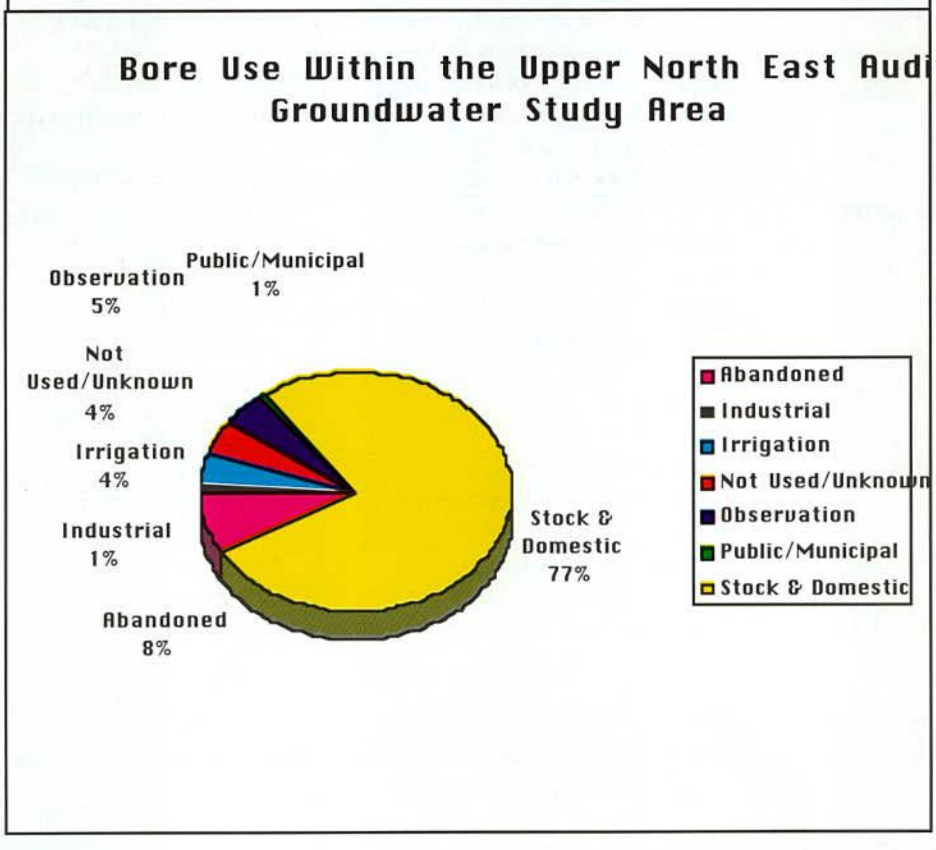


Figure 3c Bore distribution and use within the Audit Region

TABLE 3L SUMMARY OF GRANITE AQUIFER SYSTEM CHARACTERISTICS

Geology	This aquifer includes all crystalline rocks of a granitic origin. For example, those occurring in granitoid rock masses such as batholiths, stocks, sills and dykes. Common rock types consists of granite, diorite, porphyry, associated crystalline acid volcanics and gneiss.	
Hydrogeology	Groundwater occurs in shallow weathered layers, and joint/fissured zones, at depth. Conditions range from unconfined to confined. Most supplies are encountered in the shallower parts of the aquifer system. Very low permeability formation in general.	
Bore yields	Commonly in the range 0.2 - 0.4 L/s, with supplies more than 1.0 L/s fairly rare.	
Volume of water in storage	Area of aquifer:	5 196 km2
	Estimated saturated thickness:	15m
	Porosity:	1%
	Estimate:	780 000 ML
Hydrochemistry	Total dissolved salts:	199 mg/L
	pH:	7.0
	Hardness:	124 mg/L
	SAR:	0.7
Recharge – discharge	Average annual rainfall:	1 153 mm
	Proportion of rainfall infiltration:	0.5% (5.7 mm/year)
	Estimate:	10 000 ML/yr
Usage	Number of water supply bores:	28
	Estimate of use:	250 ML/yr
Management approach to resource allocation	Safe yield	
Yield (per year)	30 000ML	
Potential contamination sources	Excessive fertiliser and pesticide/herbicide application.	
Significance of public lands	Total area of public lands overlying groundwater resource: 1 703 km2 representing 32% of the surface extent of the aquifer.	

Source: McKibbin 1995; Groundwater Technology pers. comm., 1995.

TABLE 3M SUMMARY OF NEW ENGLAND METASEDIMENTS AQUIFER SYSTEM CHARACTERISTICS

Geology	Lithologies include greywacke, slate, phyllite, quartzite, intermediate volcanics, tuffs and some limestones. These rock units are interbedded and are all of Palaeozoic age.	
Hydrogeology	Groundwater almost invariably occurs as secondary porosity ie. joints, fractures and fissures and weathered zones along these features. Conditions range from unconfined to semi-confined. Generally low permeability.	
Bore yields	Generally around 0.5 L/s with occasional supplies up to 5.0 L/s.	
Volume of water in storage	Area of aquifer:	8 339 km2
	Estimated saturated thickness:	50m
	Porosity:	1%
	Estimate:	4 170 000ML
Hydrochemistry	Total dissolved salts:	312 mg/L
	pH:	7.0
	Hardness:	135 mg/L
	SAR:	1.5
Recharge – discharge	Average annual rainfall:	1153 mm
	Proportion of rainfall infiltration:	1% (11.5mm/year)
	Estimate:	1300 ML/yr
Usage	Number of water supply bores:	96
	Estimate of use:	1 300 ML/yr
Management approach to resource allocation	Sustainable Yield	
Yield (per year)	96 000ML	
Potential contamination sources	Excessive fertiliser and pesticide/herbicide application.	
Significance of public lands	Total area of public lands overlying groundwater resource: 4 906 km2 representing 58.0% of the surface extent of the aquifer.	

Source: McKibbin 1995; Groundwater Technology pers. comm., 1995.

REFERENCES

Coffey Partners International Pty. Ltd 1989, *Newrybar mineral sands project groundwater assessment.* Report No. G214/1. Coffey Partners International Pty. Ltd., Sydney.

McKee, L. & Eyre, B. D. (in press) 'Nutrient export from a large rurally diverse northern NSW coastal catchment' *Proceedings of the National Conference on the Downstream Effects of Land Use,* Rockhampton 26-28 April 1995.

Ferguson, A. & Eyre, B. D. 1995, 'Local and regional impacts of acid runoff from acid sulphate soils in the Richmond River Estuary, Northern NSW.' *Program and Abstracts Australian Marine Science Association Meeting, Sydney 3 -6 July 1995.* (n.p.)

Finlayson, D. 1989, A risk assessment of groundwater contamination by pesticide residues in selected aquifers of New South Wales, Master of Applied Science Project Report, Centre for Groundwater Management and Hydrogeology, University of New South Wales, Sydney (unpub.).

Knight, M. J. 1993, 'Organic chemical contamination of groundwater in Australia – an overview to 1993', *AGSO Journal of Australian Geology and Geophysics* vol. 14, pp. 107-122.

Lin, C. & Melville, M. D. 1993, 'Control of soil acidification by fluvial sedimentation in an estuarine floodplain, eastern Australia', *Sedimentary Geology* vol. 85, pp. 271-284.

McKibbin, D. 1995, *Upper North Coast Groundwater Resource Study for the Natural Resources Audit Council (NRAC).* Report No. TS 95-011, Department of Water Resources, Technical Services Division, Parramatta.

Public Works Department 1988, *Final report on injection well effluent, Belongil Beach – Byron Bay.* Public Works Department, Sydney.

Ross, J. B. & McKibbin, D. 1992, *North Coast sustainable strategy – groundwater aspects.* Report No. TS92.024, Department of Water Resources Technical Services Division, Parramatta.

Sammut, J; Callinan, R.B. & Fraser, G.C. 1993, 'The impact of acidified water on freshwater and estuarine fish population in acid sulphate soil environments' *Proceedings of the National Conference on Acid*

Sulphate Soils ed. Bush, R. sponsored by CSIRO, NSW Agriculture & Tweed Shire Council .(n.p.)

Sinclair & Knight 1986, *Byron Bay sewerage strategy study – investigation of disposal of effluent via sand dunes at Tallow and Belongil Beaches.* Public Works Department, Sydney.

Sinclair & Knight 1987, *Byron Bay sewerage effluent disposal: Tallow Beach deep well investigation.* Public Works Department, Sydney.

White, I; Melville, M.D; Wilson, B.P; Price, C.B. & Willett, I.R. 1993, 'Understanding acid sulphate soils in canelands' *Proceedings of the National Conference on Acid Sulphate Soils,* ed. Bush, R. sponsored by CSIRO, NSW Agriculture & Tweed Shire Council. (n.p.)

Whittow, J.B. 1984, *The Penguin Dictionary of Physical Geography.* Penguin Books Australia, Ringwood, Victoria.

Source: McKibbin 1995; Groundwater Technology pers. comm., 1995.

GLOSSARY

aeolian deposits – Fine grained sands and silts deposited after transport by wind.

alluvium – Sediments, deposited by rivers, creeks and lakes, made up of clay, silt, sand, gravel and cobbles beds.

anion – A negatively charged ion in a solution, for example, the chloride ion in a solution of sodium chloride.

aquifer – A term used for a geologic unit sufficiently porous to store water and permeable enough to allow water to flow through them in economic quantities.

basalt – Fine grained dark rock of volcanic origin with a high percentage of iron and magnesium.

batholiths – Large intrusions, commonly of granite, which can be up to hundreds of kilometres wide; and deeply buried into the country rock. Their formation is accompanied by great heat and pressure, and many smaller intrusive bodies may be associated with them.

bore – A work that is constructed using a drilling plant and lined with tubing (usually steel or PVC) which allows the inflow of groundwater at depth.

cation: – A positively charged ion in a solution, for example, the sodium ion in a solution of sodium chloride.

conglomerate – cemented gravels and cobbles.

electrical conductivity – a measure of the ability of water to conduct an electric current between electrodes placed in a sample of the water; the value obtained relates to the nature and amount of salts present in the water and increases with concentration.

estuarine deposits – sediments deposited in the tidal reaches of coastal streams.

fluviatile – produced by the action of a flowing river.

fractured rocks: – rocks in which the main groundwater storage is provided by the voids of fractures, joints and partings.

geological fault – a fracture in the surface of a rock mass which has led to a permanent displacement.

gneiss/schist – coarse alternating bands of quartz, mica and silicate minerals.

granite – Coarse grained rock composed chiefly of quartz and potassium and sodium rich silicate minerals of varying colour.

greywacke – sandstone containing rock fragments and clay minerals.

groundwater – water saturating the voids in rocks; water in the zone of saturation in the Earth's crust.

hardness – a measure of the concentration of calcium and magnesium which are the scale-forming salts in the water. It is expressed as mg/L calcium carbonate.

hydrologic cycle – a term to describe the cyclic series of events that water passes through. The groundwater part of the cycle can involve extremely long periods, sometimes more than tens of thousands of years.

igneous rocks: – rocks which have been solidified from a hot molten mass. Examples are granite and basalt.

irrigation bores – bores used for the extraction of groundwater for irrigation purposes.

licensed – bores licensed by the Department of Land and Water Conservation.

limestone – consists essentially of carbonate minerals and formed by chemical precipitation or accumulation of shells and skeletons of organisms.

metamorphic – characterised by change of form.

metamorphic rocks – Rocks altered by heat and pressure, sometimes in conjunction with chemically active fluids. Common examples are quartzite, slate and gneiss.

phyllite – medium textured rock which tends to break into layers or slabs.

outcrop – the area over which a rock formation emerges or is exposed to the earth's surface

perched water table – a water table caused by the retention of water on an isolated relatively impermeable layer within a rock strata some height above the normal water table, from which it is separated by layers of unsaturated rock.

permeability – the relative ease with which a porous medium can transmit a fluid.

4.1 INTRODUCTION

Water is fundamental to the functioning of all natural systems. Civilisations have flourished with the development of reliable water supplies, and then collapsed as the water supply failed. Australia is the driest of the populated continents making water Australia's most important natural resource. Hydrology is the science that deals with the interrelationships and interactions between water and its environment (Gordon et al., 1992).

This chapter deals with the rainfall, runoff and evaporation parts of the hydrological cycle. Other aspects of the hydrological cycle have been discussed elsewhere (volume 3 chapter 3 Groundwater and volume 2 chapter 1 Climate). The spatial distribution of rainfall across the catchments within the Upper North East Region, and the longer term temporal variation in annual rainfall will be presented as these are important driving factors of the Region's hydrology (seasonal rainfall variability has already been described in volume 2 chapter 1 Climate). Evaporation rates, stream characteristics (runoff, annual discharges, stream variability, and stream persistence) and flood hydrology and frequency in the Audit Region will also be presented.

4.2 RAINFALL

Rainfall is the initial input of water to the terrestrial phase of the hydrological cycle, and therefore will directly influence the hydrology (groundwater, river flow and evaporation). Under natural conditions, variation in rainfall is usually closely reflected by variation in river flow and flooding. Rainfall may vary in a number of ways:

- spatially, according to the interaction between prevailing weather conditions and local topography;
- annually according to the seasons;
- from year to year according to the Southern Oscillation; and
- climatic variations over much longer periods of up to 50 years, linked to long-term trends in the Southern Oscillation (Ferguson 1995).

4.2.1 Spatial rainfall variation

Tweed and Brunswick

The Tweed and Brunswick River catchments are the wettest within the Audit Region (see figure 4a, Median rainfall). Highest annual rainfall occurs along the McPherson Ranges which form the northern boundary of these catchments with annual median falls of between 1800 and 2600mm. This area is drained by the Rous River. Annual median falls exceeding 1700mm occur along the coastal fringe and along the ranges forming the remaining boundaries of the drainage area, which feed the headwaters of the Oxley and Tweed Rivers. The driest part the catchment is along the valleys of the middle reaches of the Tweed River in the vicinity of Uki where the annual median is about 1400 mm.

Richmond

Highest annual rainfall occurs along the coastal strip from Ballina to Byron Bay (median falls in excess of 1800mm), and along the Tweed Ranges at the head of the Leycester and Wilson's Creek sub-catchments (see figure 4a). The driest part of the Richmond River catchment is along the valleys of the middle reaches of the Richmond River, and to the south over the Bungawalbyn Creek sub-catchment where median falls are around 1125 mm.

Clarence

Highest annual rainfall occurs along the Dorrigo Plateau (median 1800mm) at the southern boundary of the catchment drained by the Nymboida and Orara Rivers. The south western boundary drained by the Aberfoyle, Sara and Mann Rivers exists in a rain shadow with median falls below 900 mm. The Gibraltar Range, along the western perimeter, experiences slightly higher falls (up to 1000 mm). The northern part of the catchment at the headwaters of the Clarence River is in another rain shadow (median annual less than 900mm). This rain shadow is formed by the Richmond Range along the north eastern boundary of the catchment where annual median rainfalls are up to 1200 mm.

4.2.2 Long-period climatic variation

Climatic records for most coastal catchments along the New South Wales coast show evidence of long-period climatic fluctuations characterised by alternating flood- and drought-dominated regimes occurring on a forty to fifty year cycle (Warner, 1993). During a flood-dominated regime, floods are both larger and more frequent than during a drought-dominated regime. Rainfall and flood records dating back to the 1850s in the Audit Region show that there have been two distinct periods of flooding (1850 to 1895, and 1945 to present), and one period of drought where virtually no floods occurred (1895 to 1935) (see figure 4b) (Ferguson, 1995). This marked variation in flooding has important environmental and economic implications in the Audit Region (see table 4a) given the large size of the Region's floodplains and the extensive flood-prone agricultural, residential and industrial development.

GAUGING STATION LOCATIONS

Location of gauging stations referred to in this chapter may be obtained as hard copy maps from the Department of Land and Water Conservation or via the Community Access Interface geographic information system available in the Department of Land and Water Conservation's Grafton office. For further information or to arrange access to Community Access Interface, contact the Department of Land and Water Conservation's Grafton Office on (066) 42 7799.

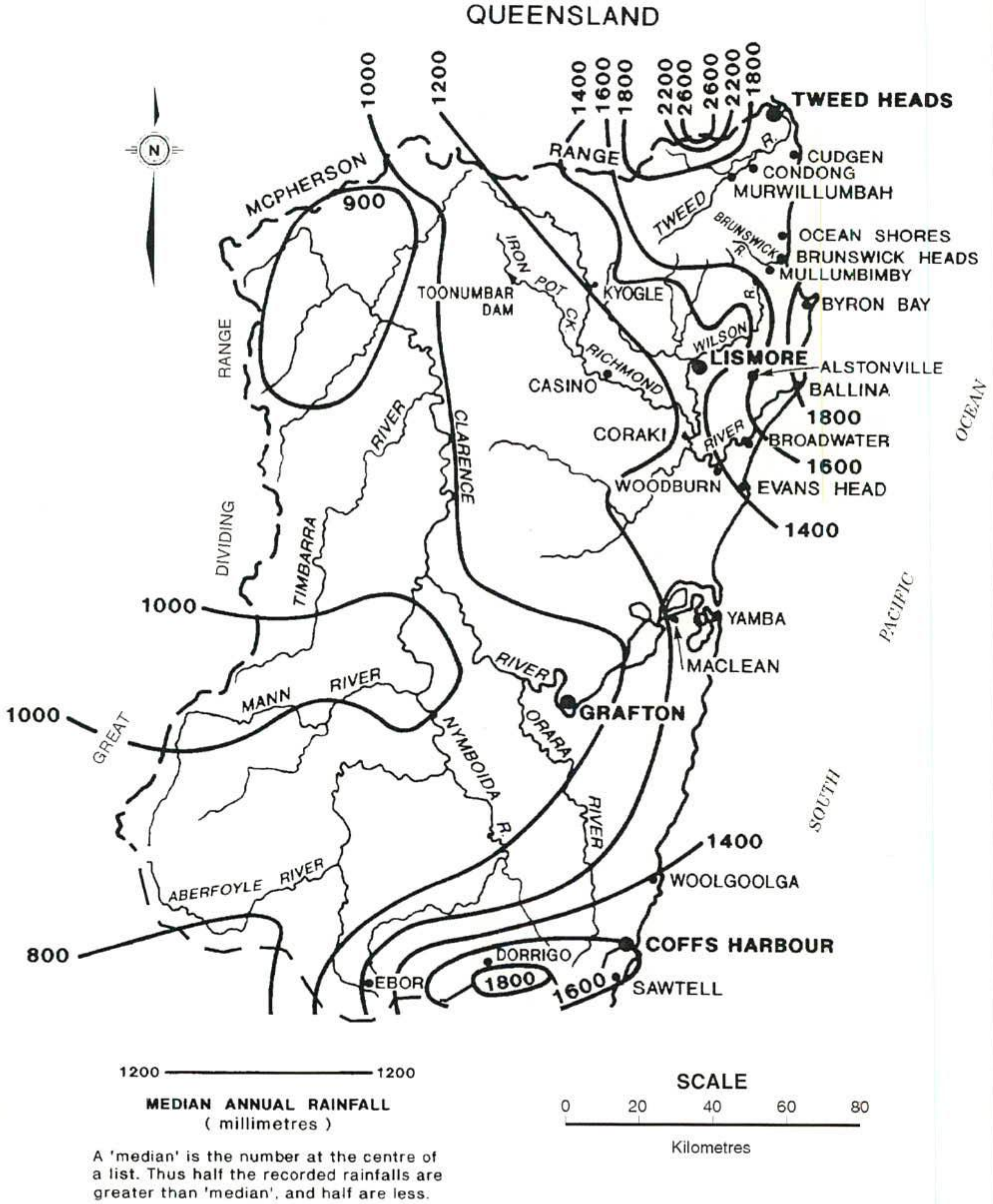


Figure 4a Annual median rainfall across the Audit Region.

TABLE 4A THE LIKELIHOOD OF FLOODING AT LISMORE

Flood event date	Stage height at Lismore [m]	FDR		DDR		Flood study estimate	
		A.E.P. (%)	A.R.I. (years)	A.E.P. (%)	A.R.I. (years)	A.E.P. (%)	A.R.I. (years)
March, 1974	12.95	3.9	25.0	0.8	125	1.4	69
April, 1989	12.06	11.7	8.5	1.3	75	5.9	17
March, 1987	11.21	21.5	4.6	4.2	23	16.7	6
April, 1988	10.24	39.2	2.5	6.1	17	33.3	3

Source: Sinclair Knight & Partners, 1993

The average exceedence probability (A.E.P.) and average return interval (A.R.I.) are presented in table 4a for historical floods in the Richmond River catchment during flood-dominated regimes (FDR) and drought-dominated regimes (DDR). The Flood Study estimates are those calculated from all available records disregarding the presence of FDRs and DDRs.

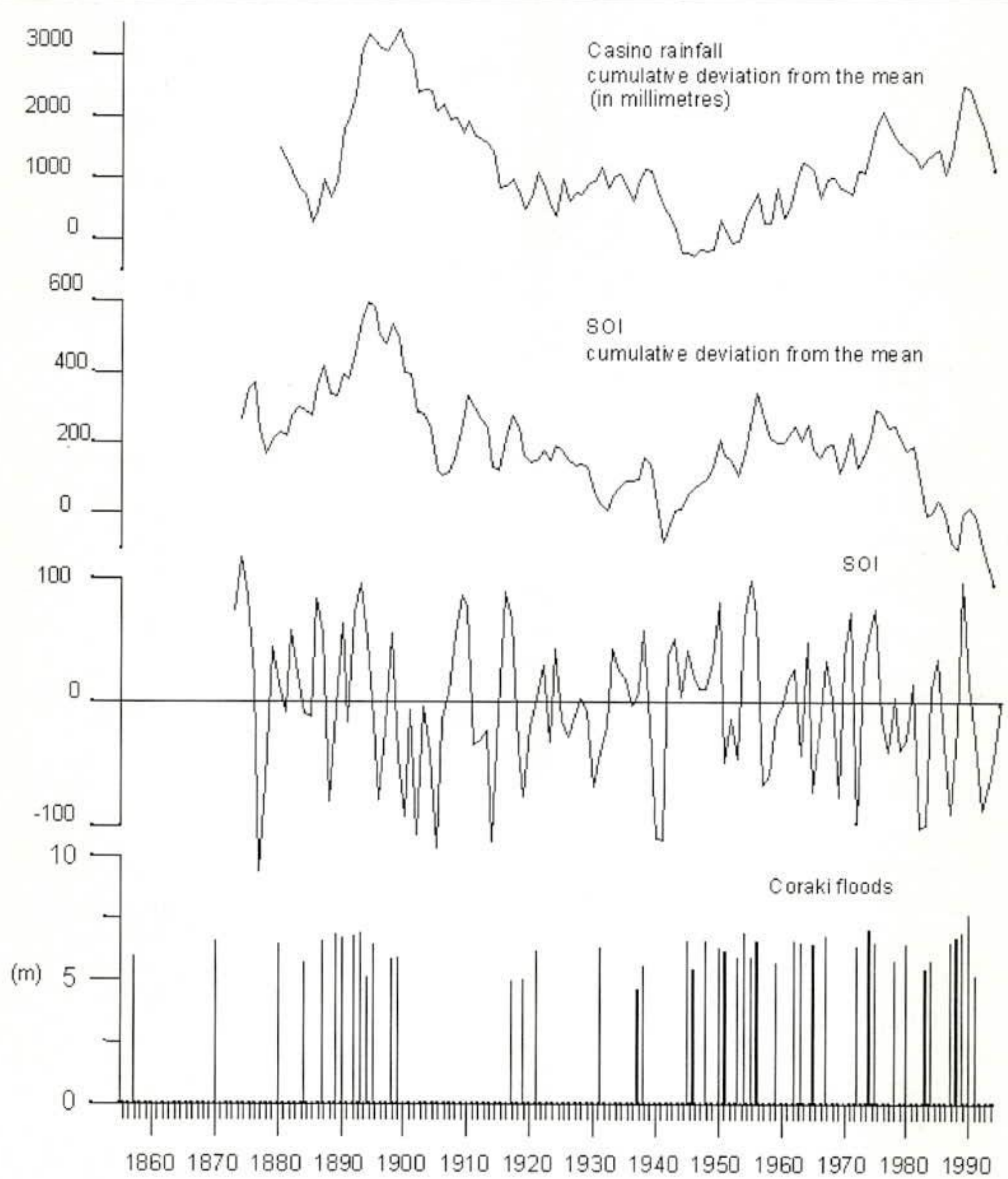
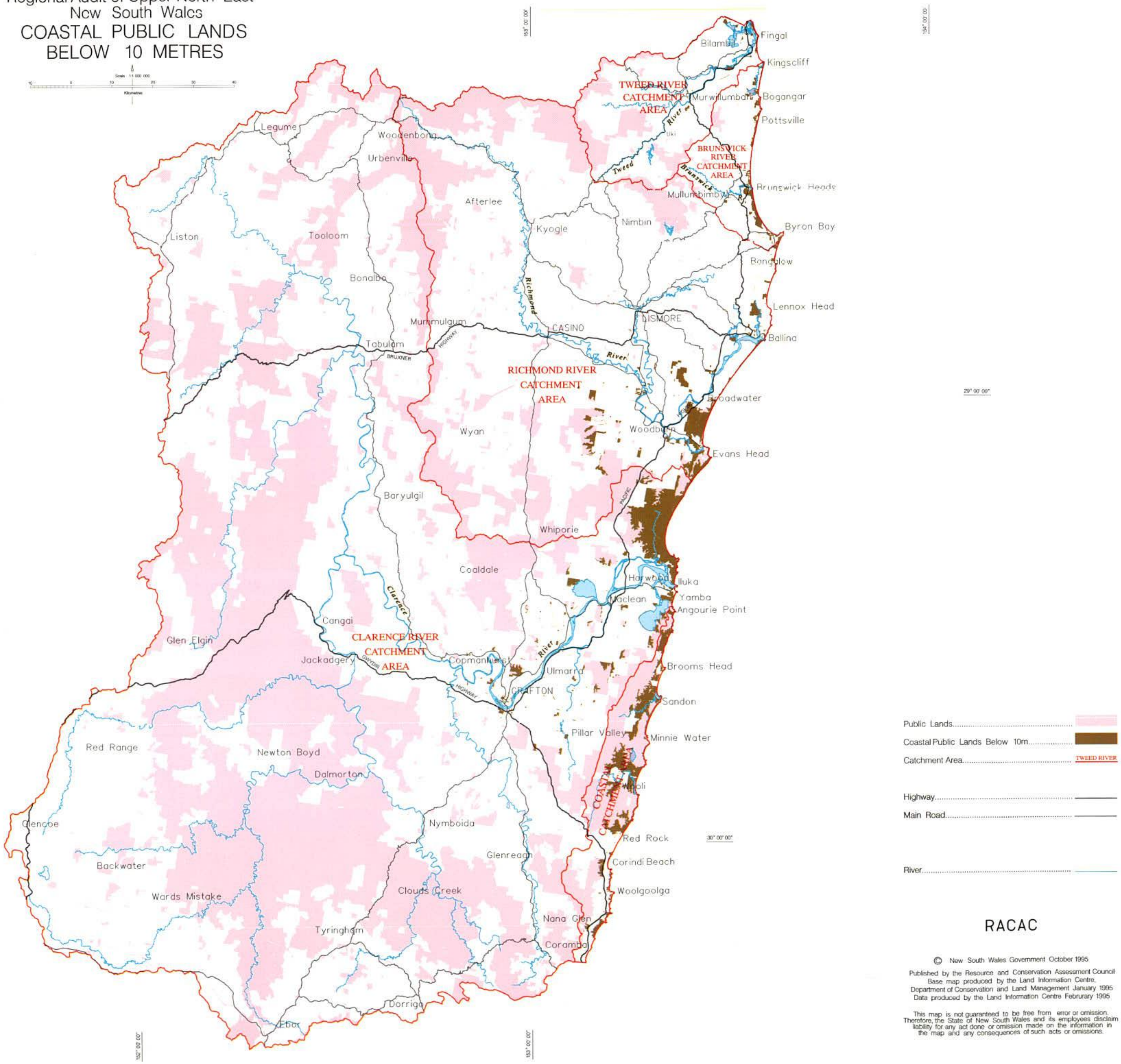


Figure 4b An example of long term climatic variation in the Audit Region.

Regional Audit of Upper North East New South Wales
COASTAL PUBLIC LANDS BELOW 10 METRES



RACAC

Published by the Resource and Conservation Assessment Council
Base map produced by the Land Information Centre, Department of Conservation and Land Management January 1995
Data produced by the Land Information Centre Februrary 1995

Figure 4b shows the long-period relationship between the Southern Oscillation Index (SOI), rainfall and flooding at Coraki in the Richmond River catchment. The cumulative deviation from the mean curves help highlight longer-period trends, with a downward sloping line indicating years with less than average rainfall and vice versa (Ferguson, 1995). The figure illustrates a marked increase in flood frequency since the beginning of the current flood-dominated regime around 1945.

4.3 EVAPORATION

Evaporation in the Audit Region is generally greatest in the hot dry months (October to January) and tends to become less throughout the more humid wet season months (February to May), reaching minimum values during cooler winter months (see table 4b Evaporation). There is only limited evaporation data available for a small spread of stations with most records beginning in the early 1970s (Tyalgum in the Tweed River catchment, Alstonville in the Richmond River catchment, and Coffs Harbour and Glen Innes on the perimeter of the Clarence River catchment). Data from Tabulam is only available for 1993.

4.4 RUNOFF

Runoff is that part of rainfall that finds its way into creeks, rivers and streams. In much of New South Wales, only a small part of a year's rainfall becomes runoff, averaging about ten per cent along the coastal catchments down to only four per cent in the Murray-Darling Basin, west of the Continental Divide. On the far north coast of New South Wales, however, annual runoff is much higher, averaging over 20% of rainfall. In the Audit Region this generates a combined yearly average river flow of more than eight million megalitres - over one quarter of the State's total river discharge produced from only one twenty-fifth of its land area (Department of Water Resources 1994).

In general, there is an increase in runoff with a decrease in catchment size in the Audit Region. The highest runoff per square kilometre occurs in the smallest catchment, the Brunswick, and the lowest runoff is in the largest, the Clarence. Total discharges are relative to rainfall and catchment size. Runoff increases towards the end of the wet seasons as water tables in the Region are raised and infiltration decreases.

TABLE 4B AVERAGE DAILY EVAPORATION [MM] FOR STATIONS IN THE AUDIT REGION

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tyalgum	4.3	3.5	2.8	2.3	1.6	1.5	1.7	2.3	3.1	3.7	4.3	4.7
Alstonville	5.9	5.0	4.4	3.7	2.8	2.6	2.9	3.7	4.7	5.1	5.7	6.1
Tabulam		5.2	4.5	3.1	2.3	2.2	1.7	3.1	3.8	5.1	4.7	6.2
Coffs Harbour	6.6	6.1	5.4	4.3	3.1	2.7	2.9	3.8	5.0	5.7	6.4	6.7
Glen Innes	5.4	4.9	4.3	3.3	2.0	1.6	1.7	2.4	3.6	4.3	5.2	5.7

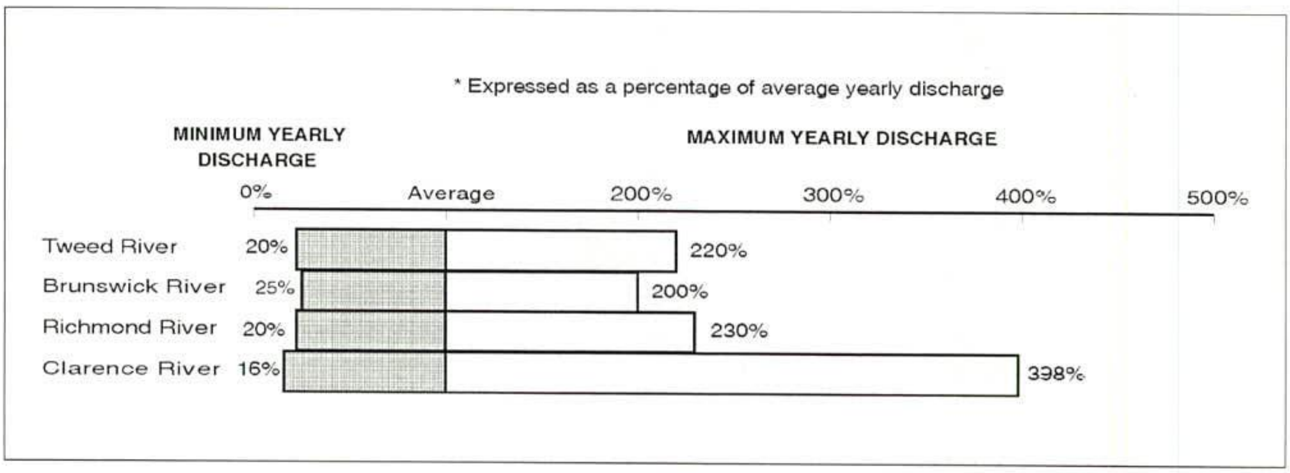


Figure 4c Flow variability of the Region's major rivers.

TABLE 4C FREQUENCY OF STREAM FLOW CESSATION IN THE AUDIT REGION

River	Frequency of flow cessation
Tweed River at Eungella	4 occasions in 20 years
Richmond River at Casino	2 occasions in 23 years
Clarence River at Lilydale	2 occasions in 45 years

Stream flows in the Audit Region exhibit a considerable degree of variability, however this variation is less than in most Australian streams due to higher and more reliable rainfalls. Streams draining the wettest areas of the Region tend to be less variable and have more persistent low flows (for example, the Rous River in the Tweed; Terania and Cooper's Creeks in the Richmond River catchment; and Nymboida River in the Clarence River catchment). Most stream flow variation in undiverted rivers of the Audit Region can be directly attributed to rainfall variability (see figure 4b Climate variability) (Ferguson, 1995). Figure 4c shows the variability of flow the Region's major rivers.

River flow and rainfall records indicate that complete cessation of flow occurs periodically in rivers as a result of prolonged dry spells. Such occurrences have been reasonably common in some tributary streams on the New England Tableland in the upper Clarence River catchment.

Elsewhere in the Region stream flows are more persistent and cessation of flow has been much less frequent and has rarely lasted for more than one month (see table 4c).

4.4.1 Tweed and Brunswick catchments

The Tweed and Brunswick River catchments experience the highest average runoff per square kilometre in New South Wales due to a combination of small catchment size and high rainfalls. Table 4d shows rainfall, runoff and river discharge in the major sub-catchments of the Tweed. Stream flow variability in the Tweed River catchment ranges from about 20 to 220% of the annual average, while variation in the Brunswick catchment is generally lower, 25 to 200%. Stream flows in the Tweed and Brunswick River catchments persist for extended periods of time after the cessation of rainfall indicating a relatively high groundwater flow into stream channels (see table 4e).

4.4.2 Richmond River catchment

In general, runoff in the Richmond River catchment is less than the smaller Tweed River catchment. An exception to this are the sub-catchments along the Tweed Range where small catchment sizes coupled with torrential rainfalls produce very high runoff (see table 4f). Extreme runoff in this part of the Wilson's River sub-catchment are responsible for severe flooding experienced in the Richmond River catchment. It should be noted that runoff given in table 4f are calculated using annual discharges which include flood discharges, and are therefore higher than would be expected during low flow conditions.

Stream flow variability is fairly high in the Richmond River catchment. The Richmond River at Casino varies between 20 and 230% of the annual average discharge, with similar variation in the Wilson's River sub-catchment (12 to 200% of annual average discharge). The most persistent streams in the Richmond River catchment are Cooper's and Terania Creeks in the Wilson River catchment (see table 4g), due to high rainfalls in this area. In general streams show similar low flow characteristics to those in the Tweed River catchment.

4.4.3 Clarence River catchment

The Clarence River has the highest annual discharge of all New South Wales rivers. However, in terms of runoff expressed as a percentage of annual rainfall, the surface water resources of the Clarence River catchment are less than those of the adjacent Richmond River catchment. This results from a combination of lower average rainfall

TABLE 4D ANNUAL RAINFALL AND RUNOFF CHARACTERISTICS OF THE TWEED AND BRUNSWICK CATCHMENTS

Catchment	Area [km2]	Average Yearly Rainfall [mm]	Average Yearly Discharge [ML]	Runoff as percentage of rainfall
Rous River above Boat Harbour	111	2000	95 844	43
Oxley River above Eungella	213	1700	145 027	40
Tweed River above Uki	275	1700	158 387	34
Tweed River	1100	1650	500 000	24
Brunswick River above Durrumbul	34	1730	34 300	58
Brunswick River	492	1730	246 000	30

Note: Average discharges were calculated from records dated 1956 to present for all stations and therefore represent flood-dominated conditions.

TABLE 4E PERSISTENCE OF STREAM FLOWS IN THE TWEED AND BRUNSWICK RIVER CATCHMENTS

Percent of the Time Flow Equalled or Exceeded	Corresponding Flows in Cumecs [m3/s] Rous River at Boat Harbour	Oxley River at Eungella	Tweed River at Braeside	Tweed River at Kunghur	Brunswick River at Durrumbul
10	5.3	9.9	4.8	1.5	3.1
30	1.9	2.5	2.8	0.85	0.85
50	1.1	1.2	1.3	0.28	0.38
70	0.59	0.59	0.68	0.13	0.16
90	0.18	0.17	0.18	0.04	0.07
100	0	0	0	0	0

Source: Water Conservation and Irrigation Commission, 1966(a)
Note: This table shows the percentage of the time a given flow is equalled or exceeded.

TABLE 4F ANNUAL RAINFALL AND RUNOFF CHARACTERISTICS OF THE RICHMOND RIVER CATCHMENT

Catchment	Area [km2]	Average Yearly Rainfall [mm]	Average Yearly Discharge [ML]	Runoff as percentage of rainfall
Wilson Creek above Eltham	223	1325	199 257	66
Coopers Creek above Repentance	62	1350	72 946	87
Leycester Creek above Lismore	327	1500	277 593	56
Richmond River above Casino	1766	1150	631 057	31
Bungawalbyn Creek	268	1000	na	<10
Richmond River	6940	1525	2 390 000	23

Note: Average discharges were calculated from records dated 1956 to present for all stations and therefore represent flood-dominated conditions.

TABLE 4G PERSISTENCE OF STREAM FLOWS IN THE RICHMOND RIVER CATCHMENT

Percent of the Time Flow Equalled or Exceeded	Corresponding Flows in Cumecs [m3/sec] Richmond River at Casino	Leycester Creek at Rock Valley	Terania Creek at Blakes	Cooper's Creek at Repentance	Wilson's Creek a- Federal
10	32	4.5	4.2	6.7	2.8
30	9.3	1.3	1.1	1.8	0.85
50	4.5	0.57	0.57	0.68	0.34
70	2.5	0.28	0.31	0.34	0.20
90	1	0.11	0.11	0.11	0.11
95	0.57	0.06	0.06	0.08	0.06
100	0	0	0.002	0	0

Source: Water Conservation and Irrigation Commission 1966(b) and a decreasing rate of runoff per square kilometre with an increase in catchment area for the larger Clarence River.

The best water yielding section of the catchment is the highland area around Dorrigo, where the average annual rainfall ranges up to almost 2000mm. Rainfall over the catchment of the Nymboida River, which drains this area, is about 30% greater than the average over the whole Clarence River catchment, and the runoff of this stream, equal to 36% of rainfall, is more than twice that of the whole catchment. The existence of a large rainfall shadow over the south-western part of the catchment is reflected in lower runoff for the Boyd and Mann River systems. Runoff details for the Clarence River catchment are presented in table 4g.

