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Tomago Tomaree Stockton groundwater : technical review

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TOMAGO TOMAREE STOCKTON
GROUNDWATER

TECHNICAL REVIEW

D. Woolley, T. Mount and J. Gill



February, 1995

New South Wales Government
Building a Better Environment



**TOMAGO TOMAREE STOCKTON
GROUNDWATER.**

TECHNICAL REVIEW

Don Woolley

Trev Mount

Jan Gill

NSW Department of Water Resources

February, 1995.

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February, 1995.

Cover photograph:

TOMAGO/STOCKTON SANDBEDS:

View from Anna Bay village, SW along Stockton Beach towards Fullerton Cove. Tilligerry Creek separates the Outer (Stockton) Dune System from the Tomago Sand Ridge in the background (photo courtesy RAAF Williamstown, September, 1993).

Cover design by Brooke Dean & Trev Mount.

Preface

The groundwater in the Tomago/Tomaree/Stockton area is important because it is a source of good quality