The greatest variation in stream flow occurs in the northern part of the Clarence Catchment, where flows in the Clarence River at Tabulam have ranged from 3 to 440% of the annual average. The smallest variation occurs in streams draining the Dorrigo Plateau where flows range from 23 to 220% of the annual average discharge. The Nymboida River is also the most persistent stream during dry periods due to a combination of high rainfall and large groundwater flows (see table 4i).

4.5 FLOODING

The historical development of many towns in the Audit Region involved them being located close to navigable waterways. This meant that development was often situated on flood prone land or floodways. The coastal

TABLE 4H ANNUAL RAINFALL AND RUNOFF CHARACTERISTICS OF THE CLARENCE RIVER CATCHMENT

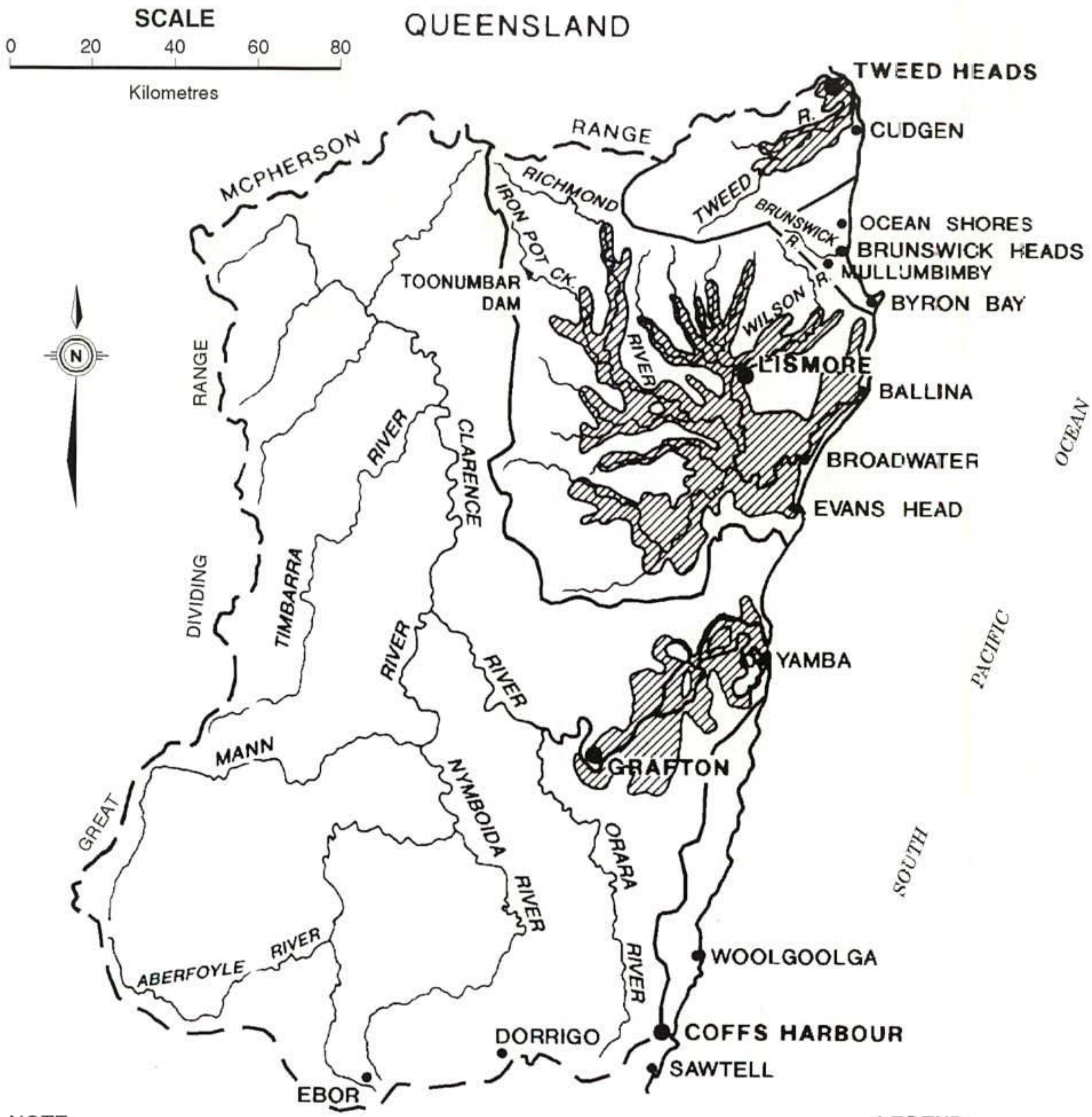
Catchment	Area [km2]	Average Yearly Rainfall [mm]	Average Yearly Discharge [ML]	Runoff as percentage of rainfall
Clarence River above Tabulam	4550	950	809 320	19
Timbarra River above Drake	1720	1000	321 544	18
Clarence River above Baryulgil	7490	975	1 534 395	21
Nymboida River above Nymboida	1660	1375	728 689	32
Boyd River above Broadmeadows	2670	925	337 684	14
Mann River above Jackadgery	7800	1025	1 743 678	22
Clarence River above Lilydale	16 690	1000	3 503 716	21
Orara River above Bawden Bridge	1790	1200	567 365	26
Clarence River total	22 660	1275	5 000 000	20

Note: Average discharges were calculated from records dated 1956 to present for all stations and therefore represent flood-dominated conditions.

TABLE 4I PERSISTENCE OF STREAM FLOWS IN THE CLARENCE VALLEY

	Corresponding Flows in Cumecs [m3/sec]				
Percent of the Time Flow Equalled or Exceeded	Clarence River at Tabulam	Timbarra River	Boyd River	Nymboida River at Nymboida	Orara River
10	42	10	28	45	9
30	10	4	8.5	17	2.4
50	3.6	2.3	4	9.9	1.1
70	1.5	1.1	1.8	6.2	0.56
90	0.4	0.42	0.5	3.4	0.19
95	0.15	0.23	0.22	2.3	0.08
98	0	0	0		
100				0.76	0.01

Source: Water Conservation and Irrigation Commission, 1968



NOTE:

This map shows approximate boundaries of the flood plains of the main rivers of the North Coast. Other flood plain areas associated with smaller rivers and creeks are not shown.

The flood plains shown are those which would be inundated by floods of 'once in 100 years' severity. Outlines have been smoothed to reduce complexity. Small areas within the boundaries, which are flood - free because of either natural elevation or levee protection, are not shown.

LEGEND

Flood Plain Land

FIGURE 9

FLOOD PLAINS IN THE UPPER NORTH EAST REGION

Figure 4d Floodplains in the Audit Region.

catchments of the Audit Region experience frequent and extensive flooding during flood-dominated regimes. Major floods are caused by high rainfalls associated with tropical cyclones, and may be exacerbated by high tide levels and storm surges. Floodplains of the Audit Region are shown in figure 4d.

4.5.1 Tweed and Brunswick catchments

Flooding within the catchment of the Tweed is restricted mostly to the main arm of the river. Surrounding channels block the system, forcing water over the banks and onto the floodplains (Acer Wargon Chapman 1994). The sources of inundation on the floodplain are:

- the tributaries of the Tweed and Rous Rivers, which cause flooding on the floodplains adjacent to those rivers from Tyalgum and Boat Harbour to Tweed Heads;
- three coastal creek catchments (Marshalls, Burringbar and Cudgera), which cause prolonged inundation of the low lying ground behind the coastal dune system from Billinudgel to Kingscliff (Cameron McNamara 1980).

The lower reaches of the Brunswick River and its tributaries are surrounded by extensive floodplains which are inundated by moderate to major floods. The towns of Brunswick Heads, Ocean Shores and New Brighton are affected to varying extents by flood waters. For instance, the expansion of Brunswick Heads is limited due to the lack of flood free land (Webb McKeown & Associates 1987).

4.5.2 Richmond River catchment

The Richmond River catchment floodplain is estimated to be 1 070 km2 or 15% of the total catchment area and is one of the most extensive in New South Wales (Sinclair Knight & Partners 1980a; 1980b). Flooding can originate from either the Wilson's, Richmond or Bungawalbyn arms of the river separately or in conjunction. However, flooding from the Wilson's River catchment predominates due to high rainfall and runoff in the north of the catchment. The fan-shaped tributaries in this area serve to concentrate runoff more quickly, and allow peaks to occur almost simultaneously. Lismore is situated at the confluence of two of these tributaries (Leycester and Wilson's Creeks) and therefore can experience severe flooding.

Bungawalbyn Creek has a larger catchment than the Wilson's River, but experiences the lowest rainfalls in the catchment. In addition, the large areas of swamp in the middle and lower reaches strongly attenuate the flood peak as it travels downstream. In the lower catchment natural levees and backswamp areas prolong inundation by flood waters.

4.5.3 Clarence catchment

The Clarence River has the highest recorded NSW flood discharge with flood discharges of up to 19 000 m3/sec

Public Works Department NSW

Lismore in flood.

recorded in the catchment (Public Works Department 1984). The floodplain starts just upstream of Grafton, and spreads out downstream to extensive flats partially protected by natural levees. Flooding upstream of the floodplain is mainly confined to the immediate vicinity of the stream channels.

4.5.4 Flood mitigation

Extensive flood damages in the Audit Region prompted alterations to the natural hydrological regimes by the early part of this century. Drainage unions were formed and a large scale construction of levees, drains and flood gates was carried out on the floodplains to reduce the frequency of inundation by minor floods. These flood mitigation structures have reduced the area inundated by small floods thereby reducing flood damages, however they have also affected the flow pattern and behaviour of flood waters, increasing velocities and channel erosion.

Many urban centres in the Audit Region are flood prone. These include extensive residential areas around Tweed Heads and Murwillumbah in the Tweed River catchment, Lismore and Casino in the Richmond River catchment, and Grafton, Maclean and Yamba in the Clarence River catchment. Various flood mitigation measures have been undertaken including diversions and levee schemes. A proposal for an extensive levee scheme protecting the Lismore urban centre is currently under investigation (Richmond River County Council 1994).

4.5.5 Flood studies

The susceptibility of public lands to inundation on the floodplains of the Audit Region is difficult to predict. It is generally accepted, however, that land below the ten metre Australian Height Datum (AHD) contour is susceptible to inundation. It is possible that there may be land below this contour which is never inundated, and land above which may suffer periodic inundation. For more detailed information, individual sites need to be investigated. Public lands under the ten metre AHD Contour are shown on map 4a, Public Land On the Coast of the Upper North East Region Susceptible to Inundation. Assessing the return intervals for floods (for example, 1 in 100 year floods) is also problematic since there are definite long-period variations in flood frequencies (Ferguson 1995).

Flood studies and floodplain management studies and plans have been prepared for the major coastal rivers and estuaries in the Audit Region. These have been prepared by local councils and NSW Public Works with Commonwealth, State and Local government funding.

Flood studies attempt to provide a comprehensive technical investigation of flood behaviour and the nature and extent of a flood problem. Floodplain management studies identify appropriate measures and evaluate options for managing floodplains and mitigating the effect of flooding. Floodplain management plans provide more detail and focus on specific areas. An inventory of studies and plans prepared for the Audit Region is presented in table 4j. Volume 5, Socio-economic attributes further discusses the infrastructure used in coastal and tidal management.

TABLE 4J FLOOD STUDIES AND PLANS PREPARED FOR THE AUDIT REGION

CATCHMENT	Coastal Rivers Floodplain Management Studies	Flood Studies/ Investigations	Floodplain Management Studies	Floodplain Management Plans/Strategies
Tweed	Yes	Chinderah Kingscliff Murwillumbah	Chinderah	Murwillumbah
Brunswick	No	Cudgen Creek Marshalls Creek Brunswick River Belongil Creek	Mullumbimby Brunswick Valley Brunswick River	Brunswick Valley
Richmond	Yes	Lismore Lower Richmond R.	Lismore	–
Clarence	Yes	Lower Clarence River	Lower Clarence River	–

(Cameron McNamara 1984; Public Works Department 1979, 1980, 1984, 1986(a), 1986(b), 1987, 1988(a), 1988(b); Laurie Montgomerie & Pettit Pty Ltd 1984; Oceanics Australia Pty Ltd 1980, 1982(a), 1982(b),1983, 1984(a), 1984(b); Patterson Consultants 1993; Sinclair Knight & Partners 1980(a), 1980(b), 1982, 1993; Soros-Longworth & McKenzie 1980(a), 1980(b); Tweed River Floodplain Mitigation Committee, 1986; Webb, McKeown & Assoc. 1986, 1987(a), 1987(b), 1989(a), 1989(b), 1993; NSW State Emergency Services and Civil Defence Organisation 1983; Russell 1978; Smith 1979; Smith & Greenway 1980; Willing & Partners 1984)

REFERENCES

Acer Wargon Chapman 1994, Tweed River entrance sand bypassing project: environmental impact statement assessment study, prepared for the NSW Public Works and Queensland Department of Environment and Heritage, Acer Wargon Chapman, Sydney. (unpub.)

Cameron McNamara 1980, *The Tweed Valley-Summary Report,* NSW Coastal River and Floodplain Management Studies Steering Committee, Sydney.

Department of Water Resources 1994, *Water Resources of the North Coast*, Department of Water Resources, Parramatta.

Ferguson, A. 1995, *Long-period Climatic Variations and their Relationship to Local Hydrology and Environmental Impacts in the Richmond River Catchment.* Southern Cross University, Department of Resource Science and Management, Lismore, NSW.

Laurie Montgomerie & Pettit Pty Ltd 1984, Brunswick valley floodplain management study-hydrology report, prepared for Byron Shire Council, Sydney. (unpub.)

NSW State Emergency Services and Civil Defence Organisation 1983, *Flood Warning Plan for Flood Emergencies in the Tweed Valley.* (n.p.)

Oceanics Australia Pty. Ltd 1980, *Cudgen/Cudgera Flooding Investigation,* prepared for the Tweed Shire Council, Oceanics Australia Pty. Ltd, Murwillumbah.

Oceanics Australia Pty. Ltd 1982(a), *Murwillumbah Flooding Investigations – Stage II*, Tweed Shire Council, Murwillumbah.

Oceanics Australia Pty. Ltd 1982(b), *Kingscliff/ Chinderah Flooding Investigations*, prepared for Tweed Shire Council, Oceanics Australia Pty. Ltd, Murwillumbah.

Oceanics Australia Pty. Ltd 1983, *Chinderah Floodway Investigations, Vols. I & II*, prepared for Tweed Shire Council and Tweed River Flood Mitigation Committee, Oceanics Australia Pty. Ltd, Murwillumbah.

Oceanics Australia Pty. Ltd 1984(a), *Murwillumbah Flooding Investigations – Stage III*, Tweed Shire Council, Murwillumbah.

Oceanics Australia Pty. Ltd 1984(b), *Murwillumbah Flooding Investigations – Stage IV*, Tweed Shire Council, Murwillumbah.

Patterson Consultants 1993, *Lower Clarence River Floodplain Management Study*, Maclean Shire Council, Sydney.

Public Works Department 1979, *Cudgen Creek-Flooding Aspects*, Report No. PWD79019, Public Works Department, Sydney.

Public Works Department 1980, *Woolgoolga Creek, May 1980 Flood Report*, Public Works Department, Coffs Harbour.

Public Works Department 1984, *Clarence River Maximum Probable Flood Estimate at Grafton*, Report No. 84026, Public Works Department, Sydney.

Public Works Department 1986(a), *Belongil Creek Flood Study*, Report No. PWD L.I.107, Public Works Department, Sydney.

Public Works Department 1986(b), *Marshalls Creek Flood Study*, Report No. PWD 86031, Public Works Department, Sydney.

Public Works Department 1987, *Lower Richmond River Flood Study*, Report No. PWD 87041, Public Works Department, Sydney.

Public Works Department 1988(a), *Cudgen Creek Flood Study*, Report No. PWD 88049, Public Works Department, Sydney.

Public Works Department 1988(b), *Lower Clarence River Flood Study*, Report No. PWD 88066, Public Works Department, Sydney.

Richmond River County Council 1994, *Environmental Impact Statement for Lismore Levee Scheme.* Report prepared by WBM Oceanics Australia. Richmond River County Council, Lismore.

Russell, J. 1978, *Aspects of Flooding in the Richmond River Valley*, thesis for Master of Engineering Science, University of NSW, Sydney. (unpub.)

Sinclair Knight & Partners 1980(a), *Lismore Floodplain Management Study*, Public Works Department, Sydney.

Sinclair Knight & Partners 1980(b), *The Richmond Valley*, NSW Coastal Rivers Floodplain Management Studies Steering Committee, Sydney.

Sinclair Knight & Partners 1982, *Richmond Valley Floodplain Atlas*, map, prepared for Water Resources Commission, 1:50 000, Water Resources Commission, Sydney.

Sinclair Knight & Partners 1993, *Lismore Flood Study and Floodplain Management Study*, Lismore City Council, Lismore.

Smith, D.I. & Greenway, M.A. 1980, *Computer Flood Damage Maps of Lismore*, Centre for Resource and Environmental Studies, Australian National University, Canberra.

Smith, D. 1979, *Flood Damage in the Richmond River Valley New South Wales: an Assessment of Tangible and Intangible Damages*, Centre for Resource and Environmental Studies, Australian National University, Canberra.

Soros-Longworth & McKenzie (in assoc. Cameron McNamara) 1980 (a), *The Clarence Valley*, NSW Coastal Rivers Floodplain Management Studies Steering Committee, Sydney.

Soros-Longworth & McKenzie (in assoc. Cameron McNamara) 1980 (b), *The Tweed Valley*, NSW Coastal Rivers Floodplain Management Studies Steering Committee, Sydney.

Tweed River Floodplain Mitigation Committee 1986, *Murwillumbah Floodplain Management Plan*, Tweed Shire Council, Murwillumbah.

Warner, R. F. 1993, 'Channel erosion and sedimentation in the alternating hydrologic regimes of the Hawkesbury River, NSW, Australia', *Catchments and Coasts in Eastern Australia*.ed. Thoms, M. C. University of Sydney, Department of Geography, Sydney.

Water Conservation and Irrigation Commission of NSW 1966(a), *Water Resources of the Tweed and Brunswick Valleys*. Report No. 9 Water Conservation and Irrigation Commission of NSW, Sydney.

Water Conservation and Irrigation Commission of NSW 1966(b), *Water Resources of the Richmond Valley,* Report No. 2, Water Conservation and Irrigation Commission of NSW, Sydney.

Richmond Valley. Report No. 2, Water Conservation and Irrigation Commission of NSW, Sydney.

Water Conservation and Irrigation Commission of NSW 1968, *Water Resources of the Clarence Valley*. Report No. 11, Water Conservation and Irrigation Commission of NSW, Sydney.

Webb, McKeown & Assoc. 1986, *Brunswick River Flood Study*, prepared for Byron Shire Council, Webb, McKeown & Assoc., Byron Bay.

Webb, McKeown & Assoc. 1987(a), *Brunswick Valley Floodplain Management Strategy*, prepared for Byron Shire Council, Webb, McKeown & Assoc., Byron Bay.

Webb, McKeown & Assoc. 1987(b), *Brunswick Valley Floodplain Management Study,* prepared for Byron Shire Council, Webb, McKeown & Assoc., Byron Bay.

Webb, McKeown & Assoc. 1989(a), *Mullumbimby Floodplain Management Study*, Brunswick River Floodplain Management Committee, Byron Bay.

Webb, McKeown & Assoc. 1989(b), *Brunswick River Floodplain Management Investigation*, Brunswick River Floodplain Management Committee, Byron Bay.

Webb, McKeown & Assoc. 1993, *Lower Richmond River*, Public Works Department, Sydney.

Willing & Partners 1984, *Clarence River Maximum Probable Flood Estimate at Grafton,* Public Works Department, Report No. 84026, Sydney.

GLOSSARY

Average exceedance probability – the likelihood that a flood of a given magnitude will occur in any year.

Average return interval – the time in years that a flood of a given magnitude will be likely to return.

Cumulative deviation from the mean – used to highlight long-term trends in data sets. Shows data which are less than average and data which are above average.

Cumec – a volumetric unit used to describe water discharge [m3/s].

Evapotranspiration – the combined water loss be evaporation from the ground and from transpiration by vegetation.

Floodplain – extensive flat land adjacent to a river channel which is regularly inundated by floods.

Median – the middle data point in a set. For example, 50% of points are greater than this value and 50% are less. Often used to describe rainfall rather than the mean since the mean can be skewed by single freak events thus giving a misleading figure.

Megalitre –one million litres.

Rain shadow – the area on the leeward side of mountains, where rainfall is less than on the windward side.

Runoff – stream discharge. Roughly equal to rainfall minus evaporation and infiltration.

Southern Oscillation – a see-saw of atmospheric pressure anomalies between the Indonesian region and the eastern tropical Pacific Ocean.

Southern Oscillation Index – measures the strength of the Southern Oscillation. Troups index compares the difference in atmospheric pressure between Darwin and Tahiti.

ACRONYMS

A.E.P – average exceedence probability

AHD – Australian height datum

A.R.I – average return interval

DDR – drought dominated regimes

FDR – flood dominated regimes

SOI – Southern Oscillation index

MAJOR CONTRIBUTORS

Author

Dr. Bradley Eyre, Southern Cross University Angus Ferguson, Southern Cross University.

Reviewer

Tom Grosskopf, Environment Protection Authority; Lee Hill, Department of Land and Water Conservation.

Other contributors

Bernie Baker, Department of Land and Water Conservation

5 CHAPTER

WATER QUALITY

Tables

WATER QUALITY

5.1 INTRODUCTION

The Upper North East Region of New South Wales has extensive aesthetic, recreational and productive values. These values, and an agreeable climate, contribute to a steady increase in population and tourism-oriented activities, while at the same time there are continuing demands placed on regional resources by the area's primary industries. These demands have put the Region's natural water systems under stress.

Previous studies have recognised the demands placed on the estuarine and freshwater reaches of catchments in the Region. These include investigations by the State Pollution Control Commission into water quality of the Region from 1982-86, and long term water quality monitoring of particular freshwater sites in the Region by the Department of Land and Water Conservation from the early 1970s to the present. Some local councils in the Region have also been active in water quality monitoring.

As part of the former Natural Resources Audit Council's audit of the Upper North East Region of New South Wales, the Environment Protection Authority conducted a twelve month study of the quality of surface waters. The study focused on the four major river catchments in the Region: the Tweed, Brunswick, Richmond and Clarence catchments. Water quality data was collected from May 1994 to May 1995, during a period of severe drought, except for a short period of higher flows which occurred after regional heavy rain in February 1995.

NRAC provided funds to assist a project by the New South Wales Environment Protection Authority to audit the quality of surface water in the Region. This Audit assessed the surface water quality of the four major river catchments in the Audit Region against the environmental values criteria of the Australian Water Quality Guidelines for Fresh and Marine Waters.

An Executive Summary and Data Quality Statement for this project, (S2) Status Report on Water Quality in the Tweed, Brunswick, Richmond and Clarence Rivers, are presented at the end of this volume.

This chapter summarises the findings of the water quality study, and provides an audit of current water quality observed during that time. It gives managers and end-users current information on quality of surface water in the Region, and highlights a number of major regional water quality issues. Further details of the study may be found in the project report The Northern Rivers - A Water Quality Assessment (EPA 1995).

Other chapters discuss the water resource in terms of the size, value and so on (see volume 3, chapters 1, 3 and 4, and volume 5, chapter 5). This chapter will discuss water quality, an integral part of the value of this resource.

5.1.1 Audit objectives

The water quality study was structured to address the following broad objectives:

1. **Measure water quality indicators at a range of sites within the four main catchments of the study area.**

   A sampling and analytical strategy was developed which ensured that data collection was accurate and representative of all the river systems in the Audit Region. Particular attention was given to site location; sampling and analytical methods; water quality indicators to be measured; and sample preservation and transport. Quality assurance procedures were incorporated into all aspects of data collection and analysis.

2. **Compare the observed water quality with the Australian Water Quality Guidelines for seven different environmental values.**

   The Australian Water Quality Guidelines for Fresh and Marine Waters (ANZECC 1992) provide a range of criteria that must be met for water to be considered acceptable for different environmental values. This study compared water quality measured at the sampling sites to the Australian Water Quality Guidelines to determine the water's acceptability for the various environmental values.

3. **Investigate the importance of water quality during high flow conditions in regional water quality assessment.**

   Water quality data collected during both low and high flow conditions has been used to assess the importance of high river flows in understanding and assessing water quality in a catchment.

4. **Compare current and historic water quality data collected in the Region.**

   Comparison has been made between water quality data presented in this chapter with both the State Pollution Control Commission study during the 1980s, and the Department of Land and Water Conservation's ongoing water quality monitoring project.

5.2 MEASURING AND ASSESSING WATER QUALITY

Community organisations, catchment management committees and the results of local surveys consistently nominate water quality as an important environmental or economic concern (for example, RAC 1993).
As pressures on water resources increase, so does the importance of determining what makes water quality 'good' or 'poor' and assessing the effects of this quality on resource users.

How is the water quality of a stretch of river, or a catchment, measured and reported? What is it about the water that makes it good or poor, and does it affect all users of the resource equally? This section of the chapter will describe how the water quality of the rivers in the Upper North East of New South Wales was measured and assessed for the many competing uses of this valuable common resource.

5.2.1 Sampling site selection

Catchments studied for this report were the Tweed, Brunswick, Richmond and Clarence. Samples were collected from 141 sites covering the four catchments. Sampling sites were selected on main water courses and smaller tributaries to provide a regional coverage within each catchment. As the water in rivers is a public resource, routine sampling sites were selected to be representative of the waterways themselves, irrespective of the surrounding land tenure or land use.

The State Pollution Control Commission (SPCC) carried out water quality sampling in the Region in the early 1980s, as part of a survey that focused on the estuarine portion of the catchments. Regional sampling of these sites has not been conducted since the project concluded in 1986, however some sites have been routinely sampled as part of ongoing monitoring by local councils.
The Department of Land and Water Conservation (DLWC) is currently monitoring six sites in the Region as part of that Department's Key Sites Monitoring Project. Where appropriate, sites used in this study coincided with current and previous monitoring sites used by the SPCC and the DLWC.

Sampling site selection was restricted to sites which had reasonable access to the river course, either by boat or by vehicle from a nearby road. A further constraint on site selection was the strict storage and handling requirements of samples for bacterial analysis. Bacterial samples need to be analysed within 24 hours of being taken and the only means of achieving this was to dispatch the samples to the testing laboratory at the end of each sampling day. Courier transport was only available from major population centres.

5.2.2 Sampling methods

Sampling sites were accessible by boat or car. In the estuarine part of the catchment a boat was used, providing direct access to the water. In rivers and streams, access was obtained by road, with samples usually being taken from a bridge.

The sampling program used a combination of primary and secondary sites to assess water quality in each catchment. Primary sites were sampled at three locations across the channel (left bank, middle and right bank), to allow for differences in water chemistry across the channel.
Primary sites were usually located near to the junction of several smaller watercourses. At secondary sites one sample was collected. Samples were collected from midstream wherever possible.

METHODS

Data Collection

Collection of the data occurred in two phases -

1. At each site, measurements were taken directly from the water body (temperature, salinity, pH, dissolved oxygen, turbidity and clarity), using a hand held meter. In addition, observations of factors such as time of sampling, river height, surrounding land use and weather were recorded.

2. Water samples were collected from each site, and were shipped to laboratories for further analysis. Measurements made included bacteria, chlorophyll-a, nutrients, major cations and anions and suspended solids. Duplicate and triplicate samples were collected at specified sites. A limited number of samples were tested for trace metals.

Data Handling

Field and laboratory data were entered into the EPA computer database, and all manipulation and interpretation of the data occurred from the database.

5.2.3 Defining low and high flows

The river flow conditions under which data collection takes place may be important in interpreting the results. This chapter considers the data collected to fall into two distinct groups, data collected during low flow, and data collected during high flow.

Low flow in a river is defined as flow levels that are achieved at least 50% of the time, while high flows are defined as flows that occur for ten percent of the time or less. These definitions have been applied to both data collected for this Audit (sections 5.2.3 and 5.7), and data from other sources used in the historical comparison of results (section 5.11.3). Data collected under flow conditions outside these percentile boundaries have not been considered.

5.2.4 Quality control

An extensive quality control program was conducted in conjunction with the routine sampling program, to ensure the reliability of the data collected. Instruments used to record data at each site were regularly calibrated, and in-field checks were carried out to detect and allow for any instrument variations.

At regular intervals, known quality control samples, blind quality control samples, and dupliate field samples were submitted to check the accuracy and precision of the laboratories.

Further details of the quality control methods, and the results from the quality control program, are presented in The Northern Rivers - A Water Quality Assessment (EPA 1995) and the data quality statement presented at the end of this volume.

Graham Sinden

Forested areas in a catchment are essential for maintaining river flow during extended dry periods (Washpool National Park).

5.3 INTERPRETING WATER QUALITY INFORMATION - AUSTRALIAN WATER QUALITY GUIDELINES FOR FRESH AND MARINE WATERS

Indicators and criteria identified in the Australian Water Quality Guidelines for Fresh and Marine Waters (ANZECC 1992) were used as the benchmark against which water quality was assessed. These Guidelines provide criteria that water must meet in order to be acceptable for a range of environmental values. These values are given below, along with brief descriptions.

Environmental Values - These are categories used by the Australian Water Quality Guidelines for Fresh and Marine Waters to identify the needs and wants of the community for shared resources. They may include the protection of in-stream values such as aquatic ecosystems or recreational use, or off-river use through human consumption or agricultural water supplies.

TABLE 5A - DESCRIPTION OF ENVIRONMENTAL VALUES CONSIDERED IN THIS CHAPTER.

Environmental Value	Description
Aquatic Ecosystem Protection	Maintain the diversity and health of the aquatic ecosystem, including both flora and fauna
Potable Water	Water suitable for direct human consumption
Primary Contact Recreation	Recreational use of the water where direct contact with, and possible ingestion of the water occurs (for example, water skiing, sailboarding, swimming)
Secondary Contact Recreation	Recreational use of the water where direct contact is minimised, and consuming the water unlikely (for example, boating, fishing, sailing)
Agriculture - Irrigation	Water suitable for irrigation of sensitive crops
Agriculture - Livestock	Water suitable for beef cattle to drink
Edible Seafood	Water suitable for protecting consumers of uncooked marine organisms

THE ESTUARY - WHICH DEFINITION?

It is often difficult to define the limits of an estuary. A convenient and often used definition is that the inland limit of the estuary is the tidal limit for that catchment. This provides a convenient, fixed boundary, however it has little to do with water chemistry or the various uses of water.

This study has used a biological indicator, the occurrence of mangrove communities, as an indicator of the long term limit of marine water influence in the river, and hence the upstream limit of the estuary.

Mangrove distribution was determined from mapping work conducted by the then NSW Department of Agriculture and Fisheries (West et al. 1985). In some areas this method will under-estimate the extent of upstream mangroves, as many have been destroyed through bank stabilisation and river iimprovementi schemes over many years. In these few circumstances, local knowledge of salinity patterns provided guidance.

While the Guidelines provide a general strategy for the assessment of water quality in this country, the lack of data for many regions, and the great variation of Australia's aquatic environments, has necessarily resulted in them being somewhat generalised. This section provides further information on:

- defining the estuary (section 5.3.1);
- water quality indicators - selection and description (section 5.3.2); and
- algae in inland waters (section 5.3.3).

5.3.1 Defining the estuary

Estuaries pose problems in the assessment of water quality, for they are influenced by both marine and fresh waters. The area influenced by marine waters will vary from time to time. Under drought conditions, as experienced during most of the field work period, marine water will move upstream preventing the use of water for irrigation or for human consumption. During large rain events, such as occurred during February 1995, freshwater may extend down to the mouth of the river and beyond for short periods. The Guidelines do not offer a strategy for assessing water quality under these highly variable conditions.

5.3.2 Water quality indicators - selection and description

The major groups of water quality parameters identified in the Australian Water Quality Guidelines for Fresh and Marine Waters are shown in table 5b. This covers the water quality indicators considered when assessing one or more of the environmental values listed in table 5a. Indicators measured as part of this study are indicated by a ✓, those not considered by a ✘, while *L* denotes a limited study.

In some cases the Guidelines suggest that the maximum value for a specific indicator may fall within a given range. For example, the Guidelines identify total phosphorus concentrations of ten-100 ug/L in rivers and streams as levels at which problem plant and algae growth has been known to occur in aquatic ecosystems. When no absolute value is provided, the researcher must select a limit against which results are compared. Prior studies may be useful in guiding this selection.

5.3.3 Algae in inland waters

The term algae is used to describe a wide variety of very simple organisms, from tiny blue-green bacteria to the giant kelps found in the ocean. They are nearly all aquatic, but are similar to land plants in the sense that their survival depends on photosynthesis. The algae found in rivers and streams are generally single celled plants.

The organisms commonly known as blue-green algae are, strictly speaking, not algae at all. In fact they are a type of bacteria (cyanobacteria). When first discovered they were mistakenly classed as algae because they contain chlorophyll-a and they produce oxygen.

Many types of algae occur naturally in inland waters, and in moderate numbers they are harmless. Environmental degradation occurs when their numbers increase rapidly, to the point where an algal bloom develops. In these

TABLE 5B - KEY PARAMETERS IDENTIFIED BY THE AUSTRALIAN WATER QUALITY GUIDELINES. REFER TO INDICATORS USED IN THIS STUDY BOX FOR DETAILS.

Physico-Chemical		Biological		Toxicants	
pH	✓	Total Plate Count	*L*	Inorganic Toxicants	*L*
Conductivity	✓	Total Coliforms	✓	Organic Toxicants	✘
Nutrients	✓	Faecal Coliforms	✓	Halogenated Toxicants	✘
Temperature	✓	Enterococci	✓	MACs	✘
Salinity	✓	*E. Coli*	✓	Phthalate Esters	✘
Dissolved Oxygen	✓	Algae (Chlorophyll A)	*L*	PAHs	✘
Turbidity	✓	Biotoxins	✘	Pesticides	*L*
Major Ions	✓				
Clarity	✓				

INDICATORS USED IN THIS STUDY

The following is a brief description of the indicators used by this study for assessing water quality.

Bacteria - certain types of bacteria in the water may indicate the presence of organisms harmful to humans (pathogens). Some of the bacteria measured for this project originate from the guts of warm-blooded animals, and are either deposited directly into rivers and creeks (for example, cattle) or are washed into the watercourse (for example, sewer overflows).

Chlorophyll-a - this is a measure of the amount of phytoplankton (microscopic and suspended plants) in the water, and is used to identify undesirable growth of phytoplankton.

Clarity - the depth at which a black and white metal disk (ìSecchiî disk) can be just seen from the surface.

Dissolved Oxygen - the amount of oxygen that is dissolved in the water. See section 5.12.1 for a fuller explanation.

Major Ions - including sodium (Na), magnesium (Mg), calcium (Ca), chloride (Cl), bicarbonate (HCO_3) and sulphate (SO_4) dissolved in the water.

Nitrogen-Phosphorus (N:P) Ratio - certain ratios of nutrients may promote the growth of undesirable algae, and this is detected by the N:P ratio (also referred to as the nutrient ratio). This report has used the measured values of total nitrogen and total phosphorus to calculate the N:P ratio.

Nutrients - the levels of phosphorus and nitrogen in the water. These nutrients are essential for plant growth, however in large amounts they can promote excessive plant growth, which in turn degrades the quality of the water.

pH - the hydrogen ion concentration in the water, a measure of the acidity or alkalinity of the water.

Salinity (Total Dissolved Solids)- this is a measure of how much salt is dissolved in the water. Salinity is not restricted to sodium chloride (NaCl), but includes all dissolved minerals in the water. The electrical conductivity of the water is used to provide an effective measure of salinity. Marine waters contain around 35 parts per thousand (3.5%) salt, while freshwater contains less than one part per thousand salt.

Sodium Absorption Ratio - certain combinations of sodium, calcium and magnesium may break down the structure of soils, reducing water infiltration into the soil and forming a hard surface crust.

Temperature - basic physical characteristic of the water body.

Suspended Solids - is the mass of material suspended in the water. Water clarity will decrease with increasing concentrations of suspended sediment.

Turbidity - a measure of the degree of light scatter in the water, which is a reasonable indicator of the amount of particulate material (for example, soil particles eroded from the catchment surface) that is in the water column.

situations algae may discolour the water, form surface scums and produce foul odours and taste. They can also cause fluctuations in pH and oxygen levels in the water, which may stress or eliminate sensitive species.

Some algae, including blue-green algae and dinoflagellates, release toxins and are therefore particularly harmful when present in large numbers. These toxins have been known to kill livestock and pets, as well as cause skin irritations in humans. They may also accumulate in the tissues of fish, posing a threat for potential consumers.

Nuisance algal problems are most likely to develop in waters with high concentrations of nutrients, particularly phosphorus. Large amounts of nutrients are introduced to rivers and streams from waste water discharges and surface run-off. They are often derived from commonly used substances such as fertilisers and detergents, as well as sewage.

In nutrient rich environments, growth of harmful algae is encouraged by a number of environmental factors. These include warm air and water temperatures, sunny conditions, low flow and clear water.

5.3.4 Environmental values - discussion and explanation

The study did not meet all aspects the Australian Water Quality Guidelines for Fresh and Marine Waters (ANZECC 1992), and given the difficulties encountered with bacterial sampling, it was necessary to modify this criterion for some of the uses being considered. In cases where the criterion was selected from a range, previous water quality studies, and published water quality objectives by other organisations, have been relied upon to provide firm criteria for the relevant indicators.

The following discussion is based largely on the Guidelines, and presents the indicators relevant to each of the environmental values used in this study, together with details of any deviation from the Guidelines. The criteria listed show the level at which, or the range within which, the indicator passes. For example -

> **Total Phosphorus <0.05mg/L -** indicates that concentrations of total phosphorus must be less than 0.05mg/L for the indicator to pass.

The most common causes of high salinity are the intrusion of marine water into river systems during drought, or salinisation of groundwater. The criteria given below are those recommended for beef cattle. Some animals, including poultry and pigs, will require lower levels of salinity for healthy growth. Others such as sheep will tolerate higher levels of salinity.

Livestock drinking water was only assessed in the freshwater section of each catchment, and was based on the following indicators and criteria.

Indicator	Criteria
Faecal Coliforms [1]	<1000 cfu/100mL
Calcium [1]	<1000mg/L
Sulphate [1]	<1000mg/L
Chloride [2]	<1600mg/L
Magnesium [1]	<600mg/L
Salinity (as Total Dissolved Solids) [1]	<4000mg/L
pH [2]	6.5-9.2

Source: [1] - ANZECC 1992
[2] - SPCC 1990

5.3.4.7 Edible Seafood - shellfish

In addition to toxicants, bacterial guidelines may also be important, especially if the organisms are eaten raw; for example, shellfish consumption has been implicated in transmitting infectious hepatitis in humans (ANZECC 1992).

These Guidelines are not aimed at protecting the animals themselves, but are specifically designed to protect human consumers of seafood. The indicators and criteria for the protection of the animals are the same as for the protection of aquatic ecosystems (section 5.3.4.1). The Guidelines cover three main risk areas, bacteria, toxicants and tainting substances. Toxicants may reach dangerous levels by accumulating in the tissue of the animals prior tc consumption, while tainting substances may affect the taste. Toxicants and tainting substances have not been investigated here.

Bacterial guidelines are particularly important if the animal is eaten raw (for example, oysters), as cooking will usually destroy bacteria pathogens. Faecal coliform levels are an especially important indicator for shellfish, as the estuaries in which they are grown are generally the receiving waters for urban runoff.

In New South Wales all oysters are treated for bacterial contamination by a process called depuration prior to sale. This system is effective in removing bacteria from the oyster, although it has little effect on toxicants.

Although the total coliform criteria given below can be applied to all seafood, the faecal coliform criterion is for shellfish only. As a result, the indicators in this category are directed at shellfish as opposed to all edible seafood, and have been assessed only in the estuarine section of each catchment.

Indicator	Criteria
Total Coliforms [2]	<70 cfu/100mL
Faecal Coliforms [1]	<14 cfu/100mL

Source: [1] - Modified from ANZECC 1992
[2] - Modified from EPA 1990

5.4 DATA HANDLING AND INTERPRETATION METHODS

Section 5.3.4 has described the environmental values and individual indicators that have been used to assess water quality in the Audit Region. This section explains the methods used to compare field and laboratory data with the water quality criteria, and the subsequent use of these comparisons to achieve a final ranking of each value at each site.

5.4.1 Pre-treatment of the data

Information presented in this chapter spans a twelve month period, with up to seven sets of low flow data collected from each site over this period. Data collected at each site were compared to the water quality criteria established for the different environmental values. From this comparison it was possible to determine whether the individual samples passed or failed the criteria. Prior to the data being analysed, the following adjustments were made to the data:

- results from primary sites (three samples at the one site) and duplicate sites were averaged to give a single value for the site for each run. Further details of this step, and of variability within duplicate and triplicate samples, may be found in the project report The Northern Rivers - A Water Quality Assessment (EPA 1995);
- samples reported by the laboratory as having a 'less than' value (for example, <0.01mg/L) were given a value equal to half the original (in this example, 0.005mg/L);
- bacterial samples reported by the laboratory as having a 'greater than' value (for example,>500cfu/100mL) were given a value equal to the original number plus one (in this example, 501cfu/100mL). Bacterial samples reported as 'too numerous' (ie the cultures were too dense to count) were assigned a value of 9999cfu/100mL.

5.4.2 Data analysis methods

To demonstrate the data analysis methods, the process of ranking primary contact recreation for the Clarence River off Ulmarra (site 15) is shown in the box Determining a Site Rank - Sample Calculations. Table 5c gives the divisions used to rank sites according to the percentage of passes in each category.

TABLE 5C: PERCENTAGE OF OBSERVATIONS REQUIRED TO PASS FOR EACH OF THE FOUR RANKS.

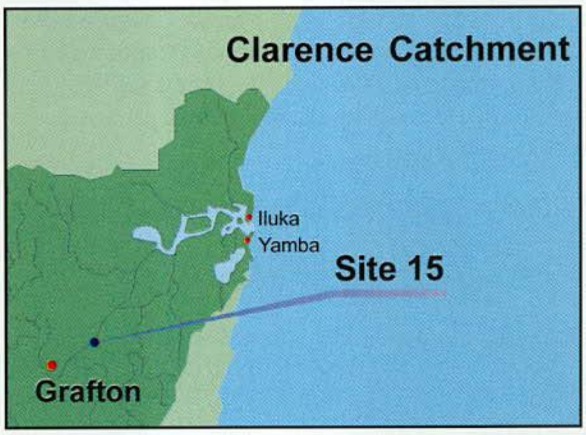
Ranking	Lower Limit	Upper Limit	Icon Colour
Good	75%	100%	Green
Fair	50%	74%	Yellow
Poor	25%	49%	Orange
Very Poor	0%	24%	Red

DETERMINING A SITE RANK - SAMPLE CALCULATIONS

With the water quality criteria selected, and the samples analysed, the results are assessed to arrive at a final ranking for each environmental value at each site.

In this example, the site off Ulmarra on the Clarence River (site 15 - see map box) is being assessed for primary contact recreation.

This process is repeated for each site in the audit area, and for each environmental value.



Step 1 - Extract relevant data

Data collected during all low flow runs at site 15 are extracted from the database.

The indicators used for primary contact recreation have been abbreviated as follows -

FC - Faecal coliforms
Ent - Enterococci
Clarity - as Turbidity (NTU)
* - indicates missing datum

Run	FC	Ent	Clarity	pH
1	2	*	4	7.2
2X	0	*	5	7.1
2Y	30	*	5	7.1
3	0	0	2	7.68
4	0	0	2	7.72
5	0.5	2	7	7.8
6X	10	1	4	7.3
6Y	2	4	4	7.3
7	20	1	3	6.97

Step 2 - Summarise the data

The results for runs where more than one sample was taken at the site are averaged. In this example, samples from runs two & six (duplicate samples collected from the same site) have been averaged to arrive at a single value for each parameter. This step is highlighted by the grey shading.

Run	FC	Ent	Clarity	pH
1	2	*	4	7.2
2	15	*	5	7.1
3	0	0	2	7.68
4	0	0	2	7.72
5	0.5	2	7	7.8
6	6	2.5	4	7.3
7	20	1	3	6.97

Steps 3 & 4 - Compare data to the criteria

By comparing the observed results to the criteria, a score of one (Pass) or 0 (Fail) is recorded for each record. If one or more of the indicators fail the criteria, then the site fails for that run.

Run	FC	Ent	Clarity	pH	Result
1	1	*	0	1	0
2	1	*	1	1	1
3	1	1	1	1	1
4	1	1	1	1	1
5	1	1	0	1	0
6	1	1	1	1	1
7	1	1	0	1	0

Step 5 - Colour ranking

In this case, the site passed the primary contact recreation criteria for four of the seven times. This site scores an 57% pass rate, and is recorded as Fair/Yellow (table 5c).

FINAL SCORE

4 Passes from seven records

Result - 57% pass

5.5 LIMITATIONS OF THE STUDY

It was not possible for this chapter to address every aspect of the Australian Water Quality Guidelines for Fresh and Marine Waters (ANZECC 1992), due to the large number of indicators identified and the complex methods for measuring them. This section addresses the major limitations of the study and, where relevant, indicates alternative strategies adopted for this Report.

5.5.1 Pesticides

The occurrence of pesticides in the aquatic environment is sporadic, with localised use and the timing of local rain exerting significant control over their movement to a watercourse. Some pesticides will be transported to the river dissolved in runoff, while others attach to sediments that can accumulate on the river bed. There is a large array of commercially available pesticides currently used in Australia, making untargeted analysis for pesticides and pesticide residue in the environment usually unproductive. A better strategy is to assess the usage patterns of pesticides in the Region, and develop a water and sediment monitoring program that takes this into account. Accordingly, a pesticide review of the Region was carried out during this study, and a summary of the review is presented in section 5.12.3.

5.5.2 Heavy metals

Very limited testing of water-borne heavy metal concentrations has been carried out, to determine if more thorough investigation is warranted in the Region. A reduced sample set was used, targeting specific localities. Heavy metals are commonly found in association with sediments, and analysis of river sediment may provide further information on heavy metal distribution and accumulation in the river systems.

5.5.3 Bacterial samples

Determining bacterial levels poses particular difficulties as these samples need to be analysed quickly, their concentrations in rivers may change rapidly and relatively frequent sampling is required for the study to be effective. For example, the measurement of bacterial indicators for primary and secondary contact recreation, requires sampling once every six days (ANZECC 1992).

With such large areas under investigation, it was not possible to meet this Guideline requirement. Although the results have been reported in this study for all sampling locations, the sampling frequency did not conform to that required for bacterial analysis and should be viewed as indicative only. This information will however allow managers in the area to identify localities which may warrant follow-up studies.

5.6 WATER QUALITY DURING LOW FLOW CONDITIONS

This section presents the water quality results collected during low flow conditions, and describes the water quality in each of the four major catchments of the Region. The results were determined by comparing the data collected with the criteria presented in section 5.3. Specific sampling site locations are given in appendix 5.1.

5.6.1 Presenting the results

5.6.1.1 The catchment map

The results collected for each site under low flow conditions have been displayed on a map of the relevant catchment. Each site was allocated a rank, from Good to Very Poor, for a number of environmental values. These ranks are represented by an icon similar to the ones below. They indicate the suitability of water for specific uses and were determined by the number of times water sampled at a given site failed the criteria for that use. Sample icons for secondary contact recreation are shown below.

Good Fair Poor Very Poor

5.6.1.2 The summary information box

Rainfall and flow conditions under which sampling occurred have been illustrated for each catchment. Rainfall data is collected regularly by the Australian Bureau of Meteorology using automatic and manual rain gauges. Daily rainfall registrations from a number of stations in each catchment were obtained, and these were averaged to summarise the rainfall conditions during the sampling period.

Immediately below the graph, the calendar months are shown by their first letter. The numbered bars on the next row depict the timing of each sampling run. This shows the relationship between sample collection and rainfall events. The timing of high flow sampling is shown in red.

The average flow conditions during each sampling run are illustrated in the right half of the information box. Again, high flows are shown in red. River flow data is recorded by the Department of Land and Water Conservation using automatic flow recording gauges in non-tidal areas. Following a method similar to that used for average rainfall calculation, data from a number of stations was averaged to provide an overall indication of flow in the catchment. The timing of flows may be different from the rainfall conditions since river flow is also influenced by groundwater inputs and delays in the catchment.

The box in the bottom left corner lists the number of water quality sampling sites in the catchment (estuarine and fresh), the number of rainfall stations and flow gauges used to collect the data.

5.6.2 Water quality in the Tweed River Catchment

The Tweed River Catchment covers an area of 1071 square kilometres and includes the catchments of the Tweed, Rous and Oxley Rivers. It is bounded by the McPherson Range to the north, the Tweed Ranges to the west and the Nightcap Range in the south (see 1, Rivers and catchments). The catchment experiences high annual rainfall, with over 65% of the catchment receiving more than 1700 millimetres of rain per year.

Despite being relatively small in area, the physical properties of the Tweed River Catchment have encouraged a number of competing land uses. The mild climate and the aesthetic value of the coast and ranges have combined to make it a popular semi-rural and recreation destination. The high rainfall and rich soils also make it a productive crop and pasture area. The high population growth rates for the area (Coastal Committee of NSW 1994), and the need to conserve the aesthetic and biological value of the catchment, will ensure that competition for the land continues in the future.

5.6.2.1 Background information

Six routine sampling runs were carried out in the Tweed River Catchment under low flow conditions, however no sampling was performed during run six. Data from run five have not been included in this Report as the flow conditions for low or high flow were not met. An additional run was performed during a period of high flow in February 1995. The timing of all sampling runs is shown in figure 5a. Rainfall and flow conditions experienced over the catchment during the field work are also illustrated.

The following section describes the results of water quality testing in the Tweed River Catchment during low flow conditions. The high flow results are discussed in section 5.9.

5.6.2.2 Results

This section explores the results presented in figure 5b, a map of the catchment indicating the ranks assigned to each site for the seven categories, and discusses major patterns in the data. Details of the indicators causing low ranks to be assigned are taken from figure 5c.

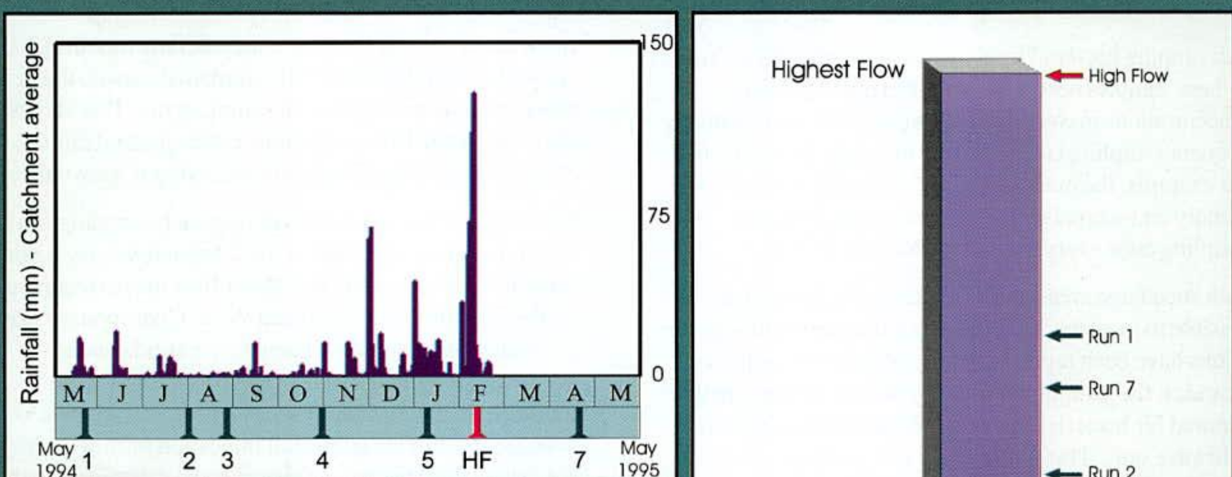
Aquatic ecosystem protection

The 35 sites in the Tweed River Catchment were divided roughly between Good & Fair ranks (37% & 9% respectively), and Poor & Very Poor ranks (17% & 37% respectively).

In the freshwater section of the catchment, 65% of the sites were ranked Good or Fair. The main reason for freshwater sites failing was low values of dissolved oxygen (percentage saturation) in 24% of observations, with pH outside the Guidelines for 11% of observations. The level of phosphorus in the water was above the criterion for 5% of observations. On all occasions when phosphorus levels were elevated, they occurred in a ratio that could favour the growth of blue-green algae. Other indicators passed the criteria for 95% or more of observations.

The estuarine section of the catchment showed a very different result. Sites at the river mouth (site 1) and

Tweed River Catchment - Summary Information
Figure 5a



Sites	Rainfall Stations	Flow Guages
15 Estuarine 20 Fresh	16	1

Chinderah (site 2) were the only sites to score a Good rank, while the Tweed River at Condong (site 25) was the only site in the Fair category. Eighty percent of all estuarine sites were ranked Poor or Very Poor (20% and 60% of sites, respectively). In contrast to the freshwater sites, the predominant reason for fails were excess suspended solids concentrations, with 56% of observations failing this indicator. Low pH, excess nutrient levels and low dissolved oxygen levels also caused a small number of fails.

Potable water

Potable water scored a Very Poor rating at 95% of the catchment's freshwater sites with Pumpenbil Creek (site 37) the only site to receive a Poor rank. The major reason for this result was excessive levels of both faecal coliforms and total coliforms. High bacteria levels would not normally present a problem for permanent water supplies, as standard treatment of the water would usually reduce or eliminate this problem. Dissolved oxygen (percent saturation) levels were below the criterion for over 20% of observations.

Primary contact recreation

Overall, water quality in the Tweed River Catchment was poor for primary contact recreation. Forty-three percent of all sites were classed as Very Poor, with a further 17% classed Poor. More than 70% of estuarine sites, and 50% of freshwater sites, fell into one of these two ranks. Five sites recorded a Good rank; three of these sites were in the freshwater reaches, at Byrrill Creek (site 34), Uki (site 36) and Byangum (site 21), while sites at Tweed Heads and Chinderah (sites 1 and 2) were in the estuary.

The most common indicators to fail the criteria were clarity and faecal coliforms, which failed 37% and 35% of observations respectively. Each of the remaining two indicators, pH and enterococci, failed 10-15% of observations.

Secondary contact recreation

The results for secondary contact recreation were significantly better than for primary contact recreation, with all sites recording a Good rank. Faecal coliform levels exceeded recommendations in less than 2% of observations, whilst enterococci levels and pH were always within acceptable limits.

Agriculture - irrigation

A good result was recorded for this category with 75% of all freshwater sites being ranked as Good. A further 10% of sites recorded Fair ranks. The few Very Poor results were scattered across the catchment. The major reasons for individual samples failing in this value were high salinity (17% fails) and an unsuitable sodium adsorption ratio (6% fails).

Agriculture - livestock

Eighty percent of all freshwater sites in the Tweed River Catchment returned a Good rating for this value with a further 5% being ranked as Fair. Poor ranks were observed at 15% of sites, while no sites were ranked Very Poor. The occasional fails that were recorded resulted mainly from low pH or excessive salinity, with just one observation failing the faecal coliform criterion.

Edible seafood

Forty percent of estuarine sites were ranked either Good (27%) or Fair (13%). However, the majority of sites fell into either the Poor or Very Poor ranks (20% and 40% respectively). All estuarine sites between Murwillumbah and the Rous River were ranked Poor or Very Poor, however the three sites from Stotts Island to the mouth of the Tweed River all recorded Good results. This pattern is possibly a result of increased tidal flushing in the lower part of the estuary. The two sites in the Cobaki Broadwater area were ranked Poor and Very Poor, whilst the sites in the Terranora Broadwater showed a variety of results.

Over 30% of total coliform observations were above the criterion for this indicator, while nearly 60% of faecal coliform observations also failed.

5.6.2.3 Discussion

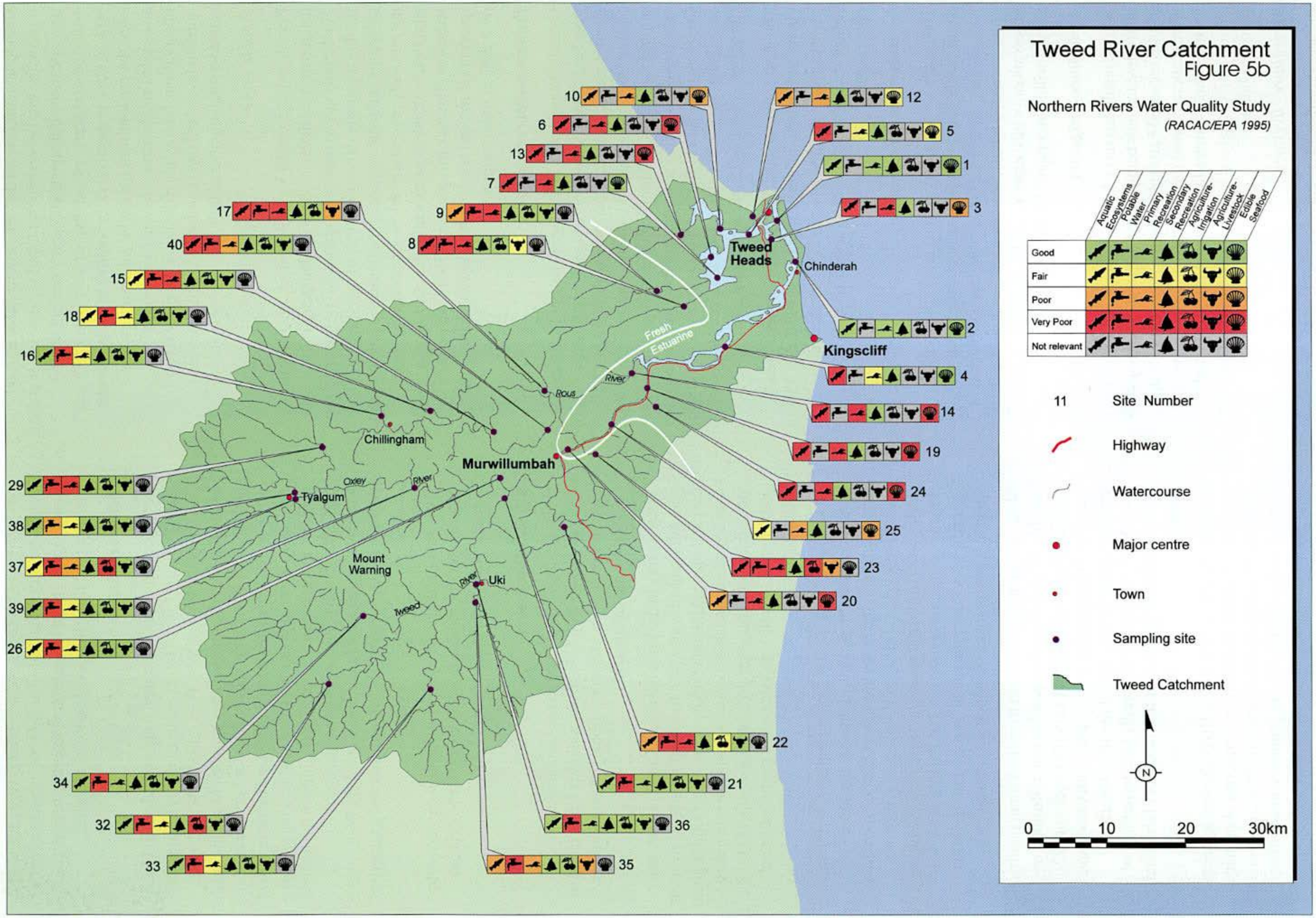
Water quality in the Tweed River Catchment was generally good, with 58% of site rankings being Good or Fair. However, some distinct regional differences were observed in the catchment.

Water quality in the Rous River and Cobaki Creek was generally ranked worse than for other freshwater rivers in the catchment. Although the site upstream of Chillingham (site 16) was ranked highly, water quality at other sites along the river became progressively less suitable for the protection of aquatic ecosystems and primary contact recreation.

Oxley River water quality showed better ranks for aquatic ecosystem protection, while there was a marginal improvement in the ranks of primary contact recreation. Excessive levels of faecal coliforms, and sometimes clarity, were the main reason for many sites failing the primary contact recreation criteria. Potable water was awarded Very Poor ranks at all sites except the Oxley River at Tyalgum (site 38) which was ranked Poor.

Most sites in the upper Tweed River had water quality suitable for uses other than potable water. Results for Rolands Creek (site 35) and Dunbible Creek (site 22) were notable exceptions to this trend, with Good ranks being assigned for only two of the six categories considered. These sites repeatedly failed a number of criteria, particularly those for pH, faecal coliforms and clarity.

Samples from the lower Tweed River showed a general downstream improvement in the categories of primary contact recreation and edible seafood. This improvement was due to improved clarity for primary contact and a large reduction in bacterial contamination in both categories. Improved aquatic ecosystem protection ranks near Murwillumbah (sites 20 and 25) and at the river mouth (sites one and two) were due largely to lower


Tweed River Catchment
Figure 5b
Northern Rivers Water Quality Study
(RACAC/EPA 1995)
Aquatic Ecosystems
Potable Water
Primary Recreation
Secondary Recreation
Agriculture-Irrigation
Agriculture-Livestock
Edible Seafood
Good
Fair
Poor
Very Poor
Not relevant
11 Site Number
Highway
Watercourse
Major centre
Town
Sampling site
Tweed Catchment
N
0 10 20 30km
Tweed Heads
Chinderah
Kingscliff
Murwillumbah
Chillingham
Tyalgum
Mount Warning
Uki
Fresh
Estuarine
Rous
River
Oxley
River
Tweed
River
1
2
3
4
5
6
7
8
9
10
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
29
32
33
34
35
36
37
38
39
40

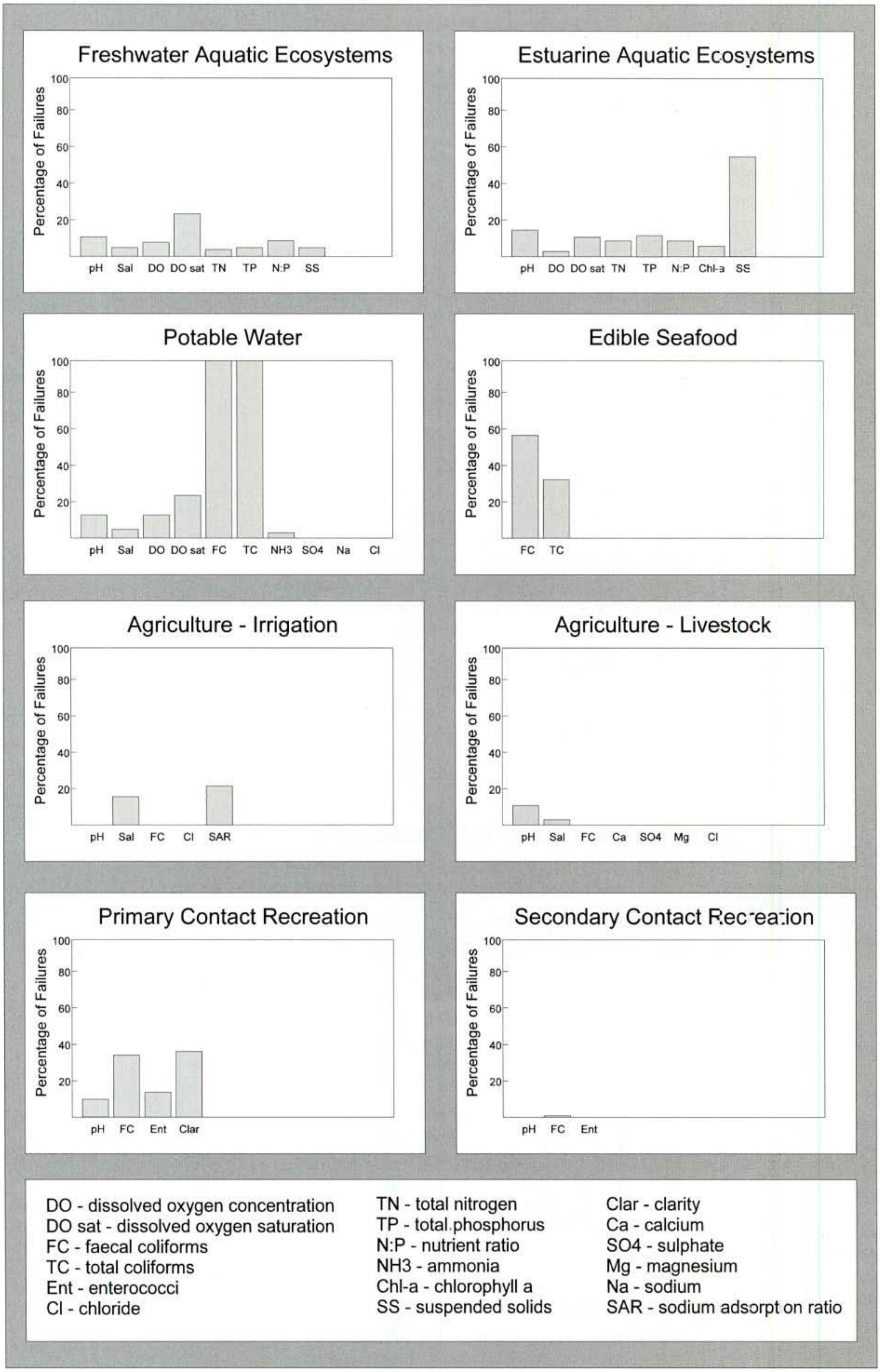


Figure 5c: Percentage of failures for each indicator, Tweed Catchment

suspended sediment concentrations. Water of poorer quality from both Bartlets Drain (site 24) and the Rous River (site 14) may have been responsible for the poor results in the mid-reaches of the Tweed River estuary, especially near Tumbulgum (site 19). Tidal flushing near the river entrance may be responsible for the improved results at the mouth (site1) and at Chinderah (site 2). The Condong Creek drain (site 23) recorded the worst ranks in the catchment, with one Good, one Poor, and four Very Poor ranks for the six environmental values. The major indicators failing at this site include pH, salinity, clarity and bacteria.

Water samples collected from the Terranora and Cobaki broadwaters and adjacent streams showed variable water quality. The two streams leading into the Terranora broadwater were ranked poorly for aquatic ecosystem protection, potable water and primary contact recreation. In the estuarine section of the broadwaters, results were generally bad, with five of the seven aquatic ecosystem ranks, and four of the seven primary contact recreation sites, receiving Very Poor ranks. Site five, immediately upstream of Boyds Bay bridge, showed improved ranks for primary contact recreation and edible seafood, possibly due again to tidal flushing. The restricted flows at Ukerebagh Passage (site 3) may have prevented tidal flushing being effective in improving water quality at this site.

The distribution of results in the estuary suggests that tidal flushing toward the mouth of the estuary may be the process accounting for better water quality near the mouth of the estuary. If this is the case, then it follows that some pollutants are being moved offshore by tidal action. However, tidal effects appear localised, with local inputs of poorer water quality still exerting control over the final rank of sites near the river mouth.

5.6.3 Water quality in the Brunswick River Catchment

The Brunswick River Catchment has an area of 230 square kilometres, and is the smallest of the four catchments considered in this chapter. The catchment has a narrow coastal plain, with mountains rising steeply on the northern and western boundaries of the catchment (see 1, Rivers and catchments).

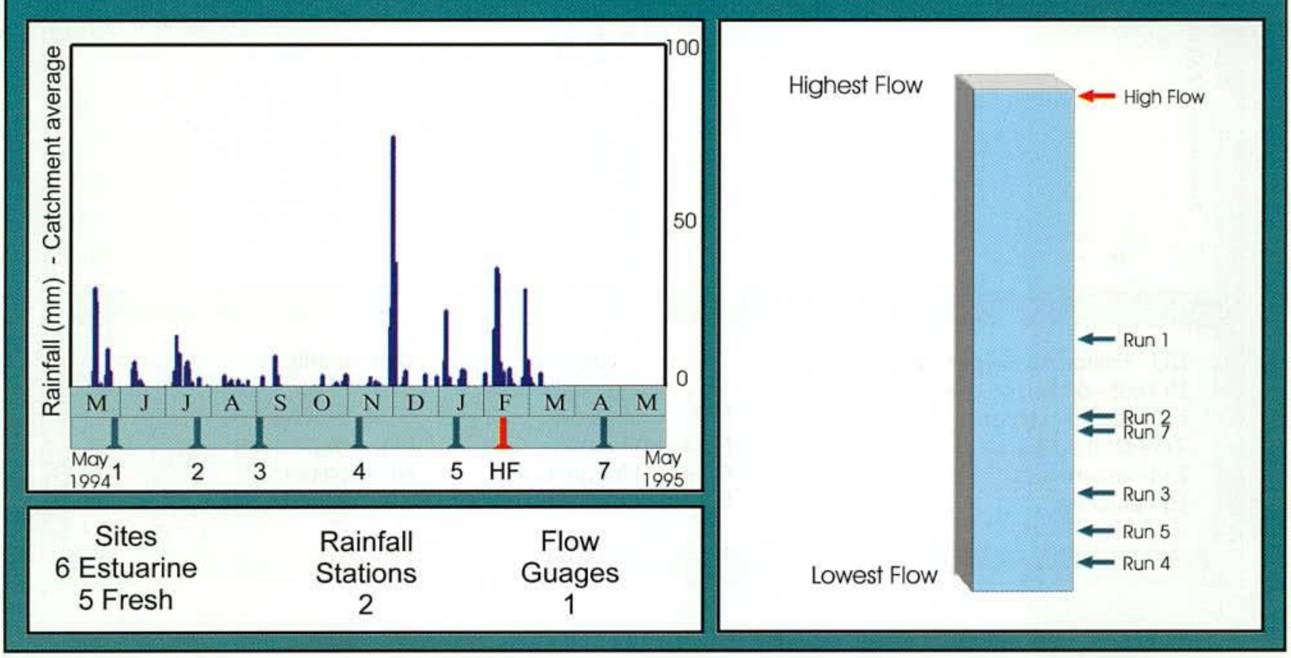
High mean annual rainfall extends across the catchment. Two thirds of the area receive 1700 - 2000 millimetres per year, with the remainder of the catchment receiving over 2000 millimetres of rain per year. The high rainfall, high mountain range and narrow lowland area interact to form a river system that responds rapidly to rainfall.

Development in the catchment is centred on the coastal towns of Brunswick Heads and Ocean Shores, together with Mullumbimby, located about six kilometres inland on the Brunswick River. Dominant industries of the catchment include sugar cane, bananas and avocados, beef cattle grazing, commercial fishing and tourism.

5.6.3.1 Background information

Six routine sampling runs were carried out in the Brunswick River Catchment under low flow conditions, however no sampling was performed during Run six. An additional run was performed during a period of high flow in February 1995. The timing of all sampling runs is shown in figure 5d. Rainfall and flow conditions experienced during the field work are also illustrated.

Brunswick River Catchment - Summary Information
Figure 5d



The following section describes the results of water quality testing in the Brunswick River Catchment during low flow conditions. The high flow results are discussed in section 5.9.

5.6.3.2 Results

This section explores the results presented in figure 5e, a map of the catchment indicating the ranks assigned to each site for the seven categories, and discusses major patterns in the data. Details of the indicators causing low ranks to be assigned are taken from figure 5f.

Aquatic ecosystem protection

Aquatic ecosystem protection ranked poorly throughout the catchment, with only one site assigned a Good result. Most of the estuarine sites were ranked either Poor or Very Poor (33% each). All freshwater sites were ranked Poor (40%), or Very Poor (60%).

In freshwater sites, the majority of indicators had a fail rate of greater than 20% of observations. The main causes of failures were dissolved oxygen (percent saturation), high nutrient levels and low pH. Many freshwater sites failed more than one indicator for each observation.

Estuarine sites ranked better overall than the freshwater sites, however they showed significant numbers of failures for the indicators of suspended solids, nutrients and dissolved oxygen (percentage saturation). The site at Brunswick Heads (site1) recorded a Good result, probably due to tidal flushing in the estuary. Although water quality immediately upstream of Brunswick Heads (site 2) may have also been influenced by tidal flushing, the Fair result recorded suggests that water quality at this site was influenced by water flowing from upstream. High nutrient levels and an unsuitable N:P ratio were the main reasons for a Very Poor rank at Simpsons Creek (site 7).

Potable water

Very Poor ranks were recorded for all sites assessed for this value. The bacterial indicators of total coliforms and faecal coliforms failed the criteria on 100% of observations. Other indicators that failed were dissolved oxygen and pH, with salinity also failing around 15% of observations. Half of the excess salinity readings occurred at Marshalls Creek (site 6), close to the estuarine boundary. The indicators of chloride, sodium and sulphate met the criteria for every observation.

Primary contact recreation

The freshwater sites within the catchment did not fare well for this value, with one Fair, one Poor and three Very Poor ranks being allocated for the five sites. The dominant indicator responsible for the poor water quality at these sites was elevated bacteria levels. A large number of sites also failed the clarity criterion.

In the estuary, two of the six sites received a Good rank, with one Poor and three Very Poor ranks for the remaining sites. The two sites ranked Good in the estuary were close to the river mouth. Tidal flushing may be responsible for better water quality at these sites. Simpsons Creek (site 7) again recorded a Very Poor result due to excessive bacteria levels, while a combination of elevated bacteria and reduced clarity were identified at Ocean Shores (site 5).

Secondary contact recreation

Five of the six estuarine sites in the catchment recorded Good ranks for this value, with one site in the Fair class. A similar distribution of results was shown for the freshwater sites, with four of the five sites being ranked Good and the remaining site ranked Fair. In contrast to the primary contact recreation data, the only indicator to fail a significant number of times was faecal coliforms. The indicators of pH and enterococci failed less than four percent of observations.

Agriculture - irrigation

A mediocre result was recorded for the quality of irrigation water in the catchment, with only two sites achieving a Good result. These sites were on the Brunswick River above Mullumbimby. The Brunswick River at Palmwoods (site 11) was dry for two of the six sampling runs. Two sites were classed as Very Poor (40%), with one further site being ranked Poor.

High salinity and sodium adsorption ratios were the major reason for sites failing this environmental value.

Agriculture - livestock

A majority of freshwater sites were ranked Fair for this category. Water quality problems at these sites were caused mainly by excess faecal coliforms or low pH. The site at Palmwoods (site 11) recorded a Very Poor ranking for livestock water. This site was sampled only four times under low flow conditions, but repeatedly had low pH values. The salinity indicator passed 93% of observations.

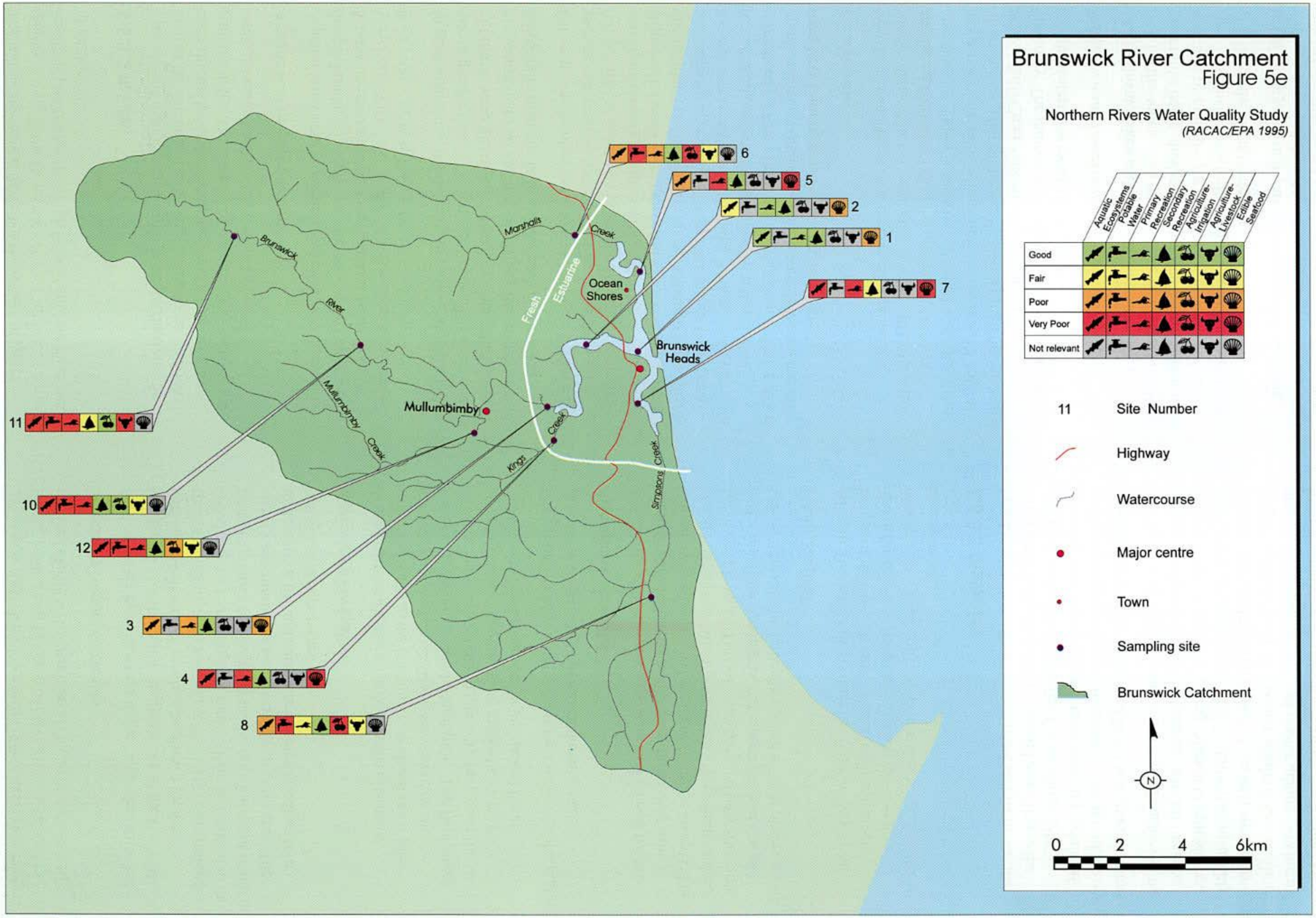
Edible Seafood

All estuarine sites fell in either the Poor or Very Poor ranges (50% for each rank). Faecal coliform levels were above the criterion for edible seafood for over 80% of observations. Total coliform levels also failed for 70% of observations.

5.6.3.3 Discussion

Water quality in the Brunswick River Catchment was the worst in the study area, when assessed according to the criteria described in the ANZECC Guidelines (1992). Estuarine sites within the catchment generally exhibited better water quality than the freshwater sites. It is likely that this is due to tidal flushing and dilution with marine waters.

The Brunswick River estuary (sites 1 and 2) achieved the best ranks of all sites in the catchment, a result likely to have resulted from tidal flushing. Sites at Ocean Shores and Simpsons Creek (sites 5 and 7) showed significantly poorer water quality, even though these sites were also subject to tidal effects. The poorer results at Ocean Shores may be attributable to water of poorer quality flowing in from Marshals Creek (site 6). The poor water quality observed at Simpsons Creek is most likely to result from the discharge from the sewage treatment plant directly


Brunswick River Catchment
Figure 5e
Northern Rivers Water Quality Study
(RACAC/EPA 1995)
Aquatic Ecosystems
Potable Water
Primary Recreation
Secondary Recreation
Agriculture-Irrigation
Agriculture-Livestock
Edible Seafood
Good
Fair
Poor
Very Poor
Not relevant
11 Site Number
Highway
Watercourse
Major centre
Town
Sampling site
Brunswick Catchment
N
0 2 4 6km
Brunswick River
Marshalls Creek
Ocean Shores
Fresh
Estuarine
Brunswick Heads
Mullumbimby
Mullumbimby Creek
Kings Creek
Simpsons Creek
1
2
3
4
5
6
7
8
10
11
12

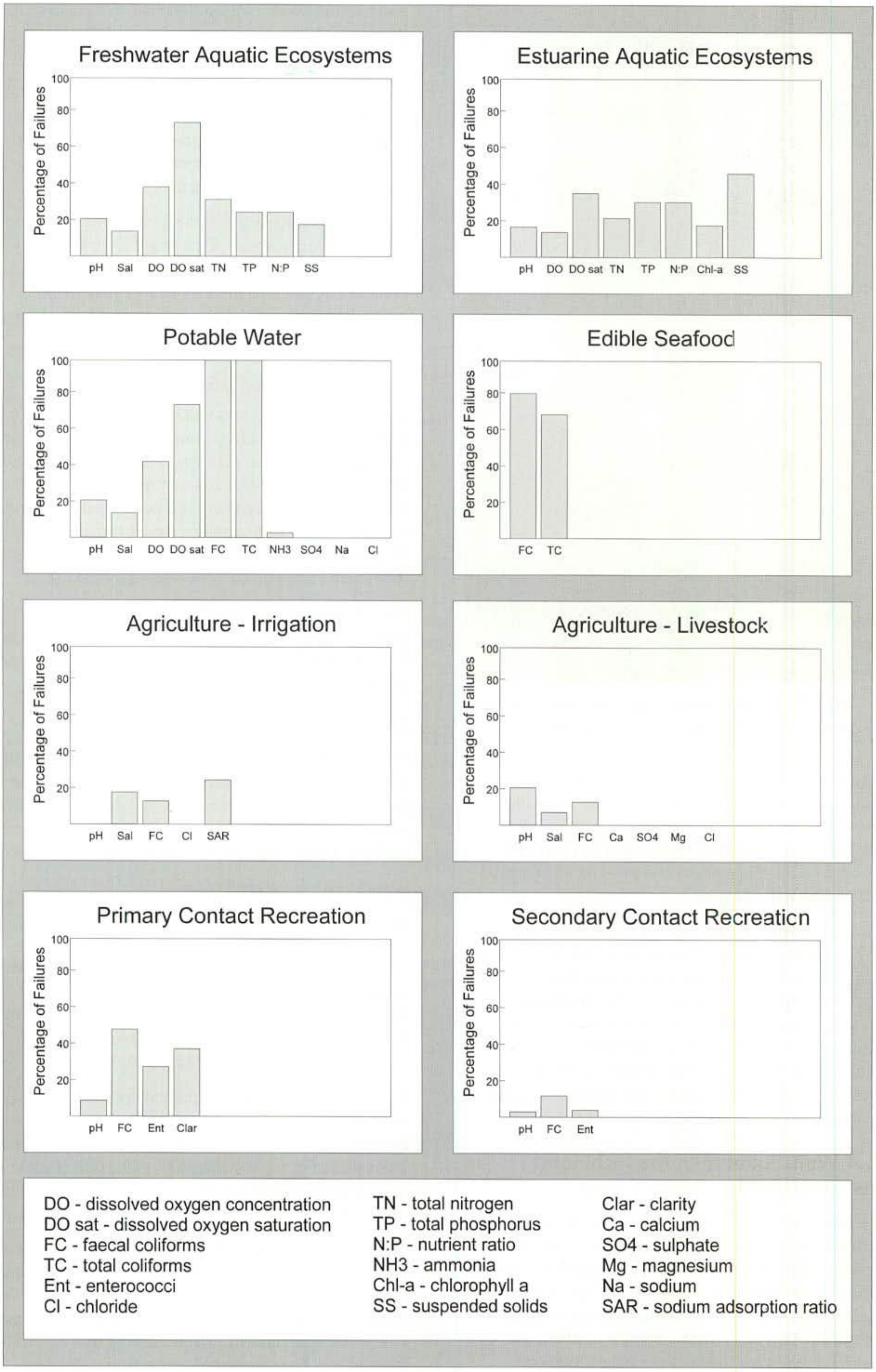


Figure 5f: Percentage of failures for each indicator, Brunswick Catchment

Graham Sinden

Poor water clarity can obscure snags in the river, and may pose a danger to primary contact recreation users.

adjacent to the site, as high nutrient levels and some elevated bacteria levels were identified. Sites at Kings Creek (site 4) and on the Brunswick River (site3) did not exhibit good water quality, probably reflecting the increasing effect of upstream conditions rather than tidal effects on the water quality.

Results from the freshwater sites were consistently bad, with all sites being ranked Poor or Very Poor for both the aquatic ecosystem protection and drinking water categories. Irrigation water supplies also fared poorly at these sites. Secondary contact recreation was the only environmental value to perform well in the freshwater sites. The main reasons for these results were high bacteria levels, low dissolved oxygen (percent saturation and concentration), and occasionally salinity.

5.6.4 Water quality in the Richmond River Catchment

The Richmond River Catchment is the second largest of the catchments presented, with a total area of 6864 square kilometres. The catchment includes the coastline from south of Evans Head through almost to Cape Byron and has a large coastal plain. The Border Ranges National Park and the Richmond Range form the northern and western limits of the catchment, with the Richmond Range continuing to the south (see 1, Rivers and catchments). Tidal influence in the catchment extends past Lismore on the Wilson River and to Tatham on the Richmond River.

Rainfall is concentrated around the north-eastern boundary of the catchment and over one quarter of the catchment receives more than 1500 millimetres of rain per year. The majority of the catchment receives between 800 millimetres and 1300 millimetres of rain per year, the lowest falls occurring around the Casino district.

The Richmond River meets the ocean at the coastal centre of Ballina, with Lismore, Casino and Kyogle the major inland population centres. Sugar cane cultivation is the dominant agricultural industry in the coastal zone, particularly between Ballina and Coraki. Cattle grazing is the major land use in inland areas.

5.6.4.1 Background information

Six routine sampling runs were carried out in the Richmond River Catchment under low flow conditions. An additional run was performed during a period of high flow in February 1995. However, no sampling of the Richmond River Catchment was performed during run six. The timing of all sampling runs is shown in figure 5g. Rainfall and flow conditions experienced over the catchment during the field work are also illustrated.

The following section describes the results of water quality testing in the Richmond River Catchment under low flow conditions. The high flow results are discussed in section 5.9.

5.6.4.2 Results

This section explores the results presented in figure 5h, a map of the catchment indicating the ranks assigned to each site for the seven categories, and discusses major trends in the data. Details of the indicators causing low ranks to be assigned are taken from figure 5i.

Aquatic ecosystem protection

In general, surface water in the Richmond River Catchment did not meet the criteria for the protection of aquatic ecosystems. Of the 49 sites in the catchment, none were assigned a Good rank for this category. Ten freshwater sites were ranked Fair (24%). Ranks of Poor or Very Poor were awarded to around 75% of all sites in the catchment (14% Poor, 61% Very Poor).

High levels of total phosphorus and low nutrient ratios were the two most common reasons for poor results in the freshwater section of the catchment. The criteria for both indicators were met less than 50% of the time. Dissolved oxygen and total nitrogen levels were outside guideline levels for more than 20% of observations.

The best results in the estuary were achieved near the river mouth, with sites one and two both recording Fair ranks. North Creek (site 8) received a Poor rank, probably reflecting the input of poor quality water from upstream rather than tidal flushing. The remaining sites were ranked Poor or Very Poor. In contrast to the freshwater sites, excessive suspended solids concentrations were responsible for the majority of failures. A large number of failures were also due to high phosphorus concentrations and a low nutrient ratio, with pH also failing over 20% of observations.

Potable water

Potable water was ranked Very Poor at all freshwater sites. Both the total coliform and faecal coliform indicators failed the criteria on 98% of observations, while low pH and dissolved oxygen measures each failed around 20% of observations. All other indicators failed less than 7% of observations.

Primary contact recreation

The Richmond River Catchment fared poorly for this environmental value, with 72% of sites being ranked Poor or Very Poor. Of the 42 freshwater sites investigated, 40% were ranked Very Poor, 36% Poor and 19% Fair. Terrace Creek (site 47), in the upper north west of the catchment, and Myall Creek (site 33) were the only freshwater sites ranked Good. Estuarine sites recorded a slightly better result than the freshwater sites, with 14% of sites being ranked Poor, and 43% Very Poor. The Richmond River at Ballina (site 1) was the only estuarine site to record a Good rank.

Low water clarity was identified in almost 45% of observations, and excessive levels of enterococci were detected in around one third of all observations. The remaining two indicators considered for this value were also significant contributors to the poor overall result, both failing for around 20% of observations.

Secondary contact recreation

This category achieved a good result, with ranks of Good or Fair reported for 95% of sites in the catchment (87% Good and eight percent Fair). A Poor and Very Poor rank were also assigned to one site each.

Thirty seven, 88%, of the freshwater sites were ranked Good, with a further fou (ten percent), sites ranked Fair. Only one freshwater site was ranked Very Poor, with the remaining six freshwater sites (86%), being ranked Good. Of the estuarine sites, there were no Very Poor results and Tuckean Broadwater was the only site ranked Poor.

In the estuary, the pH indicator was responsible for the majority of fails in this category, however enterococci, faecal coliforms and pH passed the criteria for over 90% of observations.

Agriculture - irrigation

Ranks of Good or Fair were assigned to 52% of sites; Poor (five percent), and Very Poor (43%), accounted for the remaining ranks. Eight of the eighteen Very Poor sites were located in the south-west region of the catchment.

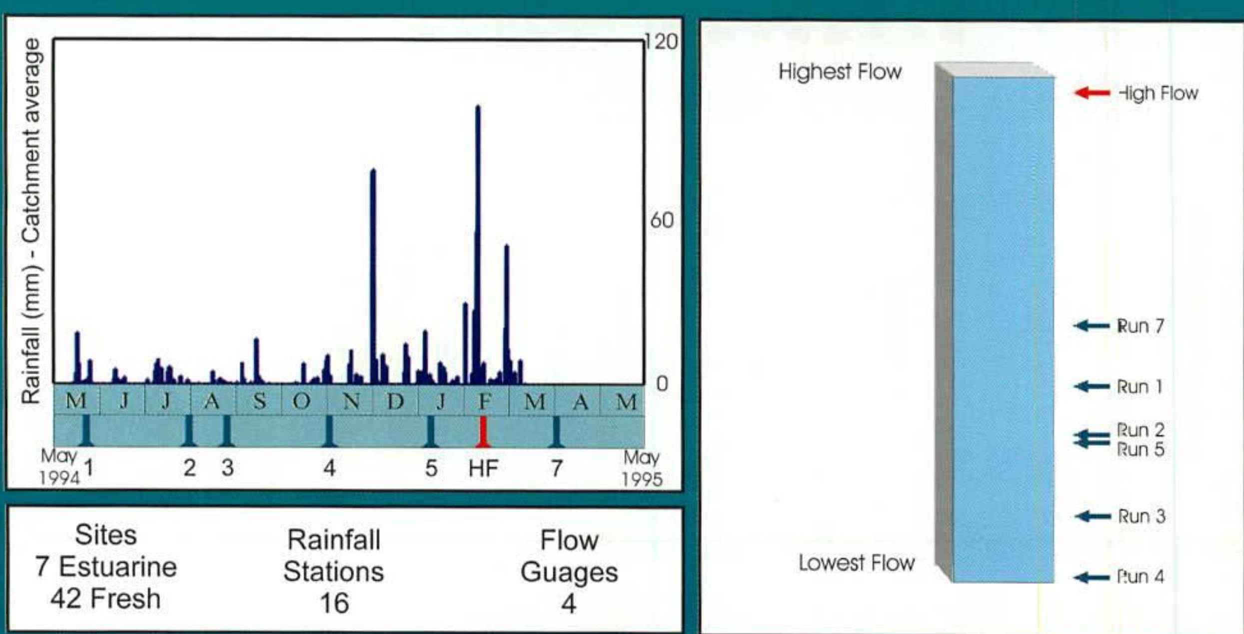
High salinity caused 45% of observations to fail in this category. The sodium adsorption ratio indicator also failed 24% of tests. The pH and faecal coliform levels were acceptable for nearly all observations, while chloride was detected at excess levels in 11% of observations.

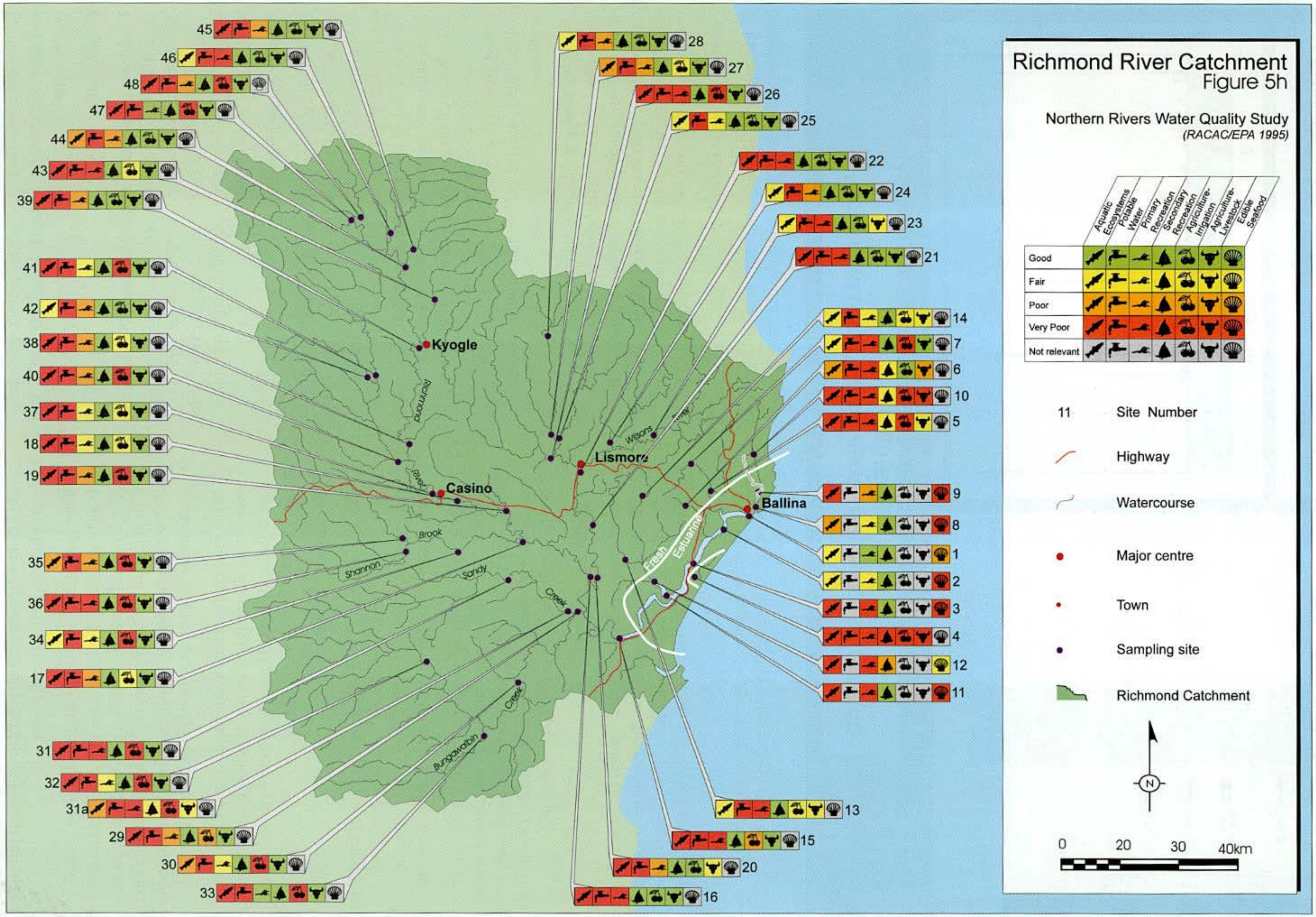
Agriculture - livestock

Ninety-two percent of sites were ranked Good or Fair, (78% and 14% respectively), in this category. Duck Creek (site 6) was the only site to be ranked Poor, (two percent), while both Reedy Creek (site 4) and North Creek (site10) were ranked Very Poor, (5%).

The criteria considered for livestock water were met in most cases, however pH failed around 15% of

Richmond River Catchment - Summary Information
Figure 5g




Richmond River Catchment
Figure 5h
Northern Rivers Water Quality Study
(RACAC/EPA 1995)
Aquatic Ecosystems
Potable Water
Primary Recreation
Secondary Recreation
Agriculture-Irrigation
Agriculture-Livestock
Edible Seafood
Good
Fair
Poor
Very Poor
Not relevant
11 Site Number
Highway
Watercourse
Major centre
Town
Sampling site
Richmond Catchment
N
0 20 30 40km
Kyogle
Casino
Lismore
Ballina
Richmond River
Wilsons River
Shannon Brook
Sandy Creek
Bungawalbin Creek
Fresh
Estuarine

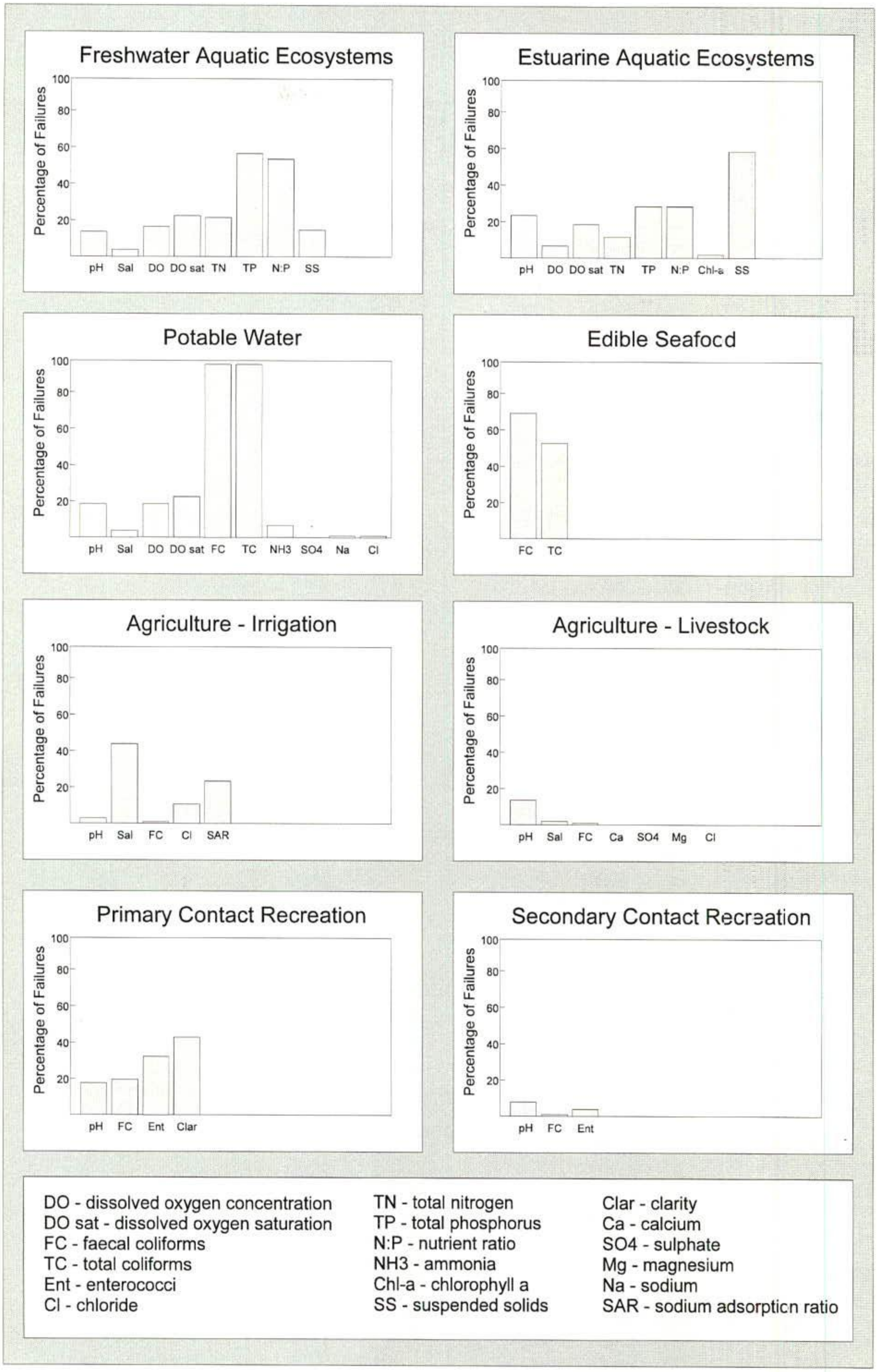


Figure 5i: Percentage of failures for each indicator, Richmond Catchment

observations. The criterion for faecal coliforms was met for 99% of observations. Measures of calcium, magnesium, chloride and sulphate were acceptable on all occasions.

Edible seafood

Water quality conditions were rarely met for this value, with five of the seven sites assessed being ranked as Very Poor (71%). Sites at the Tuckean Broadwater and Ballina (sites 12 and 1) were ranked Fair and Poor, respectively. For 71% of all observations, the faecal coliform criterion was exceeded, while 54% of observations exceeded the total coliform criterion.

5.6.4.3 Discussion

Surface water of the Richmond River Catchment had generally poor water quality under low flow conditions. However marked regional differences in water quality were not apparent, either between different freshwater regions, or between the freshwater and estuarine portions of the catchment.

Water in the estuary was generally unacceptable for aquatic ecosystem protection, primary contact recreation and edible seafood. All but one of the seven sites ranked well for secondary contact recreation. The sites at Ballina (site 1) and Hermans Lane (site 2) recorded the best ranks, with water quality quickly declining upstream of these sites. Tidal flushing of the lower Richmond River may be responsible for this pattern.

In the freshwater portion of the catchment, a result similar to that for the estuary was evident, with aquatic ecosystem protection, primary contact recreation and potable water ranking poorly. Highly fertile soils which have developed on basalts in the northern portion of the catchment (Central Mapping Authority of NSW 1987; Packham 1969) may be responsible for some of the high nutrient observations that failed the aquatic ecosystem protection criteria. Tomki Creek (site 19) recorded the highest total phosphorus concentrations of all freshwater sites, with observations being between ten and 77 times higher than the guideline concentration. Sewage input to Tomki Creek is the most likely cause of these extremely poor results. The Richmond River at Tatham (site 17) also showed elevated total phosphorus levels, possibly the result of inputs at Tomki Creek.

Secondary contact recreation and stock water generally ranked well in the catchment. A few higher ranking sites were scattered through the upper reaches of the rivers (for example, Nimbin (site 28), Terania Creek (site 25), and Wiangaree (site 44)). Throughout the freshwater areas of the catchment, high phosphorus concentrations, a low nutrient ratio and poor clarity were evident.

Irrigation water tended to score better ranks in the upper Richmond River, above Kyogle, and in the upper Wilsons River, above Lismore, than in the remainder of the catchment. In these areas, salinity readings above the guideline values were the sole reason for occasional failures. Poor readings at other freshwater sites were predominantly the result of high salinity, with other indicators occasionally failing. Fifty-six percent of all sodium adsorption ratio failures occurred in the Shannon Brook, Sandy Creek and Bungawalbin Creek catchments, along with a high number of salinity failures.

Sites close to the freshwater/estuarine boundary, including Emigrant Creek (site 5), North Creek (site 10), and Woodburn (site 15), showed a high number of salinity failures for irrigation. The most likely cause of this result is seawater extending further than usual up the river during very low flows in the river.

5.6.5 Water quality in the Clarence River Catchment

The Clarence River Catchment is the largest of the catchments in the Region, with a total area of 22 182 square kilometres. It is also the driest catchment, with over 60% of the catchment receiving less than 1200 millimetres of rain per year. Ten percent of the catchment receives more than 1500 millimetres of rain per year.

The catchment boundary is the Great Escarpment to the south and west. The Richmond Ranges and the McPherson Range form the north-east and northern limits of the catchment. The lowland portion of the river is characterised by an extensive floodplain, with the river reaching the ocean at Yamba/Iluka (see 1, Rivers and catchments). Tidal influence extends to Copmanhurst on the Clarence River, and to the Old Glenn Innes Road on the Orara River.

Grafton is the regional centre of the catchment, with Ulmarra being the divide between grazing properties, inland, and areas of cane farming near the coast. Maclean, Yamba and Iluka are important centres for the commercial fishing industry. Timber felling occurs over a significant part of the remaining forested area, with the Grafton (Forestry) Management Area wholly within the catchment. Teatree plantations are also being developed on previously timbered or grazing land.

5.6.5.1 Background information

Seven routine sampling runs were carried out in the Clarence River Catchment under low flow conditions. An additional run was performed during a period of high flow in February, 1995. The timing of all sampling runs is shown in figure 5j. Rainfall and flow conditions experienced over the catchment during the field work are also illustrated.

The following section describes the results of water quality testing in the Clarence River Catchment during low flow conditions. The high flow results are discussed in section 5.9.

5.6.5.2 Results

This section explores the results presented in figure 5k, a map of the catchment indicating the ranks assigned to each site for the seven categories, and discusses major trends in the data. Details of the indicators causing low ranks to be assigned are taken from figure 5i.

Aquatic ecosystem protection

The majority of sites tested fell into either the Good or Fair ranks (28% and 30% respectively), with Poor (22%), and Very Poor (20%), ranks representing a minority of sites.

The majority of failed observations in the freshwater reaches of the catchment were due to low dissolved oxygen and high total nitrogen levels. Measures of total phosphorus and the nutrient ratio were only a very minor negative influences on water quality, with both meeting the criteria for more than 95% of observations.

In the estuary the majority of sites were ranked Poor or Very Poor (33% each), with the Clarence River at Cowper (site 14) and at Goodwin Island (site 3) the only sites to record a Good rank. The suspended solids indicator was responsible for the majority of fails, with 45% of observations not meeting the criterion. Dissolved oxygen (percent saturation) and pH failed between ten percent and 15% of observations each while the remaining indicators failed less than 10% of observations. Nutrient levels and the nutrient ratio were identified as minor problems.

Potable water

All sites in the freshwater part of the catchment were ranked either Poor or Very Poor (19% and 81% respectively).Total coliform levels exceeded the criterion for 97% of observations while faecal coliform were detected at excessive levels in 93% of observations. Dissolved oxygen (percent saturation) was below the recommended levels for 22% of observations. The pH levels failed 12% of observations, while salinity was above the criterion in less than 8% of observations. The chloride and ammonia indicators failed a very small percentage of tests while sodium and sulphate passed on all occasions.

Primary Contact Recreation

Forty-four percent of sites in the catchment were assigned a Good (7%), or Fair (37%), rank for this category, with a further 35% ranked Poor, and 22% ranked Very Poor.

The freshwater portion of the catchment performed slightly better than the estuary, with 48% of freshwater sites being ranked either Good or Fair. Sixty-six percent of estuarine sites were ranked Poor or Very Poor.

Poor clarity was the main reason for the bad results in this category, with 40% of all observations failing the criterion for this indicator. Elevated levels of enterococci also caused a number of sites to fail. The remaining two indicators were within acceptable levels approximately 90% of the time.

Secondary contact recreation

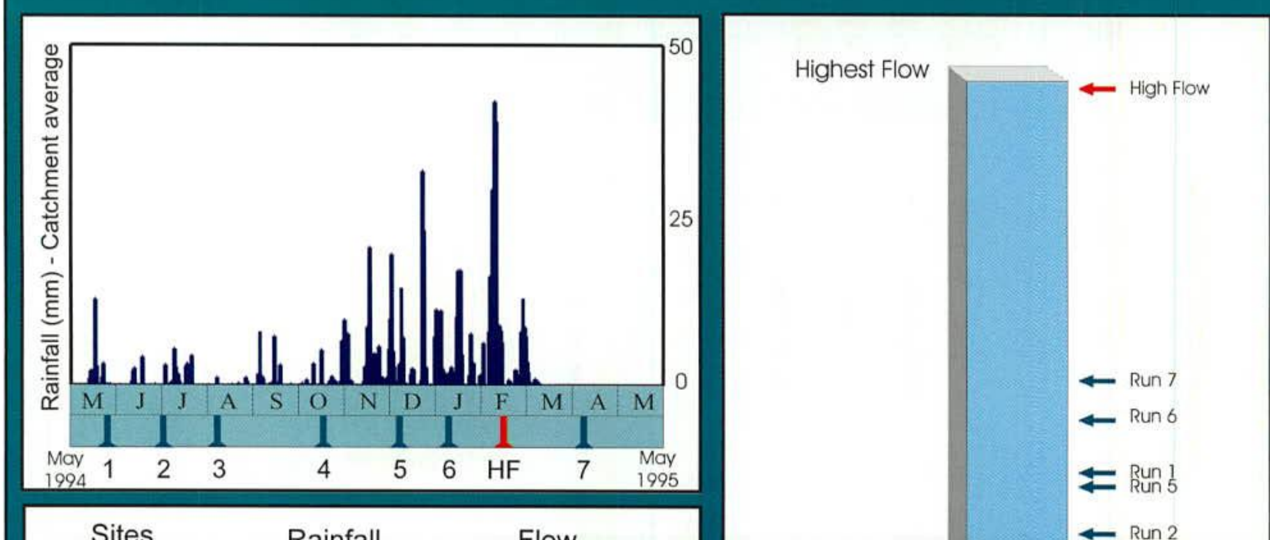
With all sites recording a Good or Fair rank, this was the best performing value in the catchment. Ninety-three percent of estuarine sites and 90% of freshwater sites were assigned a Good rank while all remaining sites scored a Fair rank.

Occasional failures were primarily due to low pH, however this indicator still passed over 95% of observations. Bacterial indicators had relatively little impact on the final results.

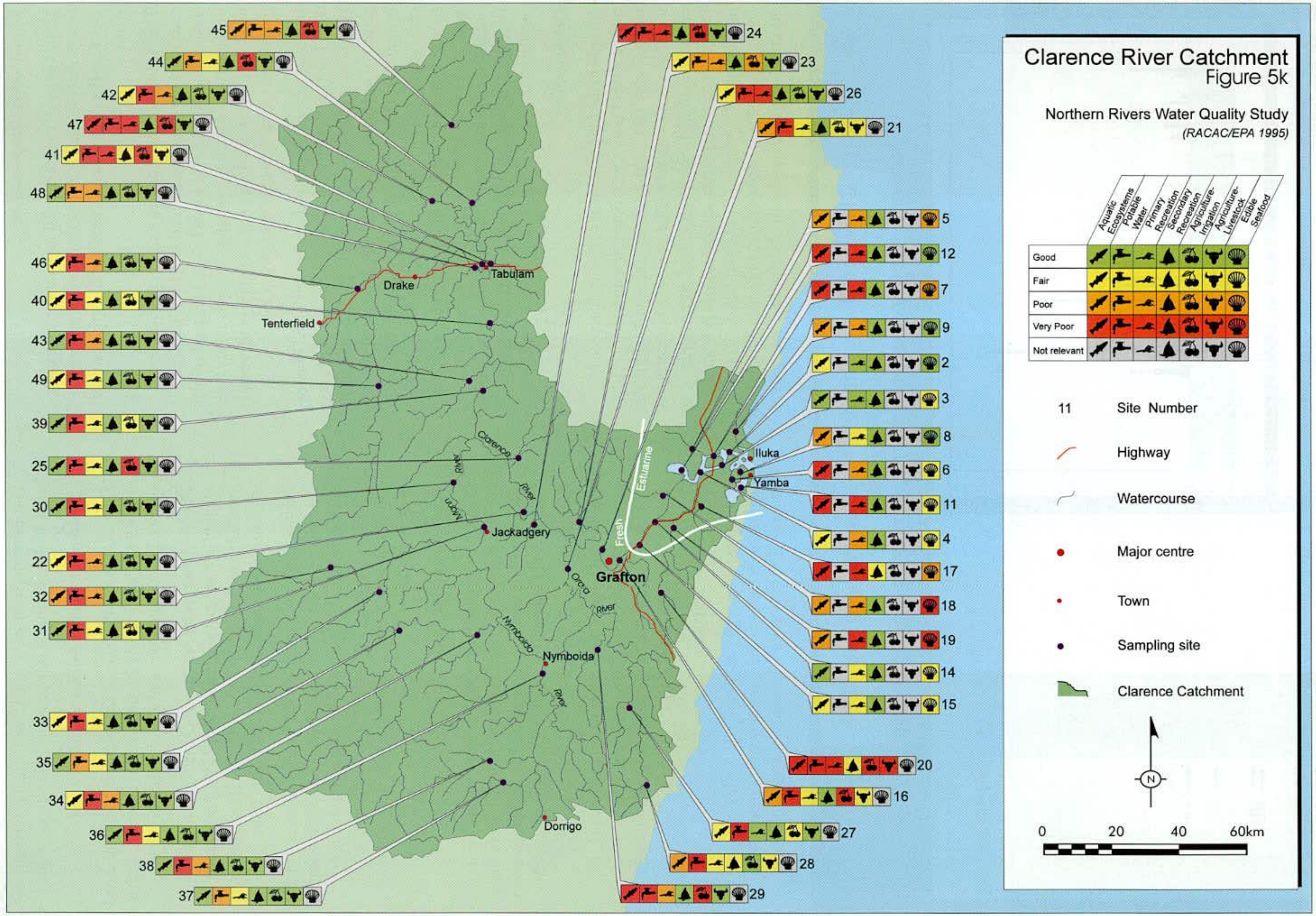
Agriculture - irrigation

Although the majority of sites (68%), in this category were ranked Good or Fair, a significant number, 29%, were ranked Very Poor. The main indicators on which

Clarence River Catchment - Summary Information
Figure 5j



Sites	Rainfall	Flow
15 Estuarine 31 Fresh	Stations 28	Guages 8


Clarence River Catchment
Figure 5k
Northern Rivers Water Quality Study
(RACAC/EPA 1995)
Aquatic Ecosystems
Potable Water
Primary Recreation
Secondary Recreation
Agriculture-Irrigation
Agriculture-Livestock
Edible Seafood
Good
Fair
Poor
Very Poor
Not relevant
11 Site Number
Highway
Watercourse
Major centre
Town
Sampling site
Clarence Catchment
N
0 20 40 60km
Tabulam
Drake
Tenterfield
Jackadgery
Grafton
Iluka
Yamba
Nymboida
Dorrigo
Clarence River
Mann River
Orara River
Nymboida River
Fresh
Estuarine
45
44
42
47
41
48
46
40
43
49
39
25
30
22
32
31
33
35
34
36
38
37
24
23
26
21
5
12
7
9
2
3
8
6
11
4
17
18
19
14
15
20
16
27
28
29

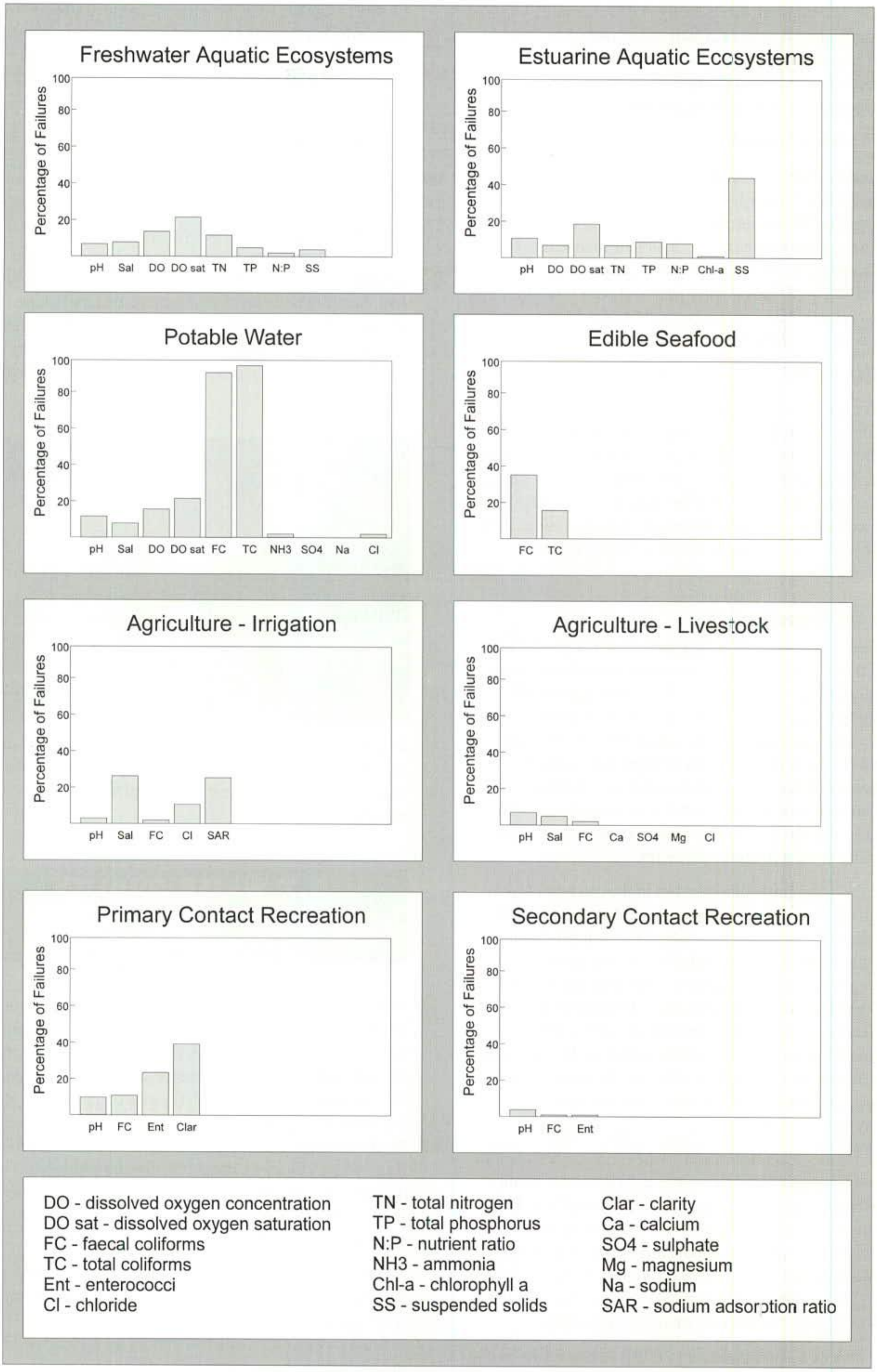


Figure 51: Percentage of failures for each indicator, Clarence Catchment

observations failed were salinity and the sodium adsorption ratio, both of which failed more than 26% of observations. The amount of chloride in the water exceeded the criterion for 11% of observations. Faecal coliform levels and pH were generally acceptable.

Agriculture - livestock

Eighty-four percent of sites were ranked Good for this value, with a further 13% ranked Fair. Upper Coldstream River (site 20) was the only site ranked Very Poor in the catchment, with high salinity being the main cause of the bad ranking. Despite being the major cause of failures, the indicators of pH and salinity passed at least 90% of observations. The indicators of calcium, sulphate, magnesium and chloride passed all observations.

Edible seafood

Water quality in the Clarence estuary showed the best results in the study area for the production of edible seafood. 27% of sites scored a Good rank and 40% were Fair. Three sites, 20%, were ranked Poor and two sites, 13%, Very Poor. Both bacterial indicators were identified exceeding the criteria, with faecal coliforms failing 36% of observations and total coliforms failing 17% of observations.

5.6.5.3 Discussion

Overall, water quality in the Clarence River Catchment was the best of the four catchments studied in the Audit Region. Forty-one percent of all site rankings for all categories in the catchment received a Good rank, with a further 20% ranked Fair. The categories with the least number of acceptable results were primary contact recreation and, as in the other catchments, potable water. The main reasons for this result was failure to meet the clarity criterion for primary contact recreation, and the bacteria criteria for both categories.

Results in the freshwater reaches of the catchment were generally very good. Water sampled at most sites in the Clarence River between the Mann River and Tabulam, and the Mann and Nymboida Rivers, was generally suitable for aquatic ecosystem protection, secondary contact recreation, and agriculture. Primary contact recreation was generally ranked Fair to Poor in this region. Upstream of Tabulam the water quality declined, with a number of Very Poor ranks for the categories of irrigation, primary contact recreation and aquatic ecosystem protection.

Sites on the Orara River, and on the Clarence between the Mann River and Grafton, revealed poorer water quality than further upstream. A number of Poor and Very Poor results were assigned for both aquatic ecosystem protection and primary contact recreation, with mixed results reported for agricultural supplies. Kangaroo River (site 29) and Main Creek (site 24) received Good or Fair ranks for just two of the six categories presented.

The upper Coldstream River (site 20) displayed the worst water quality of the Region, receiving a Very Poor rank for five of the six environmental values considered. Water quality at this site may have been adversely affected by water flowing from the Crowsnest Swamp area, but this has not been demonstrated. The results for the lower Coldstream River (site 19) indicate a slight improvement in water quality down the river.

A significant number of estuarine sites scored either Poor or Very Poor for aquatic ecosystem protection, the major reason being high suspended solids concentrations. There were mixed results for primary contact recreation, while secondary contact recreation exhibited good water quality. Edible seafood ranks were the best of the four catchments studied, with a majority being ranked Good or Fair. Samples collected from the main channel of the Clarence River generally ranked better than sites located on tributaries. This indicates that tidal exchange and marine water dilution processes may be active in the main channel of the estuary.

Graham Sinden

Despite their initial appearance, estuarine tributaries such as Shark Creek (site 17) were generally awarded worse ranks than sites in the main channel of the Clarence estuary.

5.7 WATER QUALITY DURING HIGH FLOW CONDITIONS

Rainfall in Australia does not have the regularity of many other countries - extended periods of drought are a natural part of the Australian climate, along with high intensity rainfall events and floods. Erosion of soils and transport of sediment by rivers is similarly a natural process. Sediment transported by the rivers is largely responsible for the floodplain development apparent in the Audit Region (see volume 2, chapter 4, Geomorphology). The quantity of nutrients and sediments transported by the rivers in the Region has been exacerbated by past and current changes to land use.

The previous sections described water quality in the Region under low flow conditions. This section examines water quality data collected during the period 14 - 19 February 1995, when rain throughout the Region resulted in higher flows being recorded in the river systems. During this period, river flows were at a level occurring less than 10% of the time.

The first part of this section will compare high flow water quality to the guidelines for environmental values, using a similar method to that used for low flow conditions. The second part of the section will present river load estimates, the mass of material that is transported over a given time, for different rivers in the Region and examine the differences between loads under different flow conditions.

5.7.1 Background

Although rivers transport material under low flow conditions, heavy rainfall provides the mechanism by which large amounts of material from the catchment surface are transported to, and by, the river system. Rainfall runoff will erode unconsolidated soils (for example, ploughed fields and recently logged forests), moving not only soil particles but also material attached to soil particles (including phosphorus, some pesticides and heavy metals) into the river. Bank erosion and entrainment of material from the river bed may also be significant sources of river load. Soluble materials, such as nitrogen and some pesticides, will dissolve in the water and be transported to, and by, the river. Other effects may be apparent, such as the leaching of acid water from drained acid sulphate soils in coastal reaches of the rivers. Once in the river system, higher flows act to rapidly move large quantities of the material downstream.

Thus, rainfall will increase the volume of water flowing in a river, the concentration of particles and compounds in the water, and as a consequence, the load being transported by the river.

5.7.2 The importance of water quality during high flow

High flow levels are a natural response of rivers to high intensity rainfall. Although high river flows are generally not maintained (they are usually apparent for a few hours to a few days), the water quality of the rivers during this time is an important aspect of river systems in Australia. Water quality under high flows has sometimes been overlooked, either because the flows last a relatively short time, or because it was difficult to collect measurements under higher flow conditions. However, it is important as the water quality and loads identified during high flow conditions may reflect much larger scale, and longer term, changes to the ecological sustainability of the catchment.

The quality of river water during high flow may reflect changes to catchment land uses more than during periods of low river flow.

5.7.3 Scope of the high flow sampling program

Rainfall during the sampling period resulted in more difficult access to sites, and an increase in the time required to collect water samples. In addition, the short period of high flow in the rivers limited the available sampling time. To overcome these constraints, a reduced number of samples were collected from the study area.

5.7.4 Summary information

Summary information for high flow sampling is presented in table 5e. Additional information on the sampling period, catchment rainfall and river flows can be found in the figures given in the table.

5.8 ASSESSING HIGH FLOW WATER QUALITY

The data collected under high flow conditions were assessed using two methods -

- *Environmental values*

  The data collected were compared to the Australian Water Quality Guidelines for Fresh and Marine Waters, using the same indicators and criteria used in assessing the water quality under low flow conditions (section 5.6). This will provide a direct comparison of water quality under different flow regimes at a regional and catchment level. Although it is possible to compare individual sites, the reduced sampling set required for sampling higher flow conditions means not all sites were sampled under higher flow conditions. Individual site comparisons have, therefore, not been presented.

- *River loads*

  River load is the mass of material that the river transports over a given time, and can be expressed as kilograms per day. To calculate the load, the concentration of different indicators in the river, and the volume of water flowing in the river, must be known.

TABLE 5E - SUMMARY INFORMATION FOR THE HIGH FLOW WATER QUALITY DATA.

Catchment	Freshwater Sites	Estuarine Sites	Total Sites Sampled	Date(s) Sampled	Summary Flow Information
Tweed	20	15	35	14-16 February 1995	figure 5a
Brunswick	5	6	11	14-15 February 1995	figure 5d
Richmond	9	3	12	18 February 1995	figure 5g
Clarence	9	6	15	17 February 1995	figure 5j

River loads were calculated for eight sites in the Region, under both low and high flow conditions. Sites suitable for load calculation were restricted by the availability of both river flow information and water quality results during higher flow conditions.

5.9 ENVIRONMENTAL VALUES AND HIGHER FLOW CONDITIONS

Higher flow conditions will not be sustained without continuing heavy rainfall, and river systems generally return to more "normal" flows within a few days of the main rain event passing. Thus, this assessment of water quality will apply for only a short period of time.

Water quality was assessed with reference to the seven environmental values examined under low flow conditions. The indicators and criteria used in assessing high flow water quality are identical to those used in assessing low flow water quality (section 5.6).

5.9.1 Results

Results for high flow water quality in the Region, based on the criteria for the seven environmental values, are presented in table 5f. These results demonstrate that water quality declined significantly during the higher flows accompanying this rain event.

5.9.2 Discussion of environmental values

The following discussion provides details on the indicators that failed the criteria under higher flow conditions for each environmental value. Refer to figure 5m for a summary of indicator performance in the study area.

5.9.2.1 Aquatic ecosystem protection

Excess levels of nitrogen and phosphorus, together with a low nutrient ratio, were identified at a majority of sites throughout the study area. High suspended solids levels were found in all catchments.

Low dissolved oxygen levels, especially saturation levels, were a feature of the estuarine reaches of the catchment. Dissolved oxygen (percent saturation) was below the criterion for almost 60% of observations in the estuaries, while pH failed the criterion at around 70% of sites. All other indicators passed more than 50% of observations.

5.9.2.2 Drinking Water

All observations in the four catchments failed the criteria for drinking water. Excessive levels of bacteria (both faecal coliforms and enterococci) were identified at all sites. Dissolved oxygen (concentration), pH, and to a lesser extent ammonia, also failed the criteria for a number of observations.

5.9.2.3 Primary contact recreation

Of the 73 sites sampled, only site one in the Brunswick River Catchment passed this category. It is likely that sampling occurred at this site before significant runoff had influenced the water quality.

Poor water clarity was apparent in 99% of observations. Faecal coliform concentrations exceeded the criterion at 92% of sites, while enterococci levels were excessive at 79% of sites. The remaining indicator of pH also failed over 30% of all observations.

5.9.2.4 Secondary contact recreation

The results for this category were significantly different to primary contact recreation, with 55% of sites in the study area passing the criteria. A total of 18 from 35 sites in the Tweed, four from 11 sites in the Brunswick, seven from 12 sites in the Richmond, and 11 from 15 sites in the Clarence catchments passed the criteria for secondary contact recreation. The number of sites passing in fresh and estuarine portions of the catchments were similar.

Excess levels of faecal coliforms failed almost 40% of observations, and were identified at a significant number of sites in the Tweed, Brunswick and Richmond

TABLE 5F - PERCENTAGE OF OBSERVATIONS PASSING THE CRITERIA FOR EACH ENVIRONMENTAL VALUE UNDER HIGH FLOW CONDITIONS.

Environmental Value	Tweed	Brunswick	Richmond	Clarence
	% Pass	% Pass	% Pass	% Pass
Aquatic Ecosystem Protection	0%	0%	0%	0%
Potable Water	0%	0%	0%	0%
Primary Contact Recreation	0%	9%	0%	0%
Secondary Contact Recreation	51%	36%	58%	73%
Agriculture - Irrigation	50%	0%	44%	89%
Agriculture - Livestock	35%	0%	11%	33%
Edible Seafood	0%	0%	0%	0%

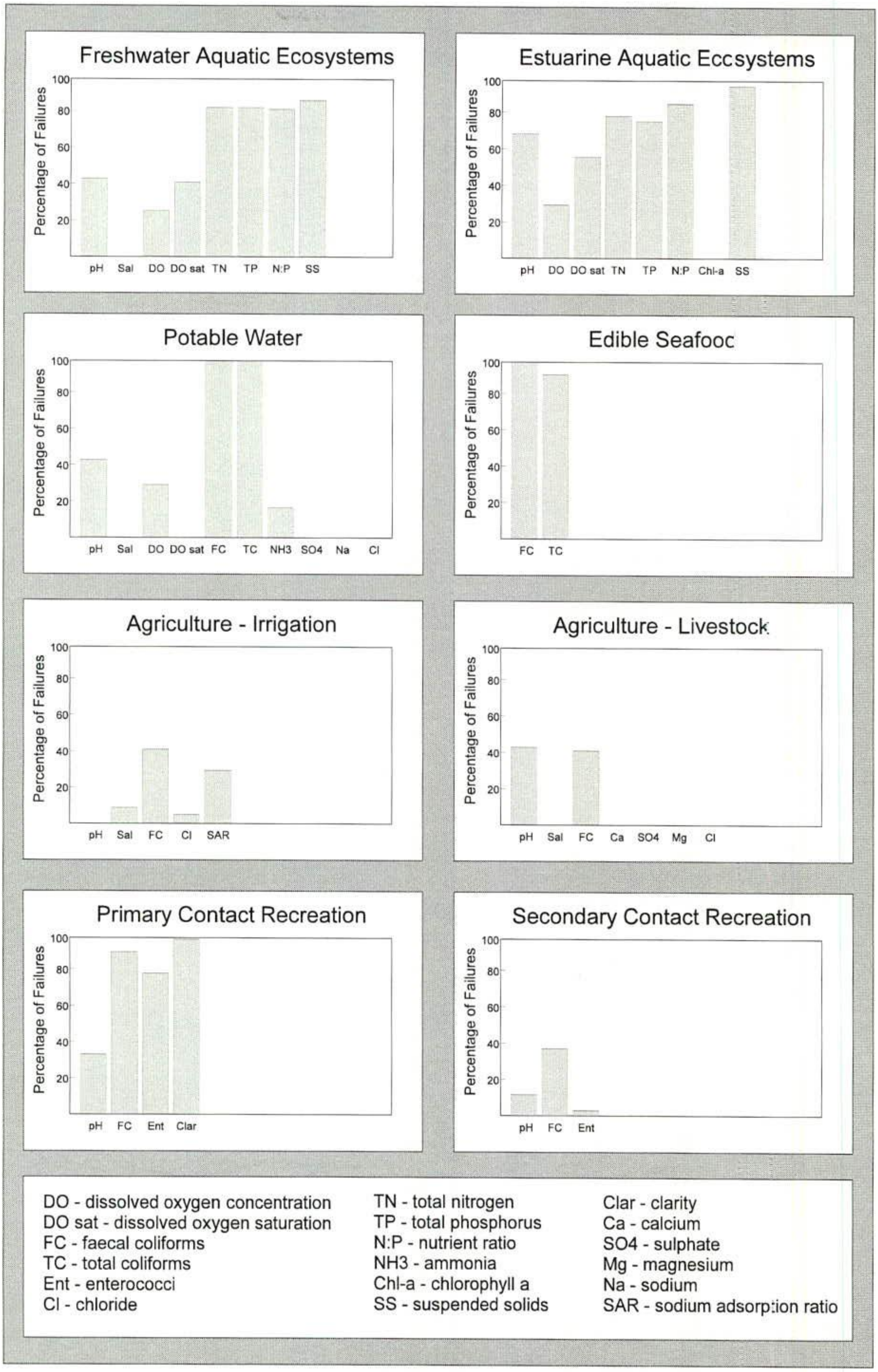


Figure 5m: Percentage of failures for each indicator, entire Audit Region, High Flow Conditions only.

catchments. All but one site in the Clarence River Catchment passed this indicator.

5.9.2.5 Agriculture - irrigation

Twenty-eight percent of freshwater sites passed this environmental value, with the Clarence River Catchment having the highest proportion of sites passing, eight out of nine sites. Ten of 20 sites passed in the Tweed River Catchment, while five of nine sites passed in the Richmond River Catchment. The Brunswick River Catchment fared worst in this category, with all sites failing.

Throughout the study area, 42% of faecal coliform concentrations, along with 30% of sodium adsorption ratio observations, were above the criteria for irrigation water. The sodium adsorption ratio criterion was particularly important in the Richmond and Clarence catchments.

5.9.2.6 Agriculture - livestock

The Tweed and Clarence catchments fared best in this category, with 35% of Tweed sites and 33% of Clarence sites passing the criteria for stock water. All Brunswick River Catchment sites, along with 78% of Richmond River Catchment sites, failed this category. The indicators of pH and faecal coliforms were responsible for all fails observed in the Region. Excessive faecal coliform levels were not distributed evenly through the Region, with 100% of observations in the Brunswick River Catchment exceeding the criterion, while only 11% of observations exceeded the criterion in the Clarence River Catchment. The indicators of calcium, sulphate, magnesium and chloride passed for all sites in the study area.

5.9.2.7 Edible seafood

All sites in the study area failed the criteria for edible seafood, with 100% of faecal coliform concentrations, and 93% of total coliform concentrations above the criteria. The two observations that passed the total coliform criterion were both in the Brunswick River Catchment estuary. It is probable that these sites were sampled prior to runoff from the rain period having a significant effect on water quality in the estuary.

5.9.3 Summary

A significant decline in water quality was identified under high flow conditions, compared to the low flow water quality results, throughout the Audit Region. Environmental values which were ranked poorly under low flow conditions, such as drinking water and edible seafood, failed all observations under higher flow conditions. Environmental values which ranked well under low flow conditions, such as secondary contact recreation, showed a large decline in water quality under higher flow conditions.

As was discussed earlier, the relatively short duration of most high flow events means that the results presented here occur in the river only for a short time. They do, however, provide a useful insight into the response of the catchment to heavy rainfall, and provide a ready comparison to the low flow results presented in section 5.6.

5.10 SEDIMENT AND NUTRIENT LOADS

This section examines the amount of material being transported at different points in the river systems. Sediment and nutrient loads are calculated for both low and high flow conditions, with the results for the Region being discussed.

5.10.1 River loads in the Audit Region

When water flows down a river, it carries with it material from the catchment. This material may be either dissolved

TABLE 5G - SUMMARY INFORMATION FOR LOAD CALCULATIONS

		High Flow		Low Flow
Catchment	Site	Date Sampled	Peak Flow Date	Number of Samples
Tweed	39	14 Feb 95	15 Feb 95	4
Brunswick	10	15 Feb 95	15 Feb 95	5
Richmond	37	18 Feb 95	17 Feb 95	7
Richmond	44	18 Feb 95	16 Feb 95	7
Clarence	22	17 Feb 95	17 Feb 95	6
Clarence	31	17 Feb 95	16 Feb 95	7
Clarence	36	17 Feb 95	16 Feb 95	7
Clarence	39	17 Feb 95	*	4

* - unable to determine peak flow date due to missing flow data.

in the water, or moved as solid particles in the river. This material is the load of the river, and is generally measured as the amount in kilograms of material moving past a point on a river in a given time. The amount of material moving down a river will vary depending on the volume of water and the concentration of material in the water column.

Load calculations have been made for suspended solids, total nitrogen and total phosphorus at eight sites in the study area. Loads for low flow conditions have been calculated from up to seven observations in the period April 1994 to May 1995. Loads under high flow conditions have been calculated from the February 1995 high flow event. Summary information for these sites is given in table 5g.

5.10.2 Calculation of river loads

River loads were calculated by multiplying the concentration of each indicator (mg/L) by the mean daily discharge of the river on the day the sample was collected (ML/day), giving the mass of material moved in one day. An example of load calculations for suspended sediment is presented in the box.

Oxley River at Eungella - Site 39

Date - 14 February 1995 (High flow conditions)

Concentration of Suspended Solids = 21.46 mg/L
River Discharge = 3 695ML/day

Load = 21.46 x 3695 = **79 300kg/day.**

Loads were also calculated for each low flow run, with the final load being the average of all low flow loads.

5.10.3 Accuracy of load calculations – assumptions and inaccuracies regarding river loads

Calculating the load of a river requires a number of assumptions to be met, including:

- the discharge of the river is accurately measured;
- the concentration of the indicators are accurately known; and
- the concentration of each indicator does not vary throughout the profile.

Both velocities and concentrations will vary within the river cross section (Martin et al. 1992, Sinden 1993). Also, concentrations will be different at different flow levels (for example, Kachka et al. 1993). Unless a continuous set of samples are collected during a high flow event (for example, water samples and flow data collected at 15 minute intervals), it is very unlikely that the peak flow, peak concentration or peak load will be identified.

Although some inaccuracy is almost inevitable in load calculation, the differences between loads at low and high river flow are commonly very large.

5.10.4 Results

The loads calculated for eight sites in the study area are presented in figures 5n to 5q, along with further details for each catchment. Detailed analysis of the results and their implications are presented in the discussion section.

5.10.5 Discussion

Throughout the Audit Region, a clear pattern of large increases in river loads under high flow conditions was apparent for the three indicators of total nitrogen, total phosphorus and suspended sediment. Although the exact change in loads differed between different sites, high river flows occurring as a result of widespread rainfall in the Region transported large quantities of material in each of the four catchments.

Very large differences between the concentration of the different indicators were identified between low and high flow conditions. During the high flow event, total nitrogen concentration was between two and nine times higher than low flow conditions (average four times higher), total phosphorus concentration increased between two and 12 times (average six times higher), and suspended solids concentrations were between five and 200 times higher than average low flow conditions (average 70 times higher).

5.10.5.1 Loads under low flow

Under low flow conditions, phosphorus and suspended sediment loads were similar in the Richmond and Clarence catchments, irrespective of catchment size. A similar pattern was evident for total nitrogen, however loads at both sites in the Richmond River Catchment were lower than at any site in the Clarence River Catchment.

Sediment and nutrient loads in the Brunswick and Tweed catchments were significantly lower than in the other two catchments. Extremely low flows in the Brunswick River Catchment (mean flow of around 6600L/day) were responsible for the low loads; this site recorded the highest mean concentration for total nitrogen and second highest suspended solids concentration. A combination of low flows and low concentrations were responsible for the loads identified in the Tweed River Catchment.

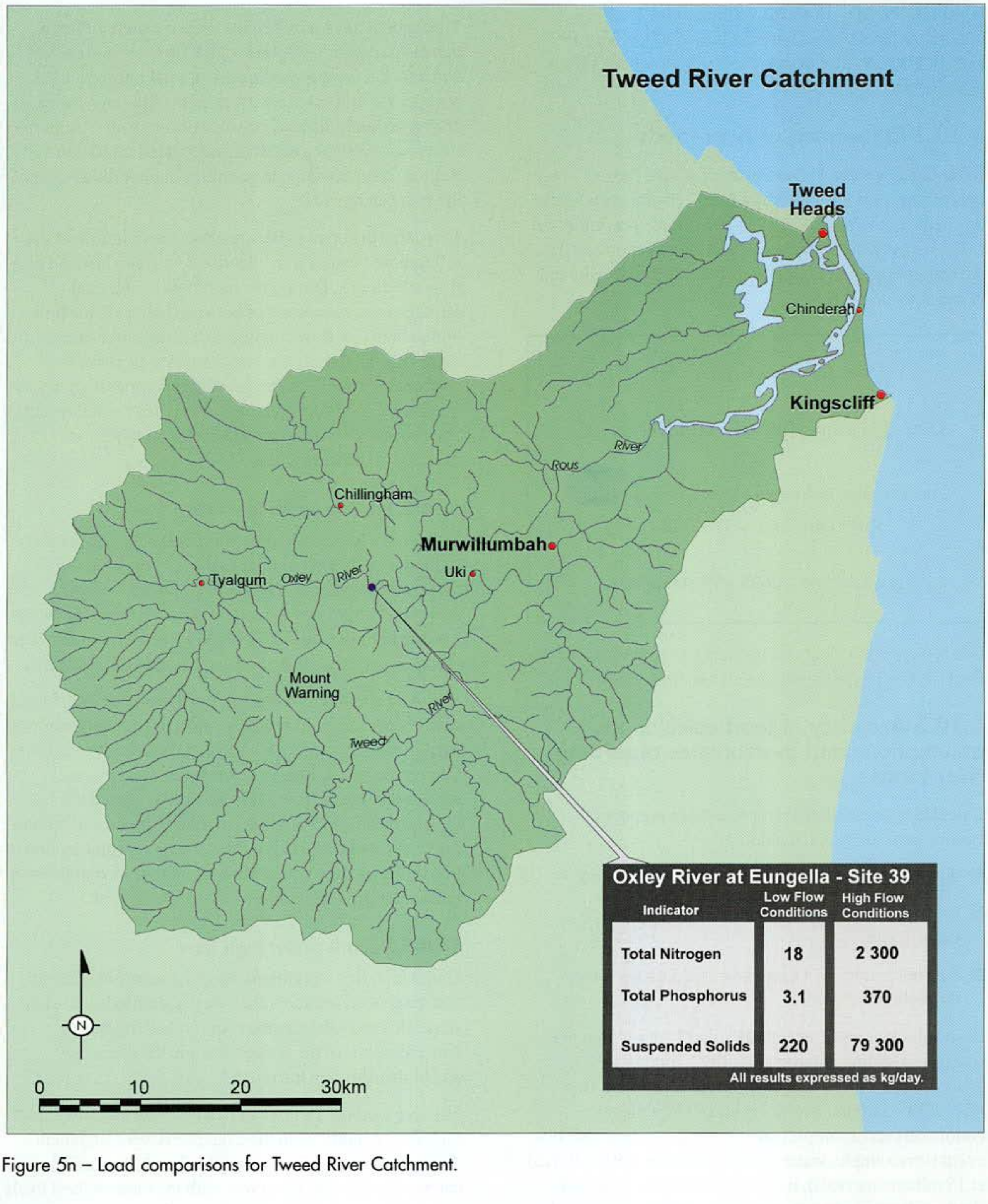
5.10.5.2 Loads under high flow

Under high flow conditions, large increases in nutrient and suspended sediment load were identified at all eight sites. This increase was the result of both higher concentrations of these substances in the water, and higher flows in the rivers.

Massive loads of all three indicators were identified under high flow conditions in the Clarence River Catchment. A general pattern of increasing load with increasing catchment area was observed, with the three highest loads for each indicator being observed in this catchment.

Tweed Catchment

The Oxley River at Eungella drains an area of 213 km^2, the majority of which is cattle pasture. The high flow loads calculated for the three indicators are likely to significantly underestimate the maximum daily load during this rain event, as flow in the Oxley River did not peak until the following day. Despite this, a very large increase in river load was detected at the site, with over 300 times the low flow load of suspendid solids being transported under high flow conditions.



Oxley River at Eungella - Site 39

Indicator	Low Flow Conditions	High Flow Conditions
Total Nitrogen	18	2 300
Total Phosphorus	3.1	370
Suspended Solids	220	79 300

All results expressed as kg/day.

Figure 5n – Load comparisons for Tweed River Catchment.

Brunswick Catchment

Draining an area of 34 km^2, sampling at this site showed an extremely large increase in load from low to high flow conditions. The amount of nitrogen being moved down the river increased by about 2 000 times, while phosphorus and suspended sediment loads were around 10 000 times higher under high flow conditions compared to low flow conditions.

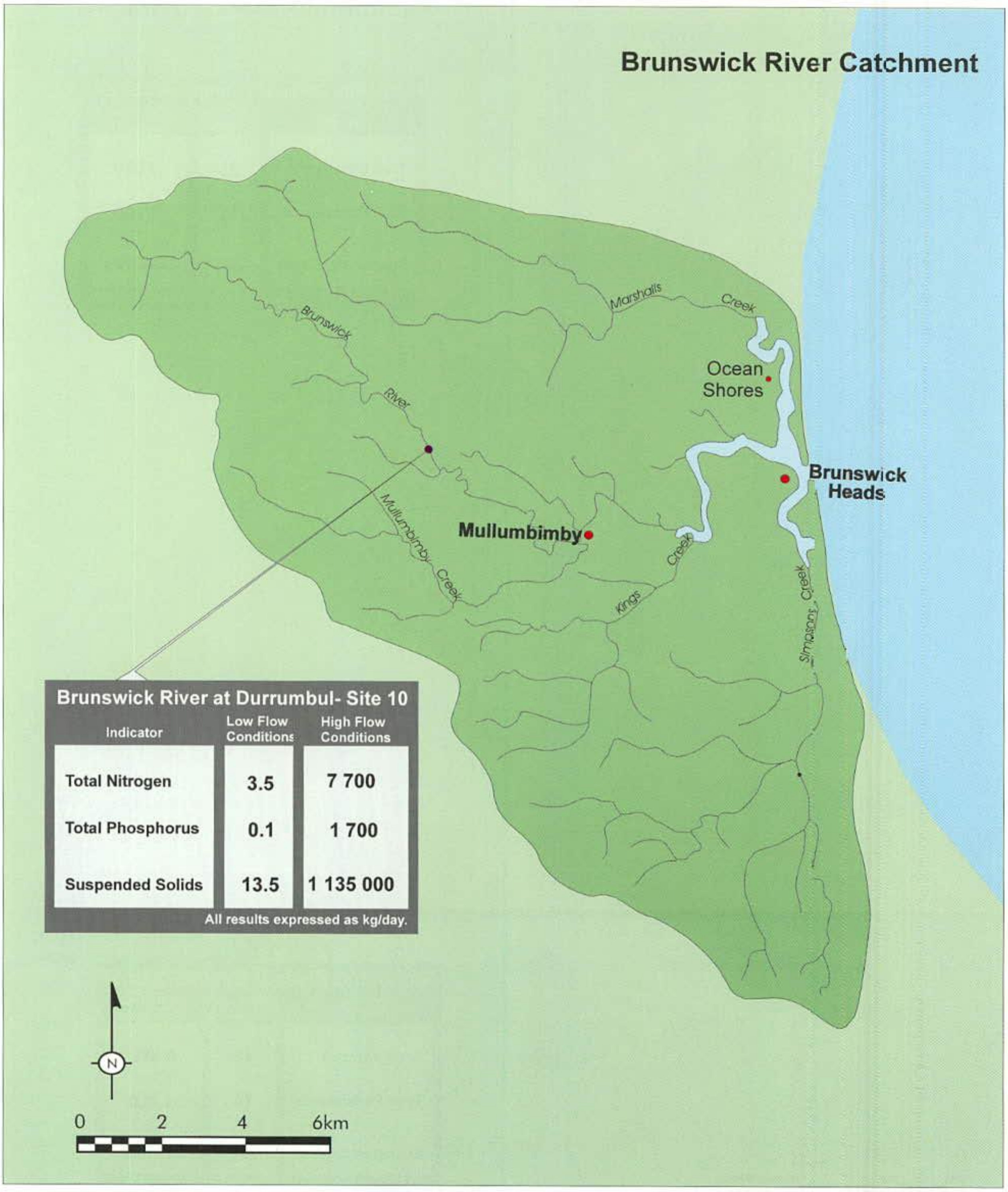
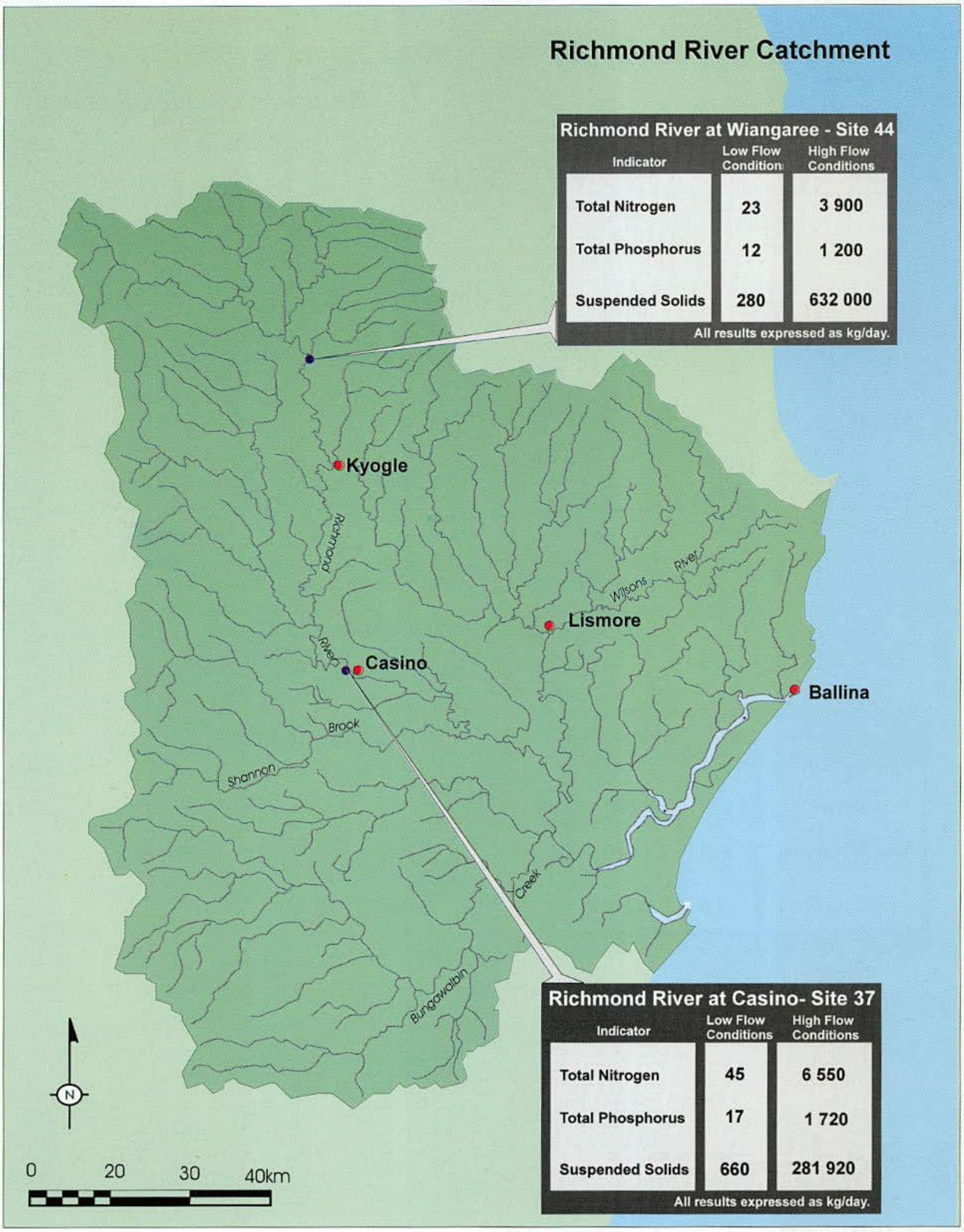


Figure 5o – Load comparisons for Brunswick River Catchment.

Richmond Catchment

Loads were calculated for the Richmond River at Wiangaree and Casino. At Wiangaree, the river drains an area of 702 km^2, with this area increasing to 1 790 km^2 at Casino. Large increases in the load of all three indicators were apparent between low and high flow, however these differences were not as extreme as at the Brunswick River site. Since these samples were collected after the peak flow in the river, it is likely that the load estimates given will be significantly lower than the peak daily load transported by the river during this rain event.



Richmond River at Wiangaree - Site 44

Indicator	Low Flow Condition	High Flow Conditions
Total Nitrogen	23	3 900
Total Phosphorus	12	1 200
Suspended Solids	280	632 000

All results expressed as kg/day.

Richmond River at Casino- Site 37

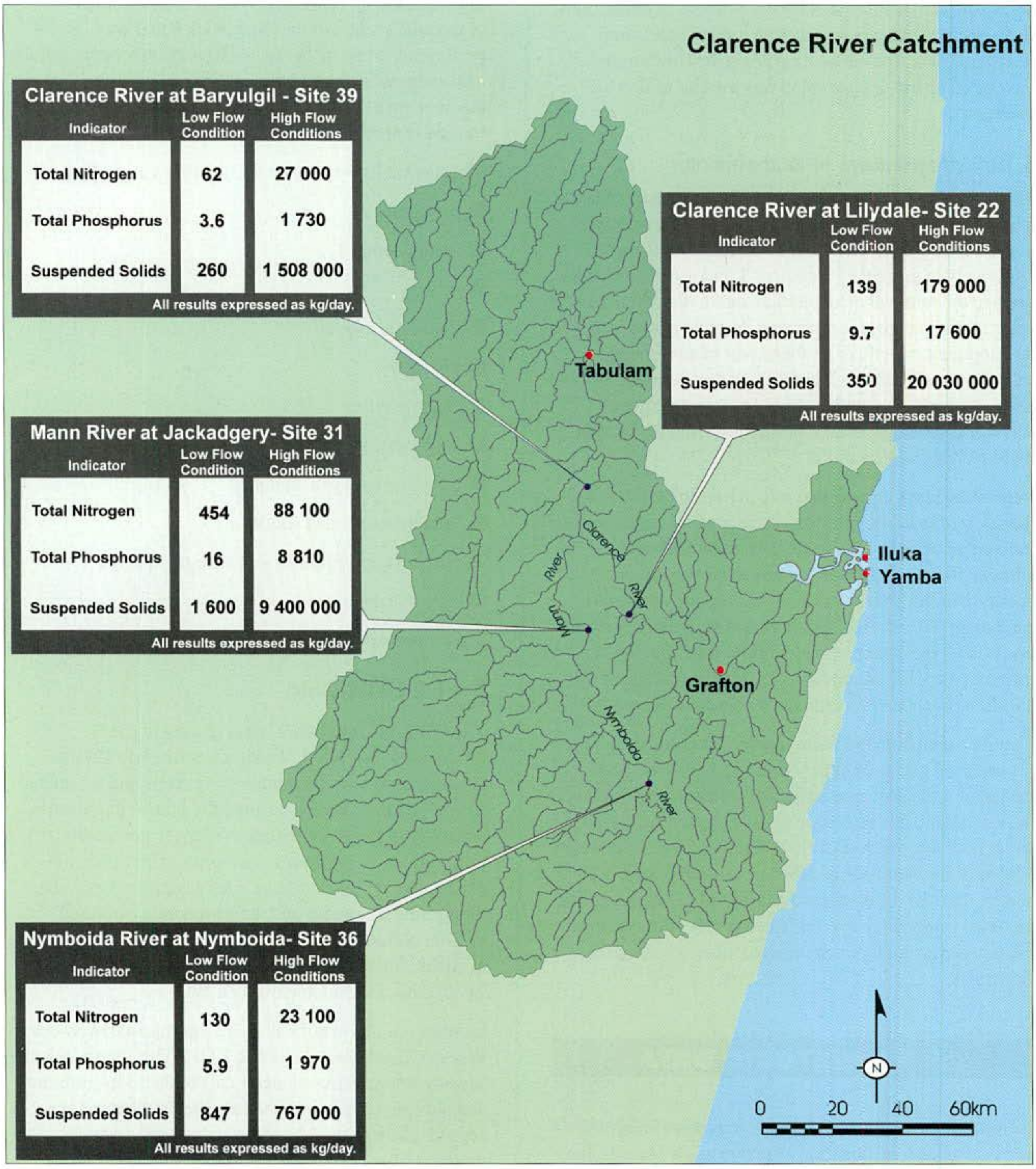
Indicator	Low Flow Conditions	High Flow Conditions
Total Nitrogen	45	6 550
Total Phosphorus	17	1 720
Suspended Solids	660	281 920

All results expressed as kg/day.

Figure 5p – Load comparisons for Richmond River Catchment.

Clarence Catchment

River flow and water quality information was available for four sites in this catchment. Large increases in the river load of the three indicators were identified at all sites, with over 9 000 tonnes of suspended sediment moving past the Mann River at Jackadgery (catchment area 7 800 km^2). Data collected from the Clarence River at Lilydale (catchment area of 16 690 km^2) provides the largest difference between low and high flow loads in the catchment, with a massive increase in suspended solids load under high flow conditions.



Clarence River at Baryulgil - Site 39

Indicator	Low Flow Condition	High Flow Conditions
Total Nitrogen	62	27 000
Total Phosphorus	3.6	1 730
Suspended Solids	260	1 508 000

All results expressed as kg/day.

Clarence River at Lilydale- Site 22

Indicator	Low Flow Condition	High Flow Conditions
Total Nitrogen	139	179 000
Total Phosphorus	9.7	17 600
Suspended Solids	350	20 030 000

All results expressed as kg/day.

Mann River at Jackadgery- Site 31

Indicator	Low Flow Condition	High Flow Conditions
Total Nitrogen	454	88 100
Total Phosphorus	16	8 810
Suspended Solids	1 600	9 400 000

All results expressed as kg/day.

Nymboida River at Nymboida- Site 36

Indicator	Low Flow Condition	High Flow Conditions
Total Nitrogen	130	23 100
Total Phosphorus	5.9	1 970
Suspended Solids	847	767 000

All results expressed as kg/day.

Figure 5q - Load comparisons for Clarence River Catchment.

The relationship between increasing catchment area above the site and increasing high flow load was generally supported, except for Casino (site 37 on the Richmond River), and the Tweed River site. Total nitrogen and suspended solids loads at Casino were significantly lower than those at Wiangaree (site 44). The Brunswick River Catchment did not fit this pattern, with loads for the three indicators being significantly higher than for sites with larger catchment areas such as Durrumbul (site 39 in the Tweed River Catchment) and Wiangaree (site 44 in the Richmond River Catchment). Considering the results in terms of the size of the catchment above the site, nutrient and suspended solids loads for the Brunswick River site were around ten times higher than for any other site. Very high river flow at the time when the Brunswick River Catchment was sampled was a major reason for this result.

5.10.5.3 Implications of load estimates

The link between high rainfall and the movement of large quantities of material from the catchments is essential to understanding how a catchment functions, and how to effectively manage the catchment. Land use practices that involve the removal of vegetation and/or disturbance of soils, including cropping, grazing, logging and urban development, will increase the export of suspended sediments and nutrients from the catchment during heavy rainfall events. Any material added to the catchment surface, such as fertiliser or pesticides, will also be more mobile under heavy rainfall.

Vegetation plays an essential role in limiting erosion and transport of material from the catchment, slowing the movement of water across the catchment surface, allowing for increased infiltration and lower erosion energy. Modification of natural vegetation systems in a catchment will alter the sediment and nutrient export levels from the catchment. High flow water quality information is important for assessing the sustainability of different land use techniques within the catchment.

To understand both the water quality conditions experienced in the catchment during most of the year, and the larger scale processes affecting water quality within the catchment, it is important to investigate water quality under both low and higher flow regimes. This comparison of results has demonstrated the large differences in water quality that can occur under differing flows, and sampling focussed solely on one or the other of these flow regimes will not form a total picture of water quality within the catchment.

5.11 HISTORIC DATA

Historic water quality data for the catchments presented in this chapter were obtained from two major sources; the former Department of Water Resources (DWR), now the Department of Land and Water Conservation (DLWC), and the former State Pollution Control Commission (SPCC) now the Environment Protection Authority (EPA).

5.11.1 SPCC Water Quality Studies

In the mid 1980s the SPCC conducted a series of water quality surveys of the Northern Rivers of NSW, focusing particularly on the estuarine and tidal reaches of the catchments (SPCC 1987a, 1987b, 1987c, 1987d). The broad aim of these studies was to develop a database containing information on water quality within the North Coast. Ten surveys were performed in both the Richmond and Clarence catchments. These were designed to test water quality under specific flow conditions. A further 17 surveys of the Clarence River were conducted at regular intervals, irrespective of flow conditions. A single survey of the tidal section of the Brunswick River was performed, while in the Tweed River Catchment a number of surveys were designed to investigate water quality and the movement of effluent discharged by local sewage treatment plants.

Measurements were made for the following indicators -

- temperature
- secchi depth
- salinity
- dissolved oxygen
- turbidity
- chlorophyll-a
- suspended solids
- biological oxygen demand
- volatile suspended solids
- nutrients - phosphorus and nitrogen species
- euphotic depth

The complete SPCC data set is available from the EPA.

5.11.2 DWR Data

The DWR has monitored water quality in rivers throughout New South Wales since the early 1970's. A wide range of water quality parameters and associated river flows have been measured for a range of purposes and under a variety of regimes. While water quality information was collected state-wide at 700 sites, the period over which particular sites were monitored, the monitoring frequency and the parameters measured varied enormously. Some historical water quality data are available for about 110 sites in the Audit Region. These data are available from DLWC.

Elements of this historic data are summarised in Sweet Water or Bitter Legacy (DWR 1991). This report includes statistical summaries of electrical conductivity, turbidity and phosphorus (considered to be key indicators) at around 90 sites throughout the state. It also contains graphical data presentations and colour coded maps summarising the three indicators listed above. This information formed the basis of the current Key Sites Program, in which 89 flow gauged river sites are monitored regularly for electrical conductivity (salinity), phosphorus and turbidity. The recently released report Window on Water, The State of Water in NSW 1993/1994 (Daly et al. 1995) provides an update to the previously published work.

5.11.3 Historic data comparison

Of the 89 sites that make up the DLWC's Key Sites Program, six are located in the Audit Region. Five of these sites were also investigated as part of the SPCC's water quality studies, and all six sites have been monitored by the EPA as part of this Audit. The sites are listed in table 5h, together with a brief site description.

5.11.3.1 Procedure

Water quality data at each site was partitioned in two groups, data collected under low flow conditions, and data collected under high flow conditions. In some cases no high flow data was available. For each flow category, the results at each site for each indicator were averaged. Table 5i provides summary information on the data used in the comparison.

TABLE 5H - DWR SITES AND CORRESPONDING EPA AUDIT SITES (THE LETTER PRECEDING THE SITE NUMBER REFERS TO THE CATCHMENT).

EPA	SPCC	DWR	Site Description
T39	190*	201001	Oxley River: Eungella
R37	240#	203004	Richmond River: Casino
R23	210*	203014	Wilsons River: Eltham
C36	---	204001	Nymboida River: Nymboida
C22	260	204007	Clarence River: Lilydale
C26	241	204041	Orara River: Bawden Bridge

Notes: * indicates that this was the SPCC site closest to the DWR site.

# indicates that data from sites 240, 242 and 244 was used in the analysis, due to the small amount of data collected from each site.

5.11.3.2 Data quality

Data collected over long time periods provides a large scope for changes in the quality of the data. Changes in sample handling and storage procedures, equipment precision and accuracy, analytical methods and data handling procedures may result in data variability that masks any changes to the water quality in the catchment.

The DWR data set used in this comparison includes a measure of the quality of each data point for each site. All DWR data used in this comparison was identified as either "data quality unknown", "data not yet quality coded", or "data not yet checked". A brief analysis of the total phosphorus dataset revealed 24 of the 202 records (12%) for the period, to be obvious outliers and apparently errors, and were omitted from the comparison. However, other poor quality data points may be included in this dataset, and will therefore influence the outcome of the comparison.

Data collected for the SPCC included claims of some quality control data, however this has not been reported, and is no longer available. A visual check of the data identified occasional data points that were obvious anomalies.

In compiling the EPA dataset for this Audit, quality control procedures were in place covering the water sampling, analysis and data handling aspects of the data.

NRAC provided funds to assist a project by the Environment Protection Authority of NSW to produce a status report on the water quality in the Tweed, Brunswick, Richmond and Clarence Rivers.

A Data Quality Statement and Executive Summary for this project (S2) The Northern Rivers - A Water Quality Assessment, are presented at the end of this volume.

TABLE 5I - SUMMARY INFORMATION FOR DATA USED IN HISTORIC COMPARISON

Dataset	T39	R23	R37	C22	C26	C36	Sample Collection Period
EPA Low Flow Data	4	6	7	6	7	7	May 1994 - May 1995
EPA High Flow Data	1	0	1	1	1	1	May 1994 - May 1995
SPCC Low Flow Data	8	3	4	2	2	0	November 1983 - April 1986
SPCC High Flow Data	0	1	3	2	1	0	November 1983 - April 1986
DWR Low Flow Data	133	89	67	81	77	47	April 1970 - June 1995
DWR High Flow Data	6	10	4	3	2	4	April 1970 - June 1995

Note - Number of data points indicates the maximum number. For different indicators the actual number may be less.

5.11.3.3 Results

Results for electrical conductivity, turbidity and phosphorus concentrations from the three water quality projects are compared in figure 5r. It is clear from this comparison that the results from the three projects are in general agreement at most sites. A detailed quantitative analysis of the results has not been attempted, as the bulk of the dataset is of unknown quality.

Electrical conductivity was consistent among the three data sets, during both low flow and high flow conditions.

Low flow turbidity readings at the six sites also showed some consistency among the three data sets, however the DWR readings for Eltham (site 23 in the Richmond River Catchment) and the lower Orara River (site 26 in the Clarence River Catchment) were significantly lower than the SPCC data and the data presented in this Audit. Under high flow conditions large variations between the data sets were apparent. Measurements from the lower Orara River (site 26) and the Clarence River at Lilydale (site 22) show data from this Audit far exceeding the results for the previous two studies.

Results for total phosphorus concentrations also showed some variability between the studies, particularly at Eltham (site 23) and Casino (site 37) in the Richmond River Catchment. Variability at other sites was also apparent, although not as pronounced.

5.11.3.4 Discussion and Implications

These comparisons show a general agreement among the three datasets for the measures of electrical conductivity, turbidity and total phosphorus. Similarity between the different datasets is better under low flow conditions than for high flow. This is understandable considering that few measurements (often only one) were available under high flow conditions.

The results and discussion presented in section 5.9 demonstrated how significant amounts of material were exported from the catchment under high flow, and that water chemistry changed significantly during this period. These findings are reinforced by this comparison of historic data, with large differences between the low and high flow results being reported in most cases.

Given an understanding that the flow regime is a major determining factor of water quality at any particular time, the use of routinely collected measures of water quality to determine time trends in Australian river systems is, at best, of very limited value. Comparisons through time need to be made with data collected under very similar flow regimes - a circumstance hard to identify in datasets of measurements made every few weeks. Varying flow contributions from different parts of large catchments can also give a false impression of a time trend at a particular monitoring site. For these reasons, and the large uncertainty about the quality of historic data, there has been no attempt to examine water quality changes through time in the Audit Region.

Another observation is that measurements that are made semi-routinely, as distinct from a strict routine, will tend to be biased away from high flow information. This is explainable because, if there is a choice, field staff will tend to make measurements and collect samples when the weather is fine and roads are not flooded. This bias is demonstrated in the DWR dataset for Durrumbul on the Oxley River (site 39 in the Tweed River Catchment). For observations of electrical conductivity, six records were collected under high flow conditions, out of a total dataset of 139 records. However, the ten percent probability of flows in the river being "high flow" suggests that closer to 14 high flow samples would be more representative of the situation.

Estimating the amount of material exported from a catchment is often a fundamental part of water quality assessment and catchment management planning. For this to be achieved, high flow events need to be specifically targeted in any water quality sampling strategy.

5.12 REGIONAL WATER QUALITY ISSUES

5.12.1 Dissolved oxygen

Dissolved oxygen is the gaseous oxygen that is contained in water. Since dissolved oxygen is fundamental to the health of aquatic ecosystems, it is important that accurate measurements are made.

There are two main methods for oxygen to be dissolved in water: from the atmosphere, including turbulence in rapid flowing streams and waterfalls, and through aquatic plants releasing oxygen directly into the water. Dissolved oxygen may be removed from water by decaying organic matter or by consumption by aquatic animals and plants when it is dark.

5.12.1.1 The Importance of dissolved oxygen

Nearly all animals that live in the water rely on dissolved oxygen to breathe. For example, fish use gills to get dissolved oxygen from the water. Just as humans find it difficult to breathe when the amount of oxygen in the atmosphere falls (such as at high altitudes), low levels of dissolved oxygen make breathing difficult for aquatic animals. This can interfere with their feeding and reproductive activities, and promote disease. In extreme cases, animals may die through lack of oxygen in the water.

5.12.1.2 Variations in dissolved oxygen

Dissolved oxygen may vary at a site over time (figure 5s). Changes in dissolved oxygen have both natural and human causes. In figure 5s, the majority of the change was from plants stimulated by sunlight to produce oxygen during the day, while lower temperatures and oxygen consumption resulted in reduced levels of dissolved oxygen during the night.

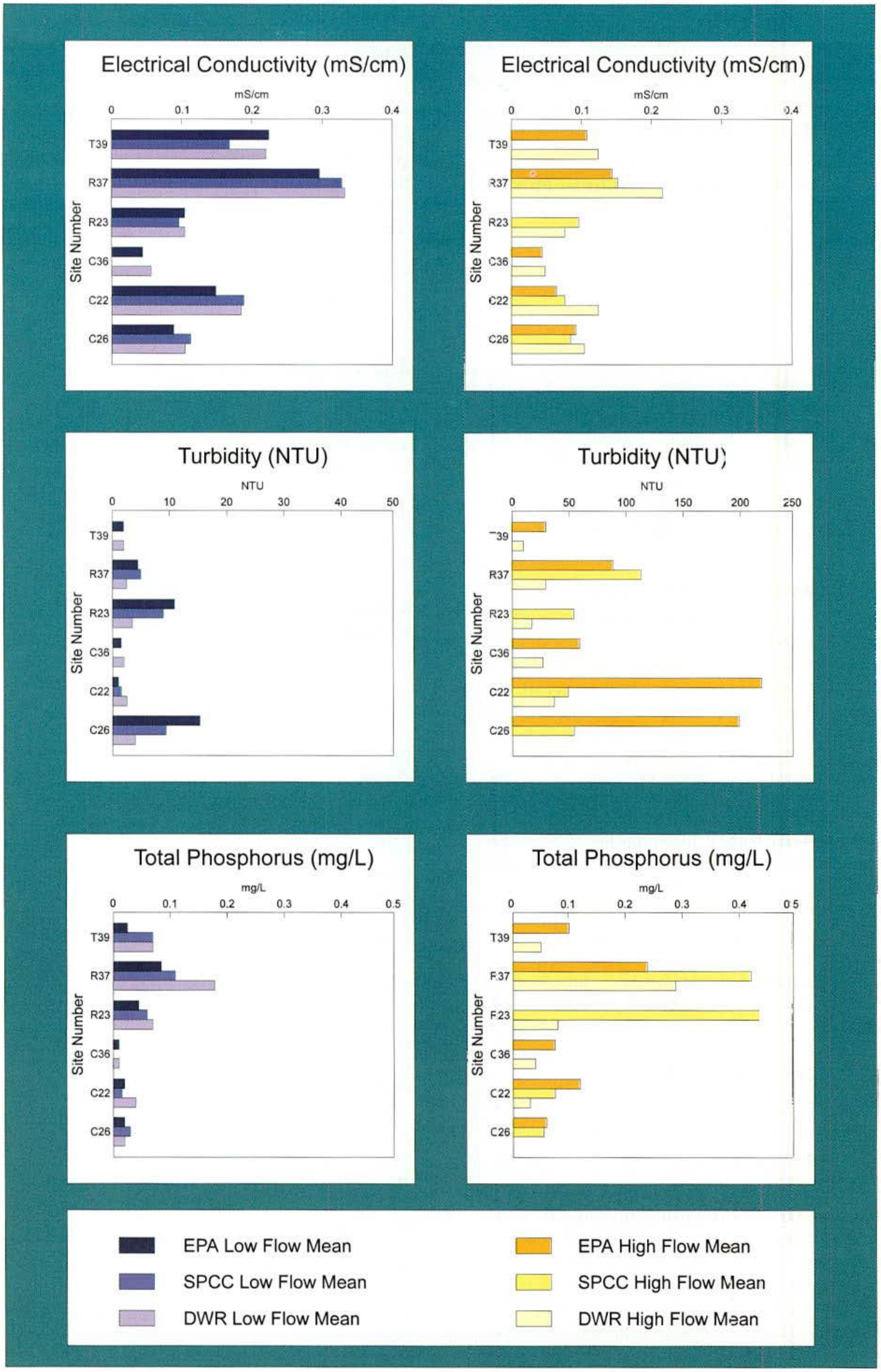


Figure 5r: Comparison of low flow and high flow data from EPA, SPCC and DWR databases

This is not always the case; for example, water with a high organic material content, such as from abattoirs, will consume dissolved oxygen. Water runoff from acid sulphate soil areas may also have extremely low dissolved oxygen levels, while algal blooms (natural or human induced) will cause wild fluctuations in dissolved oxygen.

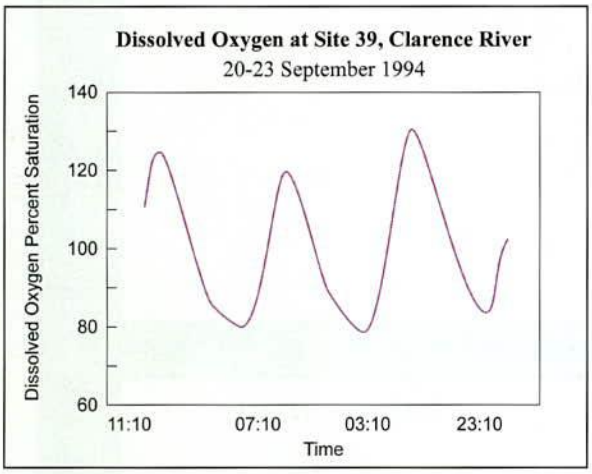


Figure 5s Dissolved oxygen at Site 39, Clarence River

5.12.1.3 Measuring dissolved oxygen

Since the amount of dissolved oxygen in rivers often changes throughout the day, it is important that sample collection reflects what is happening in the river. For the graph in figure 5s, samples were collected every six minutes for three days. This graph shows very clearly the dissolved oxygen changes that were occurring in the river. Fortunately , this amount of sampling is not always necessary for oxygen measurement.

The Australian Water Quality Guidelines for Fresh and Marine Waters recommend measuring dissolved oxygen over at least a 24 hour cycle. However, the most important aspect of dissolved oxygen is the minimum value reached, and in most rivers this usually occurs after it has been dark for several hours but before morning light. With oxygen levels reaching their lowest levels at around the same time in all rivers, just a few samples at the right time are usually sufficient to determine if dissolved oxygen is meeting the criteria.

5.12.2 Acid sulphate soils

A detailed discussion of acid sulphate soils is contained in volume 2, chapter 5 Soils, including a map of potential acid sulphate soils along the coast of the Audit Region.

The term acid sulphate soils is used to describe soil profiles or layers which are characteristically very acidic (pH<3.5) because they contain more iron pyrite than can be neutralised by surrounding sediments. These soils have occurred naturally through much of the earth's geological history due to normal biophysical processes. They occur on floodplains and in estuarine areas throughout the world and are found around most of the Australian coastline. They are a particular problem in locations with pronounced dry seasons, high temperatures and high intensity rainfall events.

5.12.2.1 Formation of acid sulphate soils

Iron pyrite remains stable when permanently below the water table, free from contact with atmospheric oxygen. In this environment it is harmless, but can be regarded as a potential acid sulphate soil. When oxygen in the air comes into contact with the pyrite a chemical reaction takes place, producing sulfuric acid and soluble iron. The soil is then classed as an acid sulphate soil. This process may occur naturally, for example during periods of drought when falling water tables allow oxidation of pyritic material. In some areas this process has been exacerbated by human activity.

5.12.2.2 Influence of human activities

The magnitude, frequency and duration of acid events have been modified by human activities. Changes in land use can greatly accelerate the process of acid soil formation. Major problems have developed where large areas of land have been drained, the water table has dropped and pyritic sediments have come into contact with oxygen. Similarly, exposure of pyritic sediments by excavation has promoted the formation of acidic soils.

5.12.2.3 Acid sulphate soils and the wider environment

Environmental problems associated with acid sulphate soils develop after significant rainfall events when groundwater and surface run-off transport acid water into rivers and streams. Rapid changes in water quality, particularly the level of acidity, often cause fish kills and disease. Aquatic ecosystems are threatened by the soluble iron and aluminium produced as acid leaches these metals from the soil. These are generally toxic to plants and animals. The environment is also subject to indirect effects, such as habitat destruction and lost spawning opportunities. Unfortunately these impacts are less widely acknowledged, and the recovery of a system is often assumed as soon as fish reappear.

5.12.2.4 Control of acid sulphate soils

There are ways of reducing the impact of land use on the development of acid sulphate soils, in order to minimise the degradation of natural resources. Preventing the oxidation of potential acid sulphate soils will reduce the chance of acid sulphate events occurring. This can be achieved by careful management of the water table and by returning excavated pyritic material to an oxygen-free environment (for example, by burial). If acid sulphate soils have already developed, they may by neutralised by lime application.

5.12.3 Pesticides

Pesticides are chemical compounds used to kill or disrupt the life cycle of living organisms which are regarded by humans as 'pests'. Pests may be bacteria, fungi, insects, plants or animals.

5.12.3.1 Use of pesticides

Agricultural enterprises are major users of pesticides in the Upper North-East Region and they use chemicals mostly to control fungus (fungicides), insects (insecticides) and weeds (herbicides). Other activities such as building (timber preservation and termite control) and non-agricultural weed control also utilise significant quantities of pesticides. Estimates of the quantities of various broad categories of pesticide used in each of the four river catchments are shown in table 5j.

TABLE 5J - ESTIMATES OF PESTICIDE USE IN THE AUDIT REGION, BY CATCHMENT.

Catchment	Insecticide (tonnes/year)	Fungicide (tonnes/year)	Herbicide (tonnes/year)
Tweed	12	7	14
Brunswick	3	10	3
Richmond	27	121	40
Clarence	13	151	18

Throughout the whole Region the most highly used particular chemicals and their usage rates are: chlorpyrifos (27 t/yr), heptachlor (13 t/yr), endosulfan (nine t/tr), copper-chrome arsenate (190 t/yr), copper oxychloride (85 t/yr), glyphosate (20t/yr), atrazine (14 t/yr), paraquat (13 t/yr) and diuron (12 t/yr).

5.12.3.2 The effect of pesticides on water

Pesticides can enter waterways by intentional application on or near waterways, unintentional spray drift during application on land, spillage, improper disposal of used pesticide containers or as direct wash-off from an area which has been treated. The actual fate of a particular pesticide depends on its inherent properties as well as how, where and when it is used. Most pesticides are not very soluble in water, and are usually attached to soil particles or sediment in the river.

5.12.3.3 Pesticides in the aquatic environment

Most of the past monitoring for pesticides in the aquatic environment of the Upper North East Region has focussed on the persistent organochlorine pesticides. Because of this persistence and their tendency to accumulate in non-target organisms, these compounds have now been withdrawn from the market or are being phased out. Of about 15 studies/investigations of pesticides in the aquatic environment conducted since the 1980s, only one incident of higher than acceptable levels has been identified. This concerned contaminated fish in the Coffs Harbour area in the late 1980s.

5.12.3.4 Monitoring pesticides

While there is little evidence of pesticides being a serious problem in the waterways of the Upper North East Region, some environmental surveillance is desirable. Because of the many and variable factors which influence what pesticides may enter waterways, routine monitoring of pesticides on a broad scale will probably not detect episodes of contamination. These are likely to be relatively localised and sporadic. An effective monitoring strategy would need to take into account the local past and present usage patterns of particular pesticides, and target these for surveillance during application periods.

5.13 REGIONAL INITIATIVES

Efforts have been made at a number of levels to address water quality issues in the northern rivers. Local councils, Catchment Management Committees and Streamwatch groups have been particularly active in this process. Regional information relevant to water quality studies can be obtained from each of these

5.13.1 Local councils

The State of the Environment Reports prepared by local councils within the Audit Region consider water quality issues within their local government areas. In their 1993/94 publications the majority of councils reported a lack of water quality data and highlighted the need to establish reliable monitoring programs Many of them have already identified potential threats to water quality within their catchments. The main risks identified were associated with -

- urban runoff and residential waste
- agricultural runoff
- industrial runoff and trade waste
- discharge from sewage treatment plants
- contaminated sites, particularly cattle dip sites
- acid water from soils
- landfill leachate
- erosion and sedimentation

In most cases, further investigation of these factors was deemed necessary. It is anticipated that results from this study will shed some light on the problems already identified and point to areas requiring further attention.

5.13.2 Catchment Management Committees and Streamwatch groups

Three Catchment Management Committees presently exist within the Upper North East Region - the Tweed Catchment Management Committee, the Richmond Catchment Management Committee and the Clarence Catchment Management Committee. All three have identified the need to maintain and enhance water quality within their catchments. As a result specific goals have been set, together with a list of strategies and proposed actions. These are designed to coordinate community and government groups in order 'to ensure that water of appropriate quality is available for sustainable community needs and protection of natural systems' (Clarence CMC 1994).

A number of schools in the Region participate in Streamwatch activities, monitoring rivers and streams of local interest. The groups test weekly or fortnightly for nine water quality parameters. These are

- dissolved oxygen
- nitrates
- faecal coliforms
- total dissolved solids
- temperature
- phosphates
- biochemical oxygen demand
- pH
- turbidity

In fresh water areas chemical water testing is supplemented with macro-invertebrate monitoring.

Data collected by Streamwatch groups is entered and stored in a state-wide database. Information can be extracted from this using the Keylink program, or can be obtained directly from participating schools.

5.14 CONCLUSION

The sampling program has been successful in obtaining current water quality information for the Tweed, Brunswick, Richmond and Clarence river catchments. Through analysis of the data collected for this Audit, and the use of historic data, this chapter has addressed its four key objectives.

The Australian Water Quality Guidelines for Fresh and Marine Waters (ANZECC 1992) were used as the basis for assessing the water quality data obtained from both routine sampling during low river flows and a single high flow event. Through the assessment of water quality at each site, local and regional patterns of water quality have been identified. High flow water quality was examined at the regional scale only, due to a reduced data set.

At a catchment level, water quality in the Clarence River Catchment was superior to that identified in the other three catchments. The Tweed River Catchment, while exhibiting poorer water quality than the Clarence River Catchment, showed an overall result significantly better than the Brunswick River Catchment. The Richmond and Brunswick catchments showed the worst water quality in the Audit Region, with excess nutrient levels, high bacteria concentrations and poor clarity the cause of many of the low ranks. In all catchments, tidal flushing was suggested as contributing to the observed pattern of water quality improving toward the mouth of the estuary.

Local causes of lower water quality were also suggested for some sites.

The major reasons for poor results were generally consistent at a regional level. Bacterial indicators were observed at excess levels in the categories of potable water, primary contact recreation and edible seafood. Water clarity was also a significant reason for failure in primary contact recreation, while high suspended solids and nutrient concentrations, and low dissolved oxygen, were the dominant causes of failures in aquatic ecosystem protection. A combination of indicators resulted in the failures observed in irrigation, sodium adsorption ratio and salinity, and stock water, pH and salinity. Secondary contact recreation showed the best overall ranking of any category.

River load estimates were provided for eight sites in the study area, under both low and high flow conditions. These results identified an enormous change in the mass of material moved by the rivers under higher flow conditions, and demonstrated the importance of water quality data collection during high flow conditions. It was clear from these results that neither routine low flow sampling, nor focused higher flow sampling, will in isolation provide a complete picture of water quality in a catchment.

A comparison of current and historic water quality data confirmed a general concurrence in the data collected during the past 30 years. This comparison also highlighted the importance of targeted high flow water quality sampling in the assessment of catchment water quality.

REFERENCES

ANZECC, 1992, *Australian Water Quality Guidelines for Fresh and Marine Waters*, Australian & New Zealand Environment & Conservation Council, Australia.

Central Mapping Authority of NSW, 1987, *Atlas of NSW*, Central Mapping Authority, Department of Lands, New South Wales.

Clarence Catchment Management Committee, 1994, Strategy plan for key natural resource issues in the Clarence Catchment, Discussion paper, (n.p.) (unpub.).

Coastal Committee of NSW, 1994, *Draft Revised Coastal Policy For NSW*, Coastal Committee of NSW, Sydney.

Daly, H., Martin, V. & Bales, M., 1995, *Window on Water - The State of Water in NSW 1993/1994*, NSW Department of Land & Water Conservation, Parramatta.

Bek, P. & Robinson, G., 1991, *Sweet Water or Bitter Legacy. State of the Rivers - Water Quality New South Wales*, NSW Department of Water Resources, Parramatta, NSW.

EPA, 1995, *The Northern Rivers - A Water Quality Assessment*, NSW Environment Protection Authority, Sydney.

Kachka, A., Simeoni, M., Gillespie, L. & Hickey, C., 1993, *Stormwater Monitoring Project Event Data Report: 4-9 July 1993*, Clean Waterways Programme, AWT Science & Environment, Sydney Water Board, Sydney.

Martin, G.R., Smoot, J.L. & White, K.D., 1992, 'A comparison of surface-grab and cross sectionally integrated stream-water-quality sampling methods', *Water Environment Research*, vol. 64, no. 7, pp. 866-876.

RAC, 1993, *Coastal Zone Enquiry Draft Report 1992*, Resource Assessment Commission, Australian Government Publishing Service, Canberra.

Sinden, G., 1993, Spatial variability and environmental monitoring, Thesis, University of Sydney, (unpub.).

SPCC, 1987a, *Water Quality in the Tweed-Terranora Estuary. Northern Rivers Study No. 1*, State Pollution Control Commission, Sydney.

SPCC, 1987b, *Water Quality in the Brunswick River. Northern Rivers Study No. 2*, State Pollution Control Commission, Sydney.

SPCC, 1987c, *Water Quality in the Clarence River. Northern Rivers Study No. 3*, State Pollution Control Commission, Sydney.

SPCC, 1987d, *Water Quality in the Richmond River. Northern Rivers Study No. 4*, State Pollution Control Commission, Sydney.

SPCC, 1990, *Water Quality Criteria for NSW*. Discussion Paper, State Pollution Control Commission, Sydney.

Packham, G.H., ed., 1969, *The Geology of NSW*, Mercury Press, Hobart.

West, R.J., Thorogood, C., Walford. T. & Williams, R.J., 1985, 'An estuarine inventory for New South Wales, Australia', *Fisheries Bulletin* 2, NSW Department of Agriculture, Sydney.

ACRONYMS

ANZECC – Australia and New Zealand Environment and Conservation Council

CMC – Catchment Management Committee

DLWC – Department of Land and Water Conservation

DWR – Department of Water Resources

RAC – Resource Assessment Commission

SPCC – State Pollution Control Commission

MAJOR CONTRIBUTORS

Author

Graham Sinden, NSW Environment Protection Authority

Reviewer

Dr John Brodie, Great Barrier Reef Marine Park Authority

Other contributors

Geoff Coade, NSW Environment Protection Authority

Tanya Wansbrough, NSW Environment Protection Authority

APPENDICES

2.1 BEACHES COVERED BY THE STATE OF OUR SURF 1993 REPORT

NSW Far North Coast

Fingal Point
Kingscliff
Hastings Point
New Brighton
Brunswick Heads
Byron Bay
Suffolk Park
Broken Head
Seven Mile
Lennox Point
Boulder
Shelleys
Lighthouse
Shark Bay
Chinamens
Snapper Point
Evans Head
Iluka

NSW Mid North Coast

Turners
Yamba Main
McKittricks (Convent)
Pippies
Rubbish Tip
Angourie
Angourie Point
Back Angourie
Woody Bluff
Shelley
Plumbago
Brooms Head
Sandon River
Minnie Water
Diggers Camp
Wooli
Station Creek
Corindi
Arrawarra Head
Mullawarra
Mullaway
Cabins (Darkum)
Safety
Woolgoolga
Hearns Lake
Sandy
Back Sandy
Emerald
Shelley
Moonee
North Sapphire
Campbells
Diggers

Surfrider Foundation Australia 1993, *State of Our Surf Report 1993 Report.*

2.2 ESTUARY INVENTORY

Tweed River and Terranora Broadwater

Estuary type:

River with tributary lakes

Estuary characteristics:

Catchment area: 1 100 km2

Waterway area: 23 km2

Entrance characteristics: twin training breakwaters

Special attributes:

- major tourist area - existing infrastructure capacity for further development
- important ecological area - easily accessible fishing and wildlife
- important commercial fish, prawn and oyster producing estuary
- approximately 85% of NSW sugar cane is grown in the Tweed River flood plain
- significant sand and gravel resources

Cudgen Lake and Creek

Estuary type:

Coastal lake and creek

Estuary characteristics:

Catchment area: 67 km2

Waterway area: 2 km2

Entrance characteristics: Open with twin training breakwaters

Special attributes:

- holiday resort of Kingscliff - lake has low to moderate recreational use
- rutile resources downstream of the Cudgera Creek Bridge (1 km upstream of the entrance) on the seaward shore of the creek
- saltmarsh area
- substantial sugar cane and exotic pine plantations within the catchments

Cudgera Creek

Estuary type:

Creek

Estuary characteristics:

Catchment area: 60 km2

Waterway Area: 0.2 km2

Entrance characteristics: open and untrained

Special attributes:

- popular holiday area
- relatively extensive mangrove stands

Mooball Creek

Estuary type:

Creek

Estuary characteristics:

Catchment area: 125 km2

Waterway area: 0.6 km2

Entrance characteristics: open with twin training breakwaters

Special attributes:

- aquatic bird habitat
- popular camping area

Brunswick River

Estuary type:

River

Estuary characteristics:

Catchment area: 160 km2

Waterway area: 2.9 km2

Entrance characteristics: open with twin training breakwaters

Special attributes:

- important tourist resort
- approximately 0.8 km2 of seagrass meadows
- a commercial fishing port was constructed in 1962

Belongil Creek

Estuary type:

Small river

Estuary characteristics:

Catchment area: 18 km2

Waterway Area: 0.3 km2

Entrance characteristics: intermittently open and untrained

Special attributes:

- highest catchment rainfall of all NSW estuaries (1 850 millimetres per year)
- 30% of catchment is fresh water swamp-aquatic bird habitat
- estuary largely covered by mangroves and saltmarsh beds

Richmond River

Estuary type:

River system

Estuary characteristics:

Catchment area: 6 850 km2

Waterway area: 19 km2

Entrance characteristics: open with twin training breakwaters

Special attributes:

- important tourist area - popular river cruises
- commercial fish producing estuary (138 tonnes per year) - also small oyster producer
- sand extraction resources
- extensive archaeological deposits
- significant waterfowl habitat
- parts of the Broadwater and Boarder Ranges National Parks are in the Catchment

Evans River

Estuary type:

River

Estuary characteristics:

Catchment area: 62 km2

Waterway area: 2.5 km2

Entrance characteristics: open with twin training breakwaters

Special attributes:

- popular holiday resort
- small commercial fishing port - also oyster production

Jerusalem Creek

Estuary type:

Creek

Estuary characteristics:

Catchment area: 43 km2

Waterway area: 0.4 km2

Entrance characteristics: double trained walls, intermittently open

Special attributes:

- 80% of the catchment including the full creek shoreline, is in Burajalong National Park.
- camping is popular in this relatively undisturbed area

Clarence River

Estuary Type:

River

Estuary characteristics:

Catchment area: 22 400 km2

Waterway area: 96 km2

Entrance characteristics: open with twin training breakwaters

Special attributes:

- important tourist resort
- the fishing fleet based in the estuary is the largest in NSW - fish and prawn production is also the largest at over 800 t/yr and 280 t/yr respectively, or 18% and 35% respectively of the total NSW estuarine catch
- second largest estuarine seagrass coverage (19 km2) and extensive mangrove stands - important aquatic bird habitat
- largest of all NSW coastal rivers - flows up to 16 800 m3/s have been recorded at Grafton while the average annual discharge is approximately 3.7 x 106 Ml/yr
- Yuraygir National Park adjoins Wooloweyah Lagoon between Maclean and Yamba
- has been identified as an area for prawn farming

Lake Arragan

Estuary type:

Lake

Estuary characteristics:

Catchment area: 10 km2

Waterway area: 1.1 km2

Entrance characteristics: intermittently open and untrained

Special attributes:

- undisturbed lake and catchment with scenic qualities
- lake foreshore provide good camp
- 90% of the catchment is in Yuraygir National Park

Lake Cakora (lagoon)

Estuary type:

Lake

Estuary characteristics:

Catchment area: 11 km2

Waterway area: 0.3 km2

Entrance characteristics: rarely open

Special Attributes:

- extensive saltmarsh areas

Sandon River

Estuary type:

River

Estuary characteristics:

Catchment area: 109 km2

Waterway area: 1.5 km2

Entrance characteristics: open and naturally trained by two rocky headlands

Special attributes:

- permanently open and navigable entrance supports a small fishing industry
- much of the catchment is in the Yuraygir National Park
- popular amateur fishing

Wooli Wooli River

Estuary type:

River

Estuary characteristics:

Catchment area: 190 km2

Waterway area: 2.8 km2

Entrance characteristics: open with twin training wall breakwaters

Special attributes:

- small but growing tourist resort
- majority of catchment is national park/nature reserve
- intensive spat catching and oyster producing estuary

Redbank River (Corindi River)

Estuary type:

River

Estuary characteristics:

Catchment area: 148 km2

Waterway area: 0.6 km2

Entrance characteristics: open and untrained

Special attributes:

- catchment includes Madams Creek Forest Reserve and part of Yuraygir National Park
- increasingly popular tourist resort
- approximately 2 km2 wetlands adjoins estuary

Arrawarra Creek

Estuary Type:

Small river

Estuary characteristics:

Catchment area: 20 km2

Waterway area: 0.2 km2

Entrance characteristics: intermittently open and untrained

Special attributes:

- good stock of mud crabs

Woolgoolga Lake, Hearns Lake and Moonee Creek

Estuary type:

Small lake and a river

Estuary characteristics:

Catchment area: 25 km2 (Woolgoolga), 9 km2 (Hearns), 40 km2 (Moonee)

Waterway area: 0.3 km2 (Woolgoolga, Hearns and Moonee individually)

Entrance characteristics: intermittently/mechanically opened and untrained (Woolgoolga and Hearns), open and untrained (Moonee)

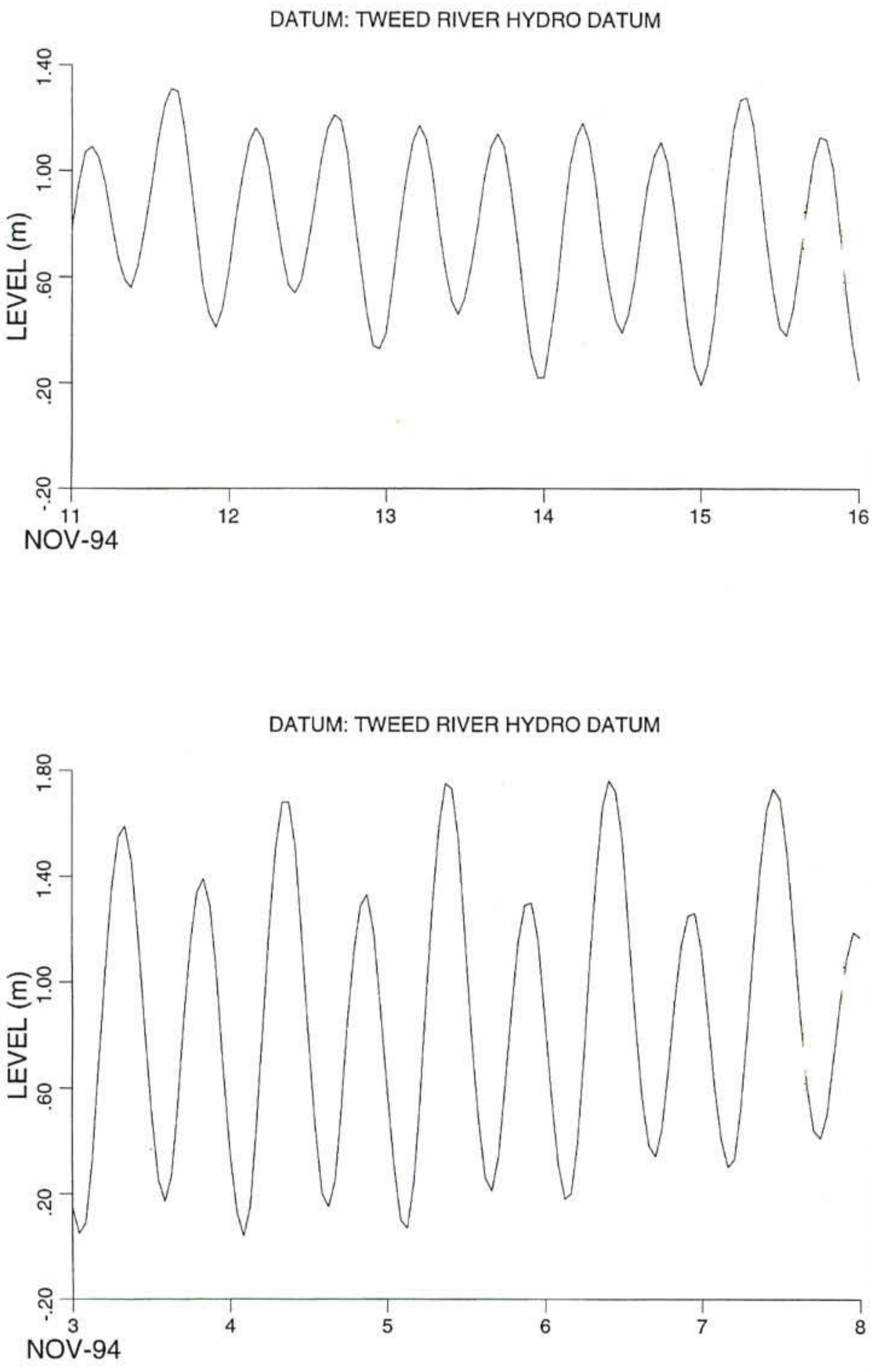
Special attributes:

- Woolgoolga Lake adjoins wetlands - important habitat for aquatic birds. Also minor recreational boating use
- rare stands of White Booyong rainforest within Woolgoolga Creek and the ocean
- Moonee Creek is stocked with fish and mud crabs while Hearns Lake is well known for its king prawns

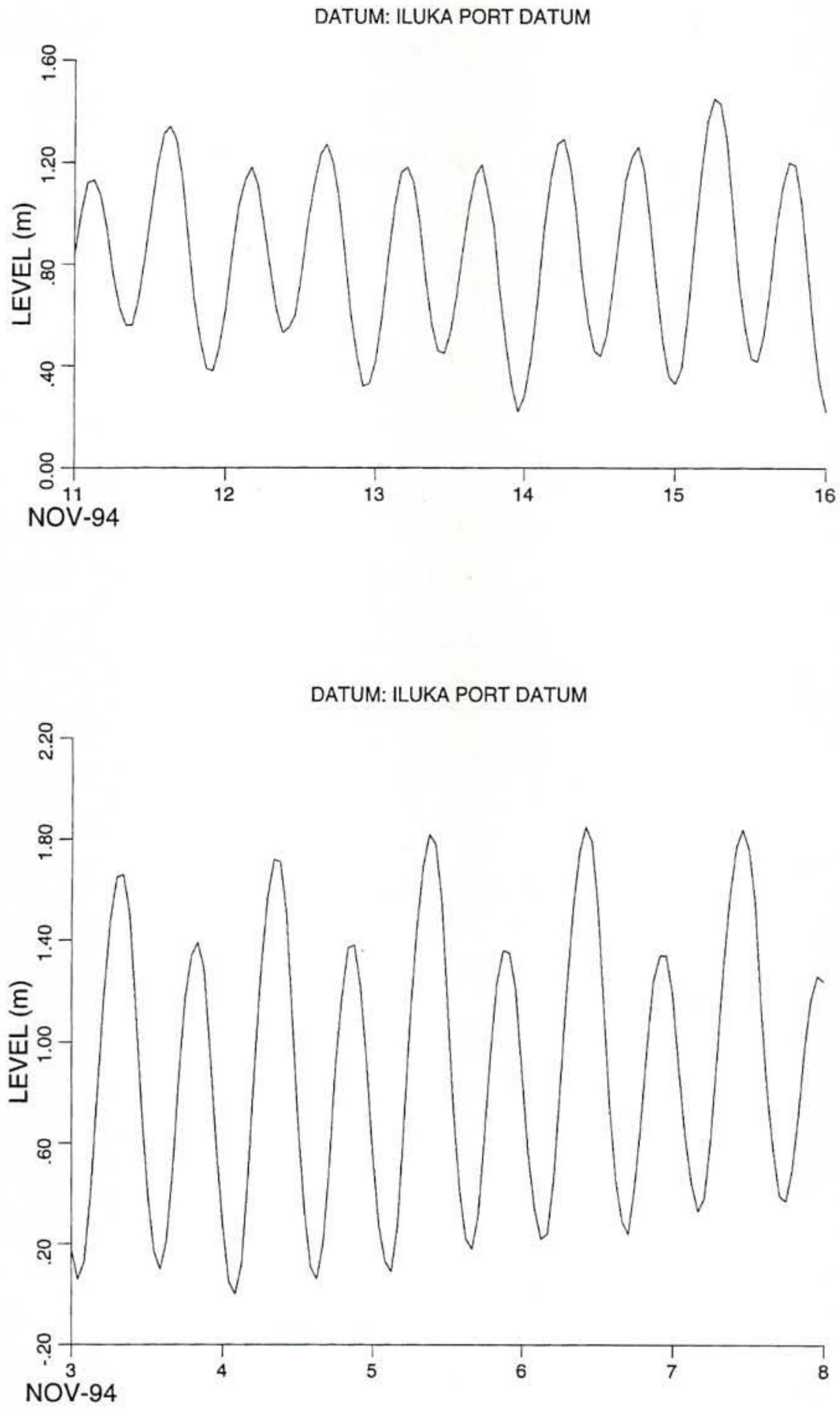
Reference:

NSW Public Works 1992, *Estuary Inventory of New South Wales*, NSW Public Works, Sydney, Internal report.

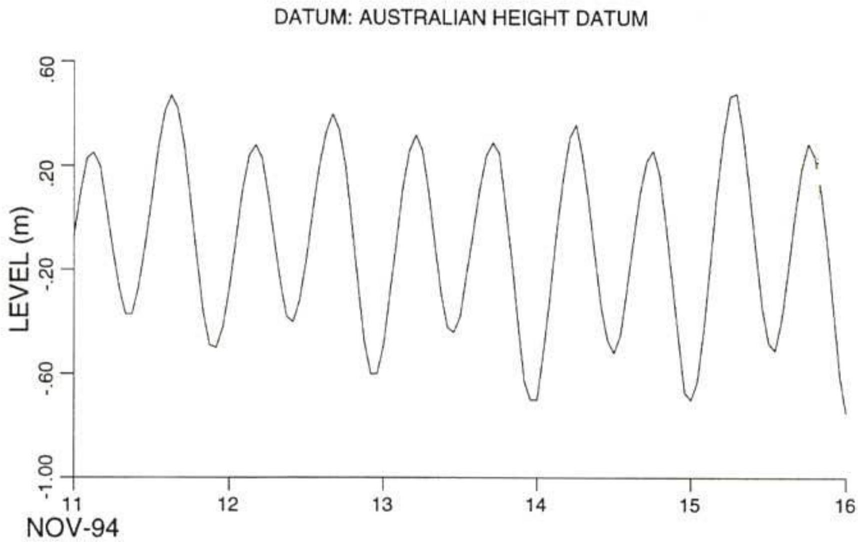
2.3 TYPICAL NEAP AND SPRING TIDES

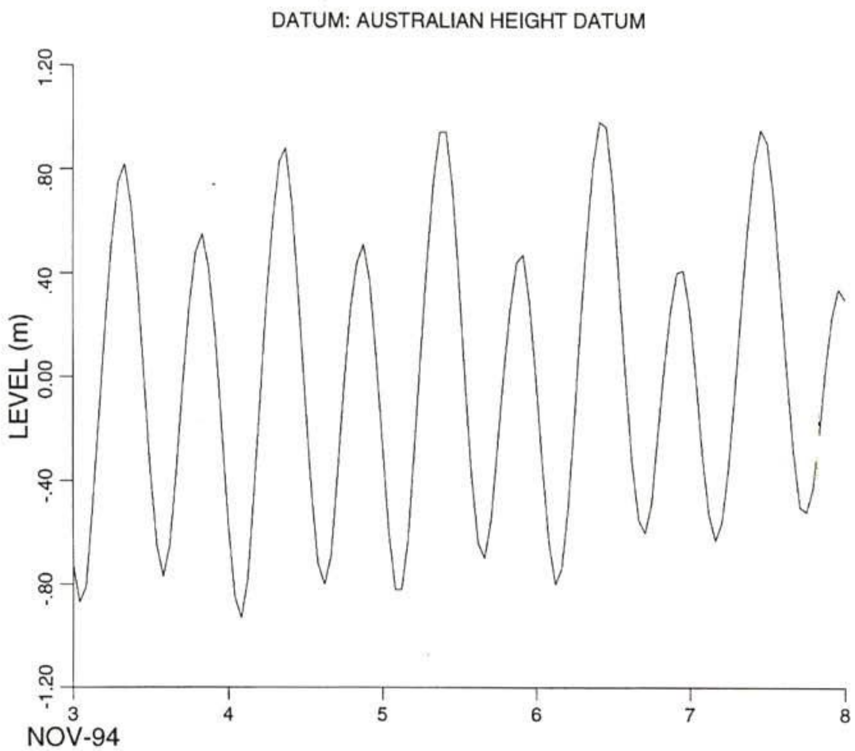


State Projects Manly Hydraulics Laboratory Report No. MHL	Tweed River Entrance Typical Neap and Spring Tides	Figure 2a

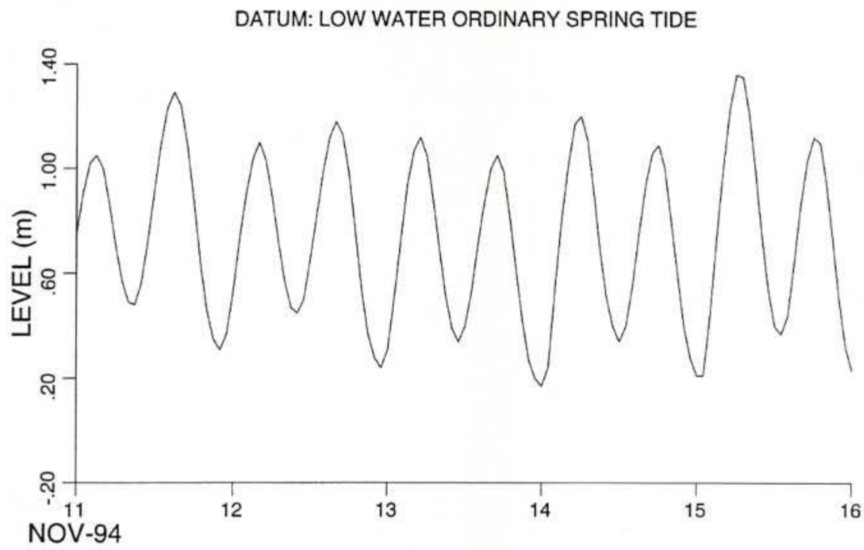


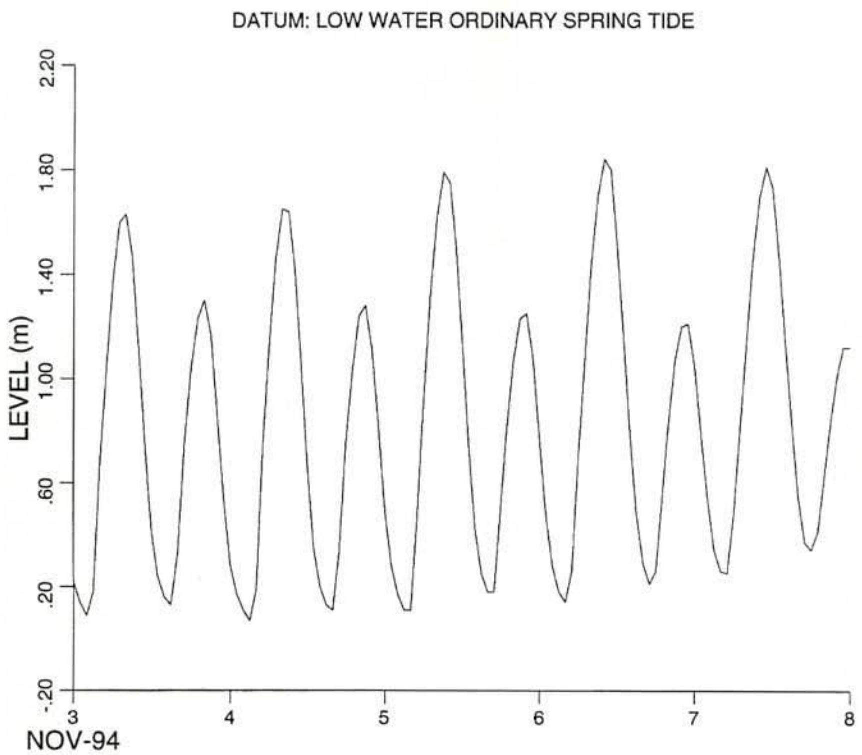
State Projects Manly Hydraulics Laboratory Report No. MHL	Clarence River Entrance Typical Neap and Spring Tides	Figure 2b





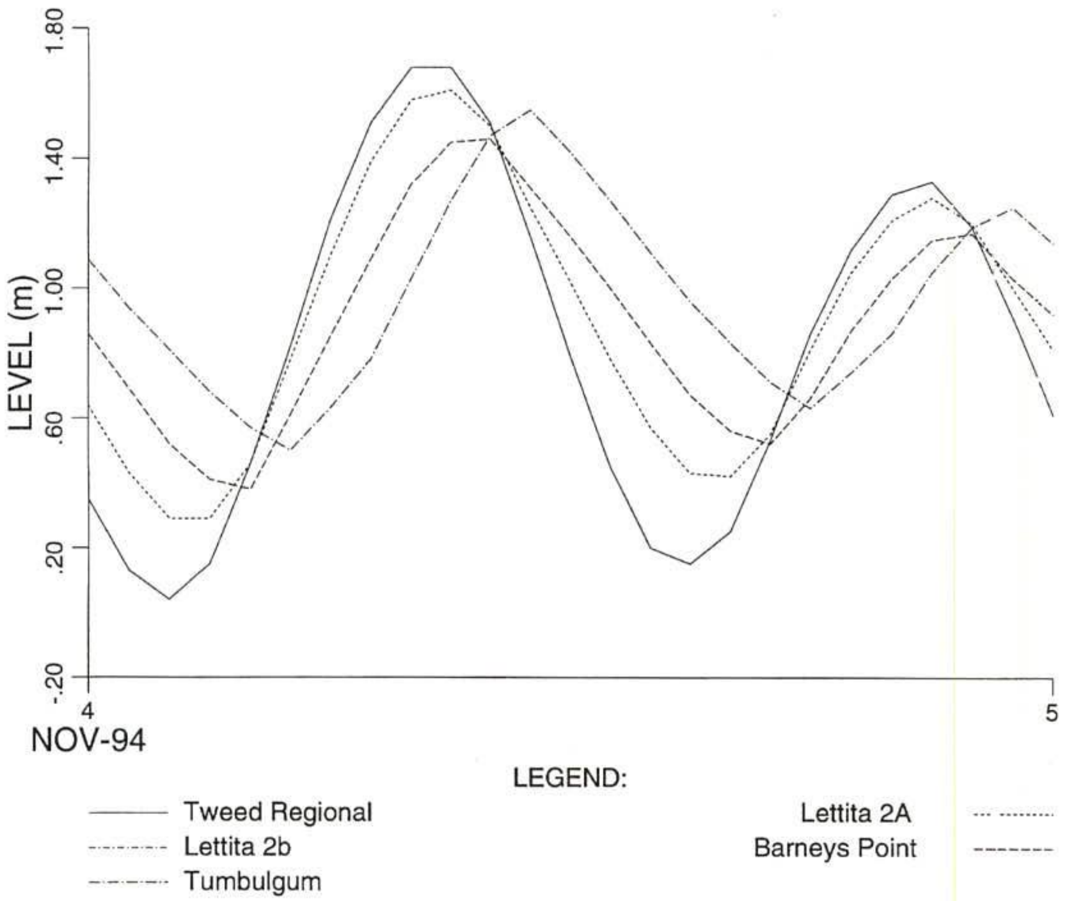
State Projects Manly Hydraulics Laboratory Report No. MHL	Brunswick River Entrance Typical Neap and Spring Tides	Figure 2c



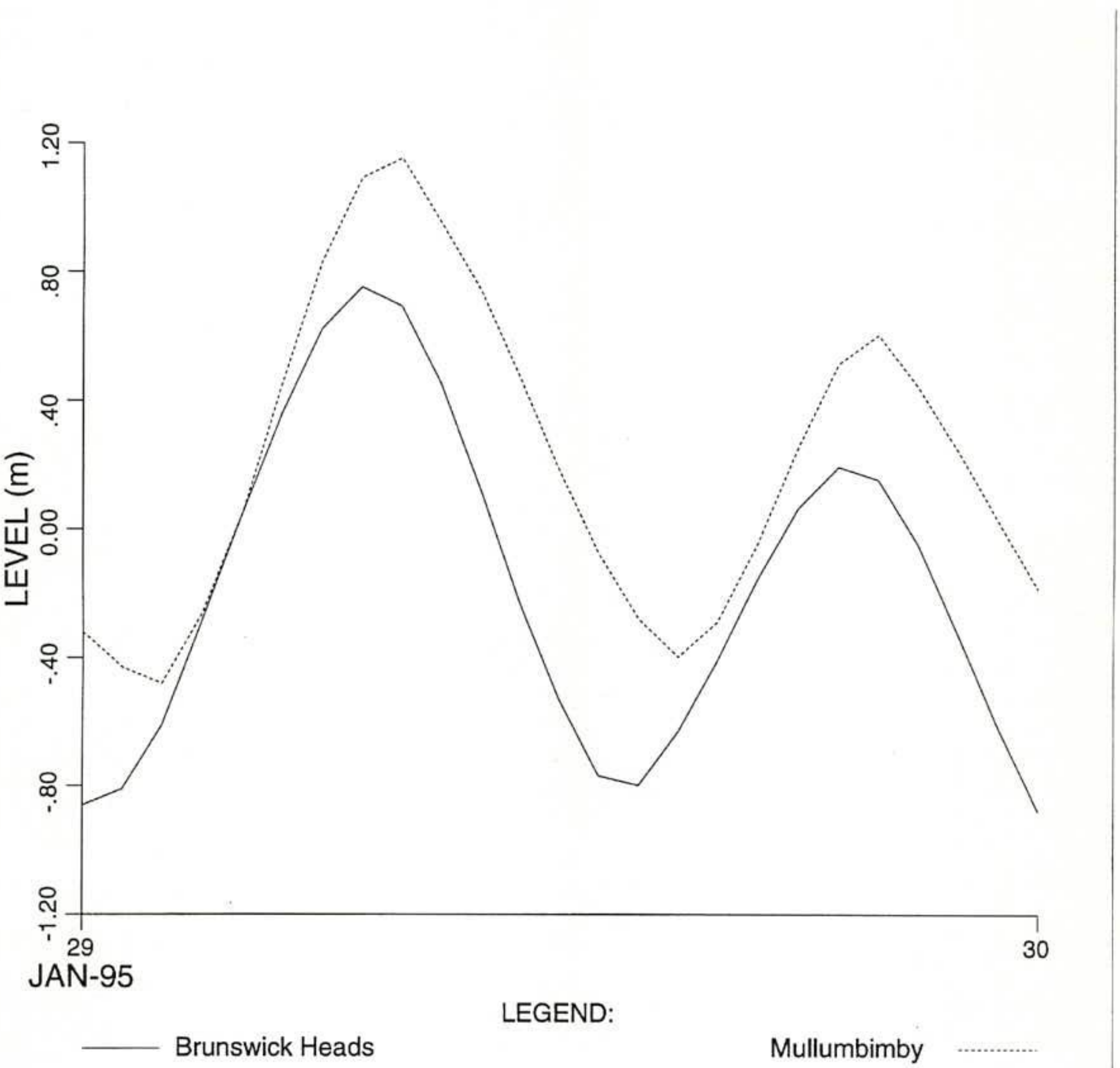


State Projects Manly Hydraulics Laboratory Report No. MHL	Richmond River Entrance Typical Neap and Spring Tides	Figure 2d

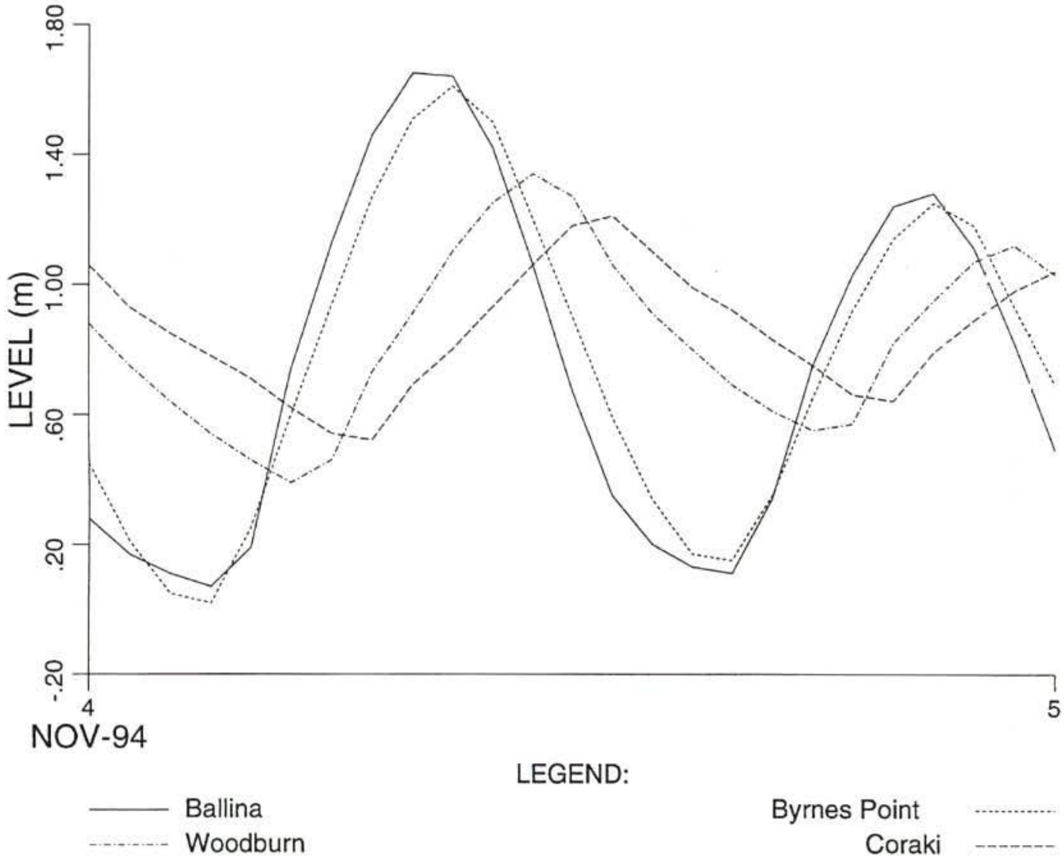
2.4 TIDAL COMPARISONS



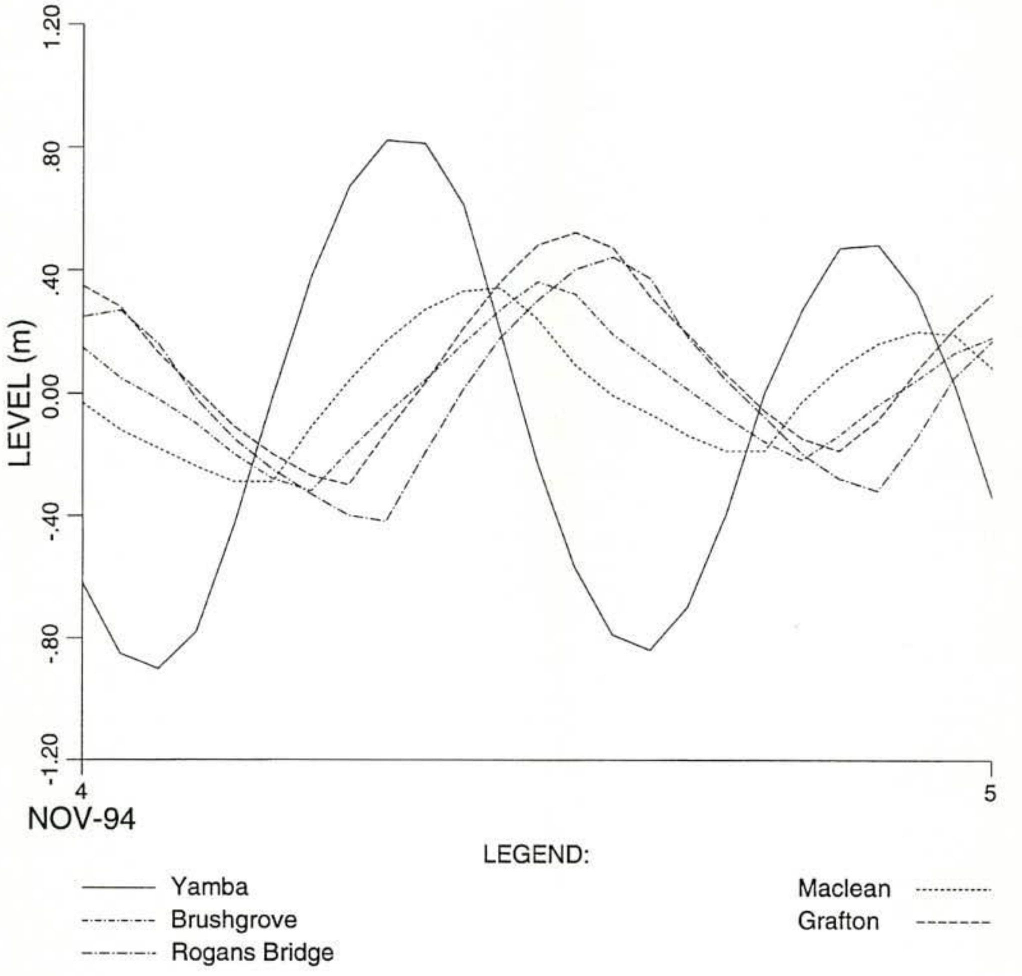
State Projects Manly Hydraulics Laboratory Report No. MHL	Tweed River Tidal Comparison	Figure 2e



State Projects Manly Hydraulics Laboratory Report No. MHL	Brunswick River Tidal Comparison	Figure 2f

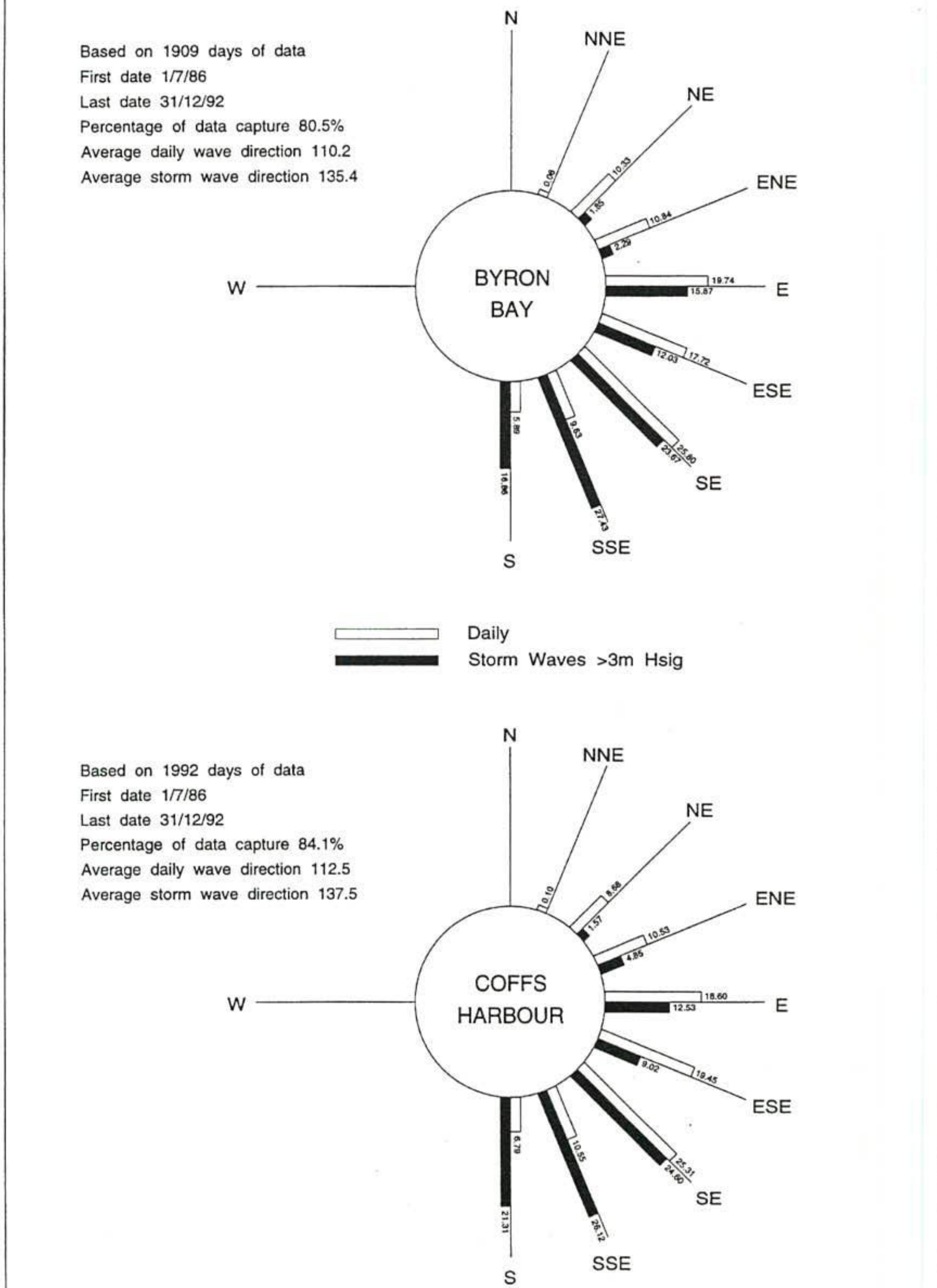


State Projects Manly Hydraulics Laboratory Report No. MHL	Richmond River Tidal Comparison	Figure 2g



State Projects Manly Hydraulics Laboratory Report No. MHL	Clarence River Tidal Comparison	Figure 2h

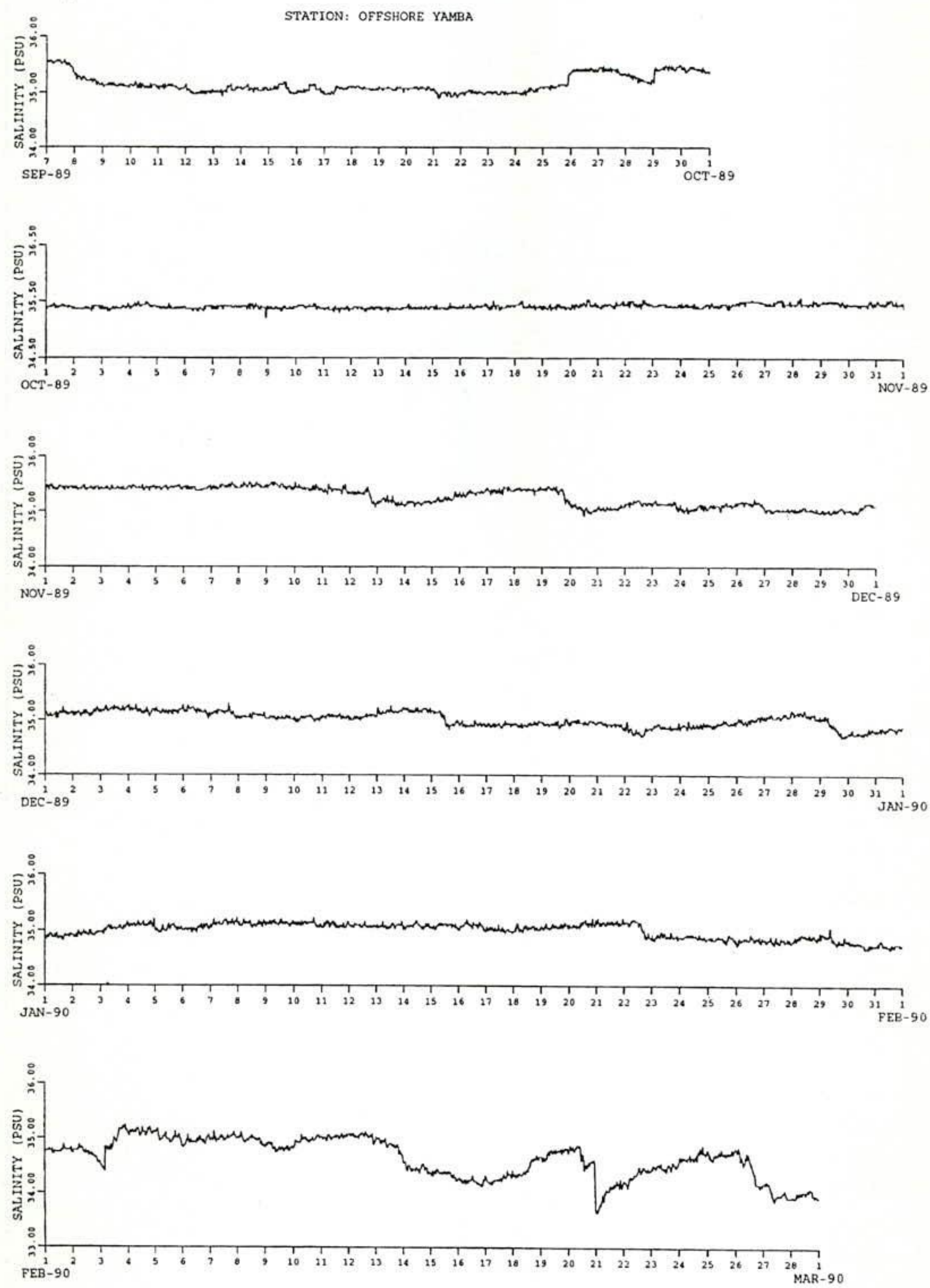
2.5 DAILY AND STORM WAVE FREQUENCY AND DIRECTION AT BOTH BYRON BAY AND COFFS HARBOUR



SOURCE: NSW PUBLIC WORKS, MANLY HYDRAULICS LABORATORY

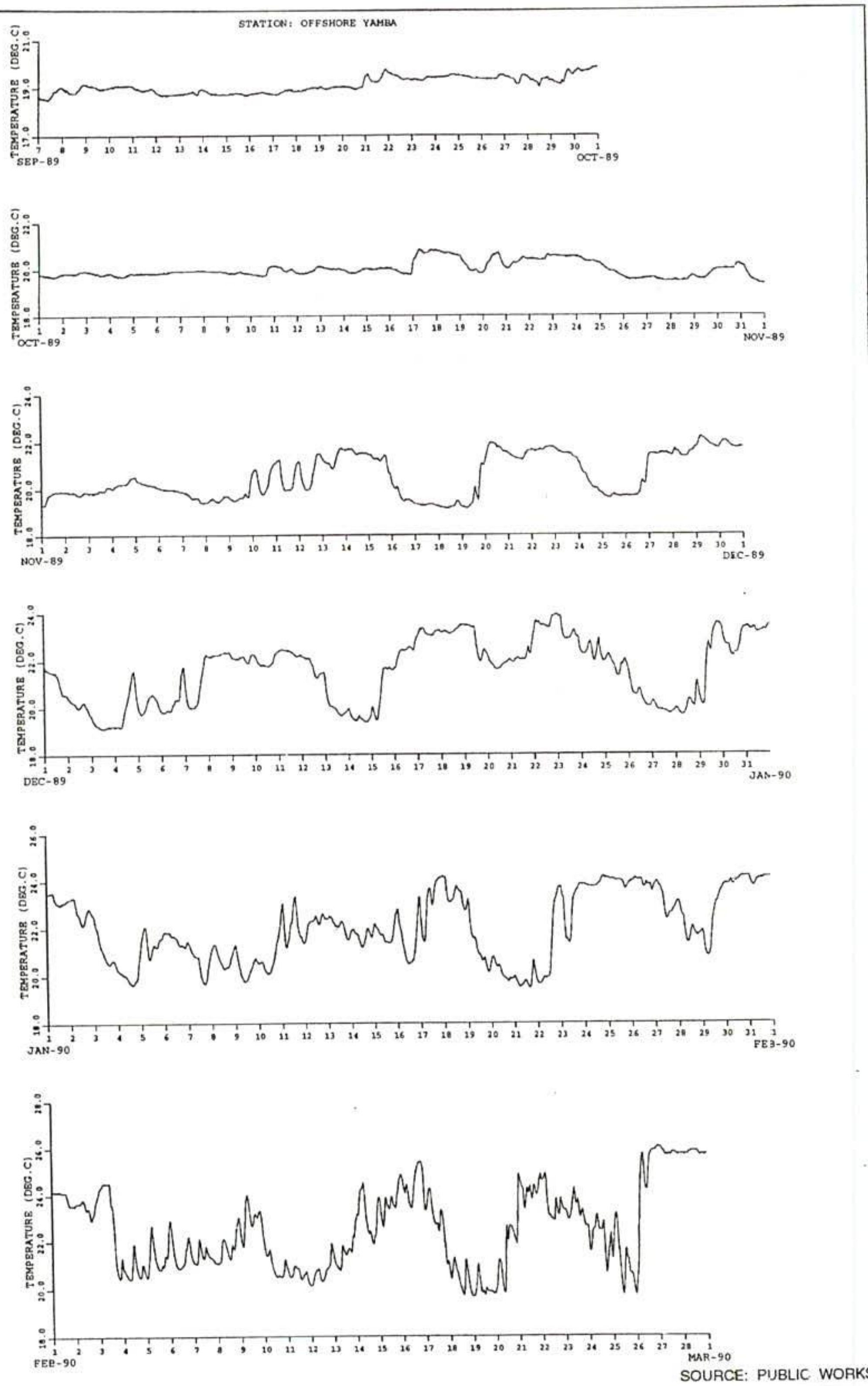
State Projects Manly Hydraulics Laboratory Report No. 662	DAILY AND STORM WAVE FREQUENCY / DIRECTION BYRON BAY AND COFFS HARBOUR	Figure

2.6 WATER TEMPERATURE OFFSHORE OF YAMBA, SEPTEMBER 1989 AND MARCH 1990



SOURCE: PUBLIC WORKS

State Projects Manly Hydraulics Laboratory Report No. 662	SALINITY OFFSHORE YAMBA SEPTEMBER 1989 TO MARCH 1990	Figure 2



SOURCE: PUBLIC WORKS

State Projects
Manly Hydraulics Laboratory
Report No. 662

WATER TEMPERATURE OFFSHORE YAMBA
SEPTEMBER 1989 TO MARCH 1990

Figure
2K

Edwards, R.J. 1979. *Tasman and Coral Sea Ten Year Mean Temperature and Salinity Fields, 1967-Ensby, R., Lennox Head Coastal Protection Strategy*, Project report, Department of Resource Management, Southern Cross University, Lismore.

Environment Protection Authority 1992. *Coastal Resource Atlas for Oil Spills from Point Danger to the Clarence River*, Environment Protection Authority, Sydney.

Environment Protection Authority 1992. *Coastal Resources Atlas for Oil Spills from the Clarence River to Smoky Cape*, Environment Protection Authority, Sydney.

Environment Protection Authority 1993. *New South Wales State of the Environment 1993,* Environment Protection Authority, Chatswood.

Floyd, C.D., & Druery, B.M. 1976. 'Results of river mouth training on the Clarence Bar, NSW, Australia', *Proceedings of the 15th Conference on Coastal Engineering*, Hawaii.

Fogarty, P.J. 1977. *Aspects of Coastal Management in the Angourie Area, Northern NSW*, Department of Natural Resources, University of New England, Armidale.

Gordon, A.D., Lord, B.D., & Nolan, M.W. 1978. *Byron Bay-Hastings Point Erosion Study*, Report No. PWD 78026, NSW Department of Public Works, Sydney.

Hamon, B.V. 1961. *The Structure of the East Australian Current*, Technical Paper No. 11, CSIRO Division of Fisheries & Oceanography, Australia.

Hamon, B.V. 1965. 'The East Australian Current 1960-1964', *Deep-Sea Research*, Vol. 12, pp. 889-921.

Hamon, B.V. & Tranter, D.J. 1971. *The East Australian Current*, CSIRO Division of Fisheries & Oceanography, Reprint 749, Australia.

Higgs, K.B., & Cox, R.J. 1985. *An Assessment of Storm High Water Levels in the Tweed Estuary in April 1984*, WRL Technical Report No. 85/03, Sydney, Hydrology Report, Byron Shire Council, Byron Bay.

House of Representative Standing Committee on Environment, Recreation and the Arts 1991. *The Injured Coastline: Protection of the Coastal Environment*, Australian Government Publishing Service, Canberra.

Kirkwood, L.F. 1967. *Inorganic Phosphate, Organic Phosphorous, and Nitrate in Australian Waters*, CSIRO Division of Fisheries and Oceanography, Technical Paper No. 25, CSIRO Melbourne.

Land Conservation Council, 1993. *Marine and Coastal Special Report: Descriptive Report*, Land Conservation Council, Melbourne.

Landsberg, H.E. 1984. *Climates of the Oceans*, World survey of climatology, vol 15, ed. van Loon, Elsevier Scientific Publishing Co. Amsterdam.

Langford-Smith, T. and Hails, J.R. 1966. 'New evidence of Quaternary seas levels from the North Coast of NSW', *Australian Journal of Science*, vol 28, pp. 352-353.

Legge Wilkinson M. 1993. *State of Our Surf.* 1993 Report. Surfrider Foundation Australia, Newcastle.

Macdonald, R., and Phillip, N. 1995. 'Issues in New South Wales marine environment', *State of the Marine Environment Report for Australia: Technical Annexes 1 and 2*, Great Barrier Reef Marine Park Authority for the Department of the Environment, Sport and Territories and the Ocean Rescue 2000 Program, Townsville.

Manly Hydraulics Laboratory 1976. *Brunswick Heads: Longshore Current Investigation*, Report No. MHL271, Public Works Department NSW, Sydney.

Manly Hydraulics Laboratory 1978. *Brunswick River Tidal Monitoring 15 March 1977*, MHL Report No. 230, Public Works Department NSW, Sydney.

Manly Hydraulics Laboratory 1978. *Richmond River 26 May 1977*, Report No. MHL245, Public Works Department NSW, Sydney.

Manly Hydraulics Laboratory 1979. *Clarence River Tidal Monitoring, Sand Sampling, 16 August 1977*, Report No. MHL265, Public Works Department NSW, Sydney.

Manly Hydraulics Laboratory 1979?, *Brunswick River Tidal Data 7 Feb 1979*, MHL Data Section File No. 1059, Public Works Department NSW, Sydney.

Manly Hydraulics Laboratory 1984.*Comparison of Wave Statistics between Byron Bay and Coffs Harbour*, Report No. 422, Public Works Department NSW, Sydney.

Manly Hydraulics Laboratory 1985. *Clarence River Tidal Data 16/17 March 1984*, Report No. MHL418, Public Works Department NSW, Sydney.

Manly Hydraulics Laboratory 1985. *Richmond River-North Creek Tidal Data, 21 July 1982*, Public Works Department NSW, Sydney.

Manly Hydraulics Laboratory 1987. *Brunswick Heads Outfall Investigation,* Report No. 580, PWD Report No. 86043, Public Works Department NSW, Sydney.

Manly Hydraulics Laboratory 1988. *Tweed River Tidal Investigation 1971-1988*, Report No. MHL550, Public Works Department NSW, Sydney.

Manly Hydraulics Laboratory 1988. *Brunswick River: Tidal Discharge 7 Sept 1983*, Report No. MHL385, Public Works Department NSW, Sydney.

Manly Hydraulics Laboratory 1989. *Clarence River Tidal Data 23 May 1979*, Report No. MHL384, Public Works Department NSW, Sydney.

Manly Hydraulics Laboratory 1991. *Storm Surge Monitored along the New South Wales Coast March-April 1990*, Report No. MHL591, NSW Public Works, Sydney.

Manly Hydraulics Laboratory. Clarence River Data Compilation Study, NSW Public Works, Sydney. (in press.)

Manly Hydraulics Laboratory 1994. *New South Wales Wave Climate, Annual Summary 1993/94*, Report No. MHL695, NSW Public Works, Sydney.

Manly Hydraulics Laboratory 1994. *New South Wales Ocean Tide Levels - Annual Summary 1993/94*, Report No. MHL658, NSW Public Works, Sydney.

Manly Hydraulics Laboratory 1994. *The Complete NSW Tide Charts and Almanac,* Horan Wall and Walker, Surry Hills.

Mitchell, H.L. & Silvester, R. 1981. *Tides Around the Australian Coastline*, Trans. Inst. Engs. Aust., CE23, No. 4.

Mulhearn P. J. 1986. *Studies of the East Australian Current off Northern New South Wales*, RANRL Technical Note 6/86, Department of Defence, Pyrmont.

Mulhearn P. J. 1987. 'The Tasman Front: A Study Using Satellite Infrared Imagery', *Journal of Physical Oceanography*, Volume 17.

NSW Cabinet Office 1990. *The NSW Coast: Government Policy*, NSW Cabinet Office, Sydney.

NSW Department of Agriculture and Fisheries 1985. *An Estuarine Inventory for New South Wales, Australia*, NSW Department of Agriculture and Fisheries, Sydney.

NSW Government 1990. *Coastline Management Manual*, NSW Government, Sydney.

NSW Government 1992. *Estuary Management Manual*, NSW Government, Sydney.

NSW Public Works 1986. *Belongil Creek Flood Study*, Report No. PWD L.I.107, NSW Public Works, Sydney.

NSW Public Works 1986. *Marshalls Creek Flood Study*, Report No. PWD 86031, NSW Public Works, Sydney.

NSW Public Works 1987. *Lower Richmond River Flood Study*, Report No. PWD 87041, NSW Public Works, Sydney.

NSW Public Works 1988. *Lower Clarence River Flood Study*, Report No. PWD 88066, NSW Public Works, Sydney.

NSW Public Works 1988. *Cudgen Creek Flood Study*, Report No. PWD 88049, NSW Public Works, Sydney.

NSW Public Works 1991. *Reviving the Tweed Feasibility Study-Nearshore Oceanographic Data*, Report No. 3.1.2, PW, NSW Public Works, Sydney.

NSW Public Works, 1991. *Reviving the Tweed Feasibility Study-Ocean Currents*, Report No. 3.1.3, NSW Public Works, Sydney.

NSW Public Works 1991. *Reviving the Tweed Feasibility Study*, Technical Reports Coastal Processes Appraisal Report No. 3.1.1C, NSW Public Works, Sydney.

NSW Public Works 1991. *Surf Environment Analysis: Corindi Beach*, PWD Report No. 91044, NSW Public Works, Sydney.

NSW Public Works 1991. *Surf Environment Analysis: New Brighton Beach*, PWD Report No.91040, NSW Public Works, Sydney.

NSW Public Works 1991. *Surf Environment Analysis: Red Rock Beach*, PWD Report No. 91041, NSW Public Works, Sydney.

NSW Public Works 1991. *Surf Environment Analysis: Sandys Beach*, PWD Report No. 91042, NSW Public Works, Sydney.

NSW Public Works 1991. *Surf Environment Analysis: Woolgoolga Beach*, PWD Report No. 91043, NSW Public Works, Sydney.

NSW Public Works 1992. *Surf Environment Analysis: North Sapphire Beach*, PWD Report No. 92052, NSW Public Works, Sydney.

NSW Public Works 1992. *Estuary Inventory of New South Wales*, internal report, NSW Public Works, Sydney.

NSW Public Works. Clarence River Photogrammetric Analysis Report, NSW Public Works, Sydney. (in press.)

NSW Public Works 1993. *Brunswick River: North Coast Estuaries Sedimentogolical Studies,* NSW Public Works, Sydney.

NSW Public Works. Clarence River Data Compilation Study, NSW Public Works, Sydney. (in press.)

NSW Standing Committee on State Development 1991. *Coastal Planning and Management in New South Wales: A Framework for the Future*, Vol 1, Report no. 4, NSW Legislative Council, Sydney.

NSW Standing Committee on State Development 1992. *Coastal Planning and Management in New South Wales: The Process for the Future*, Vol 2, Report No. 8, NSW Legislative Council, Sydney.

Pisanu P.C. and Gale, S.J. 1994. *Geomorphological Analysis of the Upper North East of New South Wales*, Department of Mineral Resources, Sydney.

Pitt, M.W. 1991. *Tourism and coastal land management: a survey of visitors on the north coast of New South Wales*, Economic Papers, Department of Conservation & Land Management, Sydney.

Prior, J. 1981. *Development Pressures in the Yamba - Angourie Area: A Study in Coastal Zone Conflict Management*, A dissertation submitted in partial fulfillment of the requirements for the Diploma in Urban and Regional Planning of the University of New England, Armidale.

Public Works Department NSW 1971. *Clarence River Entrance Model Investigation,* Manly Hydraulic & Soils Laboratory, Report No. 151, Public Works Department NSW, Sydney.

Public Works Department NSW 1979. *Clarence River Tidal Monitoring, Sand Sampling 16 August, 1977*, Manly Hydraulics Laboratory Report No. 265, Public Works Department NSW, Sydney.

Public Works Department NSW 1982. *Cape Byron to Ballina Data Collection Exercise 17/2/82 - 25/2/82*, Internal Report, Public Works Department NSW, Sydney.

Public Works Department NSW 1983. *Coastal Erosion Report Tweed Shire*, Report No. PWD 83009, Public Works Department NSW, Sydney.

Public Works Department NSW 1984. *Yamba Waters: A Summary of the Yamba Waters Coastal Engineering Study*, Public Works Department NSW, Sydney.

Public Works Department NSW 1985. *Cudgen Creek Tidal Monitoring Exercise 7th February, 1985*, Report No. Li 109, Public Works Department NSW, Lismore District Office, Lismore.

Public Works Department NSW 1985. *Clarence River: Tidal Data 16/17th March 1984*, Manly Hydraulics Laboratory Report No. 418, Public Works Department NSW. Sydney.

Public Works Department NSW 1985. *Elevated Ocean Levels-Storms Affecting the NSW Coast 1880-1980*, Report No. 85041, Public Works Department, Sydney.

Public Works Department NSW 1986. *Elevated Ocean Levels-Storms Affecting the NSW Coast 1980-1985*, Report No. 86026, Public Works Department NSW, Sydney.

Public Works Department NSW 1986. *Summary of Storm Damage and Associated Sea and Weather Conditions on the NSW Coast - 1876 to 1981*, PWD Report No. 86014, Public Works Department NSW, Sydney.

Public Works Department NSW 1989. *Clarence River Tidal Data 23rd May 1979*, Manly Hydraulics Laboratory Report No. 384, Public Works Department NSW. Sydney.

Public Works Department NSW 1991. *Surf Environment Analysis: Woolgoolga Beach,* PWD Report No. 91043, Public Works Department NSW, Sydney.

Public Works Department NSW 1991. *Surf Environment Analysis: Red Rock Beach*, PWD Report No. 91041, Public Works Department NSW, Sydney.

Public Works Department NSW & Blain Bremner & Williams 1987. *Elevated Ocean Levels Coffs Harbour*, Report No. 86005, Public Works, Public Works Department NSW, Sydney.

Rendal & Partners 1975. *Report on New Brighton Erosion Study*, prepared for Department of Public Works, Public Works Department NSW, Sydney.

Rendal & Partners 1976. *Addendum to Report on New Brighton Erosion Study*, prepared for Department of Public Works, Public Works Department NSW, Sydney.

Resource Assessment Commission 1993c. *NSW Case Study: Coastal Zone Management in the North Coast Region: Shires of Byron, Ballina and Maclean*, Australian Government Publishing Service, Canberra.

Resource Assessment Commission 1993b. *Coastal Zone Inquiry-Final Report,* Australian Government Publishing Service Canberra.

Resource Assessment Commission 1993a. *Coastal Zone Inquiry-Resources and Uses of the Coastal Zone*, Information Paper No. 3, Australian Government Publishing Service, Canberra.

Robinson, D.A. 1993. 'Tweed Heads Sand By-passing System', in *Proceedings Bruun Workshop on Beach Nourishment and Sand Bypassing*, Department of Civil Engineering, University of Queensland, 28-29 January, 1993. Brisbane.

Rochford, D.J. 1972. *Nutrient Enrichment of East Australian Coastal Waters-I Evans Head Upwelling*, CSIRO Division of Fisheries and Oceanography, Technical Paper No.33, CSIRO Melbourne.

Rochford, D.J. 1977. *The Surface salinity regime of the Tasman and Coral Seas*, CSIRO Division of Fisheries and Oceanography, Report No. 84, CSIRO Sydney.

Rochford, D.J. 1986. *Interannual Changes in Sea Surface Temperatures and Salinities of the Coral and Tasman Seas Between 1966 and 1977*, CSIRO-Marine Laboratory Report No. 172. CSIRO Sydney.

Roy, P.S. 1973. *Coastal Geology of the Cudgen Area - North Coast of NSW*, Geological Survey of NSW, Department of Mines, Geological survey report no. GS 173/286. Department of Mines, Sydney.

Roy, P.S. and Thom, B.G. 1981. 'Late Quaternary marine deposition in New South Wales and southern QLD - an evolutionary model', *Journal of the Geological Society of Australia*, vol 28, p. 471-89.

Schnierer, S., Robinson, S., Heron, R. & Nayutah, J. 1995. 'Use of the coastal and marine environment by Aboriginal communities: Case study from northern NSW South Wales', *The State of the Marine Environment Report for Australia: Technical Annexes 1 and 2*, Great Barrier Reef Marine Park Authority for the Department of the Environment, Sport and Territories and the Ocean Rescue 2000 Program, Townsville.

Short, A. and Trenaman N.L. 1992. 'Wave climate of Sydney region, an energetic and highly variable ocean wave regime', *Australian Journal of Freshwater and Marine Research*, vol 43, pp. 765-91.

Short, A. 1993. *Beaches of the New South Wales Coast: A Guide to their Nature, Characteristics Surf and Safety*, Australian Beach Safety and Management Program, Sydney.

Short, A.D. & Hesp, P.A. 1982. 'Wave, beach and dune interaction in South Eastern Australia', *Marine Geology*, vol 48, pp. 259-284.

Skinner, J. & Gillam, E. 1992. 'Coastal Growth in Northern New South Wales and Southern Queensland: the Facts', *Proceedings of a Conference on Coastal Growth and Management*, University New England - Northern Rivers, Lismore.

Tomlinson, R.B. & Hranisavljevic, D. 1988. *Tweed River Entrance Sand Bypassing Investigation-Sediment Budget Update*, Water Research Laboratory, Technical Report 87/11. Sydney.

Van Iersel, R. 1988. *New Brighton Coastal Protection Strategy*, Project report, Department of Resource Management, Southern Cross University, Lismore..

Wearne, A. Erosion damage on NSW coastline Wollongong to Tweed Heads, Resulting from storms in Autumn & Winter 1974, NSW Soil Conservation Service, Sydney. (unpub).

Zann, L. 1995. *The State of the Marine Environment Report for Australia*, Great Barrier Reef Marine Park Authority for the Department of the Environment, Sport and Territories and the Ocean Rescue 2000 Program, Townsville.

GROUNDWATER

Coffey Partners International Pty. Ltd 1989. *Newrybar mineral sands project groundwater assessment.* Report No. G214/1. Coffey Partners International Pty. Ltd., Sydney.

McKee, L. & Eyre, B. D. (in press). 'Nutrient export from a large rurally diverse northern NSW coastal catchment' *Proceedings of the National Conference on the Downstream Effects of Land Use,* Rockhampton 26-28 April 1995.

Ferguson, A. & Eyre, B. D. 1995, 'Local and regional impacts of acid runoff from acid sulphate soils in the Richmond River Estuary, Northern NSW.' *Program and Abstracts Australian Marine Science Association Meeting, Sydney 3 -6 July 1995.* (n.p.)

Finlayson, D. 1989. A risk assessment of groundwater contamination by pesticide residues in selected aquifers of New South Wales, Master of Applied Science Project Report, Centre for Groundwater Management and Hydrogeology, University of New South Wales, Sydney. (unpub.)

Knight, M. J. 1993. 'Organic chemical contamination of groundwater in Australia - an overview to 1993', *AGSO Journal of Australian Geology and Geophysics* vol. 14, pp. 107-122.

Lin, C. & Melville, M. D. 1993. 'Control of soil acidification by fluvial sedimentation in an estuarine floodplain, eastern Australia', *Sedimentary Geology* vol. 85, pp. 271-284.

McKibbin, D. 1995. *Upper North Coast Groundwater Resource Study for the Natural Resources Audit Council (NRAC).* Report No. TS 95-011, Department of Land and Water Conservation, Technical Services Division, Parramatta

Public Works Department 1988. *Final report on injection well effluent, Belongil Beach - Byron Bay.* Public Works Department, Sydney.

Ross, J. B. & McKibbin, D. 1992. *North Coast sustainable strategy - groundwater aspects.* Report No. TS92.024, Department of Water Resources Technical Services Division, Parramatta.

Sammut, J; Callinan, R.B. & Fraser, G.C. 1993. 'The impact of acidified water on freshwater and estuarine fish population in acid sulphate soil environments' *Proceedings of the National Conference on Acid Sulphate Soils* ed. Bush, R. sponsored by CSIRO, NSW Agriculture & Tweed Shire Council .(n.p.)

Sinclair & Knight 1986, *Byron Bay sewerage strategy study - investigation of disposal of effluent via sand dunes at Tallow and Belongil Beaches.* Public Works Department, Sydney.

Webb, McKeown & Assoc. 1993. *Lower Richmond River*, Public Works Department, Sydney.

Willing & Partners 1984. *Clarence River Maximum Probable Flood Estimate at Grafton,* Public Works Department, Report No. 84026, Sydney.

DATA QUALITY STATEMENTS

NRAC PROJECT S2, THE NORTHERN RIVERS – A WATER QUALITY STUDY

1. Lineage

The Audit was conducted in the Upper North East Region of New South Wales, Australia. Water quality was assessed in the four major river catchments of this Region: the Tweed, Brunswick, Richmond and Clarence River Catchments. These four major catchments cover over 90% of the Region.

Physical, chemical and microbiological indicators presented in Australian Water Quality Guidelines for Fresh and Marine Waters, published by the Australia and New Zealand Environment Conservation Council (ANZECC), were used as the basis for the assessment.

Environmental water quality attributes measured at each sampling location included both field and laboratory measurements. Field measurements of temperature, turbidity, dissolved oxygen, pH, electrical conductivity and salinity were recorded, while measurement of nutrients, chlorophyll-a, suspended solids, major dissolved salts and faecal bacteria was completed for laboratory samples.

A total of 142 sites were assessed, these sites being distributed throughout the Region and including the major rivers, tributaries and estuaries. The logistics of collecting samples from the sites was a limiting factor. There was some 7000 kilometres between sample sites, which took the field team 5 weeks to complete, including both vehicle and boat transport. The routine sampling cycle was 6 - 8 weeks, with 7 cycles being completed in the period May 1994 to May 1995. In addition, several special surveys at a reduced number of sites were conducted to investigate particular aspects of catchment water quality.

2. Positional accuracy

The sampling sites were generally at easily accessible locations on the rivers, such as bridges or causeways. In the estuarine reaches, sample sites were located near defined landmarks, and could be referenced through these descriptive locations. Positional information for the sampling locations which is included with the dataset is derived from 1:25,000 topographical maps and is within the accuracy of the maps, about 50 metres.

3. Attribute accuracy

Some water quality attributes were measured in the field, while others were determined from samples sent to selected laboratories. An operational manual which described measurement and sampling protocols, together with standardised field sheets and submission sheets, were developed for the study.

Field measurement of water quality was conducted using a Horiba U-10 Water Checker (Japanese) and the Yeokal 609 Dissolved Oxygen meter (Australian). Measurement was carried out according to the Standard Methods for the Testing of Water and Waste Water (AWWA) and the instruction manuals supplied with these instruments. The performance of these instruments was checked regularly during each sampling day against standardised solutions. The check readings were recorded, and the instrument was recalibrated if the values were outside a specified range. The selected laboratories were:

- Richmond Pathology Services, Lismore (microbiological testing);
- AWT Ensight, West Ryde (nutrient and major ion determinations); and
- Tweed Council Water Laboratories, Banora Point (chlorophyll-a and suspended solids).

The performance of these laboratories was tested against control laboratories, which were the Division of Analytical Laboratories, Lidcombe (microbiology), and EPA General Chemical Laboratory, Lidcombe (nutrients, major ions, chlorophyll-a and suspended solids). All laboratories are NATA registered (with the exception of the Tweed Council Laboratory), and they all have internal quality control and assurance procedures in place. The laboratory analyses were carried out according to methods described in the procedures manual for each laboratory.

Samples with known concentrations of determinands (standards), together with replicated samples, were regularly submitted with the field samples to all laboratories as an independent check on the level of precision and accuracy of the laboratories.

Field measurements and observations were recorded on standardised field sheets, and results from laboratories were received in printed form. This information was transferred by the field staff to a computer spreadsheet, and was checked and corrected. The spreadsheet was transferred to the EPA's water quality database, and independently checked and corrected against the original field and laboratory data sheets

4. Logical consistency report

A number of tests were made on the attribute values recorded in the water quality data bases to check for logical consistency.

5. Completeness

Due to logistical constraints, sites were not tested for faecal bacteria at the frequency specified in the ANZECC Guidelines for assessment of water suitability for primary contact recreation. The study did not measure the levels of some indicators, such as pesticides and heavy metals, which are also included in the ANZECC Guidelines.

For much of the sampling period, the Region experienced rainfall much below average and this factor will influence the results. One heavy rainfall event in February 1995 produced flooding and measurements were made at a reduced number of sites across the whole Region during this event.

NRAC PROJECT S15, UPPER NORTH COAST GROUNDWATER RESOURCE STUDY

1. Lineage

The Upper North Coast Groundwater Study has involved: an initial data review and identification of aquifer systems for the study; use of a Geographic Information System (GIS) to prepare an aquifer map of the study area and a map of public lands; field surveys consisting of bore data reconnaissance, geophysics and drilling; and compilation of aquifer data sets relating to groundwater quality and quantity and synthesis of aquifer information compiled.

The initial review provided the framework for the aquifer systems studied as well as the design of a range of field surveys to obtain data where information was lacking.

The aquifer map was compiled from 1:250,000 scale digitised surface geology supplied by the Department of Mineral Resources.

Field surveys included reconnaissance to gather basic groundwater data in selected fractured and porous rock aquifers; geophysical surveying using frequency domain electromagnetic traversing and vertical electrical sounding methods in selected areas where unconsolidated sediments occur; and test drilling at five (5) sites to provide hydrogeological control for the geophysical data.

The bulk of the groundwater data for this study was extracted from HYDSYS INTEGRATED the Department's Resource Information Data Base. The aquifer system map facilitated the compilation of relevant data sets supported by field survey data obtained during the study.

Quantified information about each aquifer system has involved a synthesis of data obtained from various components of the study.

2. Positional accuracy

The aquifer map has been compiled from published geological base maps at a scale of 1:250,000 where boundaries are estimated at best to the ± 50 metres. All field survey work undertaken has been plotted on 1:25,000 scale topographic plans. HYDSYS groundwater is recorded on topographic maps in AMG coordinates and plotted at 1:25,000 scale but source information is of variable quality often supplied to the Department on cadastal plans. Department investigation bores are the most accurately defined positions within that data set. Vertical position is defined in most cases as depth below the bore casing collar or depth below natural surface level for geophysical survey information.

3. Attribute accuracy

Groundwater data accuracy is reliant to a large extent on the Department's Resource Information data base HYDSYS INTEGRATED (groundwater and water quality modules). Much of this information is supplied to the Department by the bore owner from bore completion reports prepared by a licensed water drilling contractor. Data is of variable quality but judged to be of a fair standard as a groundwater record. Water quality is also variable where private bore information is recorded. Department investigation bores are of a high attribute standard where known field protocols for strata and water quality sampling are routine. Survey data for the study is also in accordance with general Department procedures for the assigned field task.

4. Logical consistency report

Strata log descriptions of bores for each aquifer were examined to ensure consistency with the known geology. Adjustments were mainly required where multiple aquifer systems occur for example where a bore has been constructed through an overlying surficial layer into the basement rock to obtain water supply.

5. Completeness

Field survey methodology was strategically designed to enhance data capture. The study incorporates records of 2168 bores of which 643 sites have groundwater chemistry information. Data sets examined reflect a reasonable degree of completeness to achieve a systematic audit review of groundwater resources of the region.

EXECUTIVE SUMMARIES

NRAC PROJECT S2 - STATUS REPORT ON WATER QUALITY IN THE TWEED, BRUNSWICK, RICHMOND AND CLARENCE RIVERS

Brief outline of objectives

The water quality Audit of the Upper North East of New South Wales addressed the following objectives -

- Measure water quality indicators at a range of sites within the four main catchments of the study area.
- Compare the observed water quality with the Australian Water Quality Guidelines for seven different environmental values.
- Investigate the importance of water quality during high flow conditions in regional water quality assessment.
- Compare current and historic water quality data collected in the Region.

Integral to all issues was the collection of current water quality data for the Region. Water quality data were collected at 142 sites in the Tweed, Brunswick, Richmond and Clarence catchments. Sampling sites were located in estuarine and freshwater reaches of the rivers, and samples were collected during both low and (when possible) high river flow conditions. During the study period, up to seven sets of data were collected at each site, while one observation was made at a reduced number of sites during a single high flow event in February 1995.

Methods

Environmental values presented in The Australian Water Quality Guidelines for Fresh and Marine Waters (ANZECC 1992) were used as the basis for assessment of water quality in the Audit Region. The environmental values considered were -

- Aquatic Ecosystem Protection
- Potable Water
- Primary Contact Recreation
- Secondary Contact Recreation
- Agriculture - Irrigation
- Agriculture - Livestock
- Edible Seafood

The Guidelines provide a comprehensive list of physico-chemical and biological indicators, and toxicants, that may be relevant to each of the seven environmental values. From these lists, key indicators were selected. Associated with each indicator is a criterion (or criteria) which must be met for the water to be considered acceptable in that category.

Each site was sampled a maximum of seven times as part of the routine sampling, with the sites being ranked from Good to Very Poor for each of the seven environmental values being considered.

Water samples were collected on a routine basis during low flows, however targeted sampling was employed to identify water quality under high flow conditions. High flow sampling involved a smaller number of sites, with one sample collected at each site. In addition to data collected for the Audit, historic data were obtained from two sources; the State Pollution Control Commission (SPCC) dataset generated as part of the regional studies during the 1980s, and Department of Land and Water Conservation (DLWC) data collected as part of ongoing monitoring of water quality at flow gauging sites.

Results

Water quality data were collected during a period of low river flows resulting from drought conditions in the Region. High flow data were collected during a heavy rainfall period in early February 1995.

Low river flow results

Large differences in surface water quality were identified, both between different catchments and between different environmental categories.

The Clarence catchment exhibited the best overall water quality of the Audit Region, with over half of all sites being ranked Good or Fair. The categories of secondary contact recreation and livestock water ranked particularly highly, while edible seafood was ranked Good or Fair at over 50% of estuarine sites.

While not ranking as well as the Clarence, the Tweed Catchment also ranked well for some categories. Secondary contact recreation and irrigation water ranked well, together with some edible seafood sites. Aquatic ecosystem protection and primary contact recreation showed a large proportion of Poor and Very Poor ranks in this catchment. This resulted predominantly from low dissolved oxygen and high suspended solids concentrations for aquatic ecosystem protection, and excessive faecal coliform concentrations and poor clarity for primary contact recreation.

The Richmond and Brunswick Catchments both exhibited poor water quality across a range of categories. At over 50% of sites in both catchments, ranks were either Poor or Very Poor. The only categories to be ranked well in the two catchments were secondary contact recreation and livestock. All other categories performed badly, with catgories such as aquatic ecosystem protection and edible seafood being ranked Poor or Very Poor at 75% or more of sites. A poor pass rate for the indicators of nutrients, bacteria and dissolved oxygen were a major influence on these results in both catchments.

High river flow results

A significant decline in water quality was identified in all catchments during high river flow conditions. All sites failed in the categories of aquatic ecosystem protection, potable water and edible seafood, while a significant number of sites failed in the remaining categories.

An assessment of river loads during both low and high flows revealed very large increases in nutrient and sediment loads in the rivers under high flow. For example, the Clarence River at Lilydale had a massive increase in suspended sediment load from 350 kg/day to over 20 000 tonnes/day. Large increases in nitrogen and phosphorus loads were identified at this site.

These results highlighted the importance of water quality data collected under high flow conditions to the overall picture of water quality in the catchment.

Historic data comparison

Data collected as part of this study were compared to data collected by the SPCC during a previous study, and by DLWC as part of ongoing water quality monitoring in the states rivers. Comparison between the three data sources revealed a similarity between the results at a majority of the sites. Analysis of the historic datasets revealed errors in the data reported, together with the quality of the data being unknown. For these reasons, detailed comparison of the datasets, and the identification of time trends in the data, were not attempted.

This comparison did reinforce both the importance of high flow data in water quality assessment, and the difficulty in obtaining high flow data from studies that are not specifically designed for this task.

Benefits

This Audit has identified water quality at 142 sites in four catchments in the Upper North East of New South Wales. The information presented will be of value to both users and managers of the water resource, through the provision of current water quality information, and the identification of water quality patterns in the Region.

NRAC PROJECT S15 - UPPER NORTH COAST GROUNDWATER RESOURCE STUDY

Brief outline of objectives

As part of a Natural Resources Audit Council (NRAC) funded project the Department of Land and Water Conservation's Hydrogeology has undertaken a groundwater study in 1994/95. The area investigated was defined by the catchments of the Tweed, Brunswick, Richmond and Clarence Rivers. The objective of the study was to quantify the groundwater resource potential of the region. An aim of the study was also to evaluate significance of public lands to major aquifer systems in the region. The study also aimed to establish water quality criteria for each aquifer system identified as well as estimates of volumes of groundwater in storage, recharge and safe yield.

Methods

An initial review provided the framework for aquifer systems studied as well as a strategy to undertake a range of field surveys where information was patchy or lacking. Regional geological units that have similar groundwater characteristics were used to identify the aquifer systems within the three broad categories where groundwater occurs ie. unconsolidated sediments, porous rocks and fractured rock. For the Upper North Coast Study major aquifers include:

- Beach and Dune Sands - (Unconsolidated Sediment)
- Alluvium of the River Basins - (Unconsolidated Sediment)
- Tertiary Basalts - (Fractured Rock)
- Clarence-Moreton Geological Basin - (Porous Rock)
- Basement Rocks - (Fractured Rock)

An aquifer map was compiled from 1:250,000 scale published surface geology and imported in digitised format onto the Department's Geographic Information System (G.I.S.). A map showing all public lands was also compiled using the G.I.S.

Within the constraints of the project study field survey methodology was designed to maximise data capture.

Field surveys have included:

- Reconnaissance work to gather basic groundwater data (ie bore location, depths, yield and water chemistry). Areas surveyed included all highland parts of the study region as well as the western half of the Clarence-Moreton Geological Basin;
- Geophysical surveying using frequency domain electromagnetic traversing and vertical electrical sounding methods. Survey areas included alluvial and dune sand areas within the Tweed, Brunswick and Clarence River Basins (the Richmond Valley was previously investigated in the 1970's);
- Test drilling at five (5) selected locations to provide geological control for interpolation of the geophysical data.

Separate reports have been prepared for each of the field survey activities described.

The bulk of the groundwater data for this study was extracted from HYDSYS INTEGRATED the Department's Resource Information Data Base. The aquifer system map facilitated the compilation of relevant data sets supported by field survey data obtained during the study.

Quantified information about each aquifer system has involved a synthesis of data obtained from various components of the study.

Results

The study has enabled a systematic audit review of groundwater resources of the region with respect to identified aquifer to be achieved. It has incorporated Department records of 2168 bores of which 643 sites have chemical analysis of groundwater sampled.

Study findings indicate that there are important groundwater resources located in the Upper North Coast region. To put the overall groundwater resource into perspective there is an estimated 45 million megalitres (ML) of groundwater in storage. This volume may seem substantial, but quite often the water is hard to gain access to or it is too saline for any beneficial uses. Notwithstanding, the study indicates that the total sustainable yield from the region is estimated to be very large and in the order of 750,000 megalitres, renewable on average each year through recharge

Useful groundwater resources occur in all aquifer systems identified in the region but by far the most significant occur in coastal sandbeds, fluviatile alluvium of the river basins and basalts of Tertiary age that form some of the plateau areas. Groundwater potential of the porous rock aquifers of the Clarence-Moreton Geological Basin varies somewhat due to poor quality. Aquifers associated with the basement rocks are generally of low salinity but available bore yields are small.

The Beach and Dune sandbed aquifer extends along almost the entire length of the seabord and it is estimated to contain some 2 848 950 ML in groundwater storage. This aquifer is highly permeable and bore yields from the sand beds up to about 35 litres per second (L/s) are recorded. The groundwater is of excellent quality with a median total dissolved salt content of 130 milligrams per litre (mg/L). Sustainable yield per year is estimated at 212,500 ML and present usage is 3000 ML per year.

Low salinity groundwater (less than 1500 mg/L total dissolved salts) associated with the coastal river alluvium are mostly contained in sediments of fluviatile origin. The study confirmed that useful groundwater reserves in the Tweed, Brunswick and Clarence river alluvium only occur in fairly limited upstream areas. Hence, overall potential of the alluvium of these valleys is only moderate. However, significant low salinity groundwater resources occur in the Richmond River alluvium where the volume in estimated storage is estimated to be 255 000 ML. Present usage is around 4180ML.

Tertiary basalts and associated volcanic rocks of the region constitute the most important aquifer in terms of its potential as a resource as well as present abstractions rates. These volcanic terrains occur extensively around Lismore in the north, with much smaller localised areas elsewhere in the south. Some 725 bores representing almost one third of all bores in the region have been constructed into this aquifer. It is a reliable groundwater supply resource with bore yields of 0.5 to 15 L/s. Water quality is good with medium total dissolved salt content value of 182 mg/L. Total volume of groundwater storage is estimated to be 17.8 million megalitres; sustainable yield per year is estimated to be 78 000 ML and present usage is 8800 ML per year.

Groundwater associated with rock formations of the Clarence-Moreton Geological Basin is characterised by small bore yields (around 0.5 L/s) and rather variable quality. The Kangaroo Creek Sandstone aquifer is judged to have the best potential. Total groundwater usage from all porous rock aquifers of this Geological Basin presently do not exceed 2000 ML per year.

Basement rock aquifers comprise metasediments such as strongly folded slates, phyllite, quartzites and the like as well as granite masses. In general, groundwater resource development of these aquifer systems is fairly minor; bore yields are low however good quality groundwater occurs widely in them.

Using the G.I.S. the study has integrated public lands with identified aquifers. Public Lands represent a total proportion of 35% of the region occupying 10,500 square kilometres. However, the proportion of public lands is not uniform. Almost half the Beach and Dune Sand aquifer representing an area of 314 square kilometres comprise public lands. Within the alluvial valleys the proportion is quite small varying between 5% and 10% for each valley aquifer system. The Tertiary basalt terrain occupy some 898 square kilometres or 23% of the total aquifer system's area. The largest area of public lands are located within metasediments of the New England Fold Belt (4906 square kilometres).

From the environmental perspective, groundwater systems in the study region have been closely examined because of the potential impacts to soils, surface water and ecosystems such as wetlands. It is recognised that not all groundwater constitutes a resource but land use practices may impact on streams and their associated environments where a water table may either rise of fall.

An important finding of the study was that from the reconnaissance surveying there is no evidence of regional water table rise causing adverse impacts such as dryland salinisation, notwithstanding that localised areas where this form of land degradation have been recorded. However, extensive areas where estuarine flats have been drained to permit farming pursuits and the associated environmental impact causing acid sulphate soils in some of these areas is a major concern.

All groundwater systems are environmental receptors and can transmit contaminants to more sensitive water environments and/or reduce the usefulness of the groundwater resource. The most vulnerable groundwater systems are those with shallow water tables under permeable soils. The shallow alluvial and coastal sandbeds are in this category, together with the basalt lavas and some of the granite terrain aquifers.

Benefits

In summary, the benefits/uses of this study are:

- the report provides specific groundwater resource information concerning available yields and water quality of the aquifer systems identified;
- the report provides information about the present commitment of each aquifer system in terms of a source of water;
- the report enables the beneficial resource value of each aquifer system in the regional sense to recognised;
- using the G.I.S. the significance of an area of public lands to the local groundwater resource can be evaluated where such a study may be required at a future stage; and
- the report is a reference document where possible water supply development is being considered.

INDEX
VOLUME 3

SCOPE NOTE TO INDEXES

The Regional Report includes a detailed index to each individual volume as well as a combined index to all volumes which appears in Volume 1, Setting the scene.

Each subject entry in the indexes have been referenced to the section heading number in which the subject appears. In the combined index the section heading number is preceded by the volume number in bold.

For example: algal blooms, **3** 5.3.3; **4** 5.2.4. The bolded numbers denote volumes 3 and 4 and the light numbers denote section headings 5.3.3 and 5.2.4.

A

B

C

L

M

N

O

P

R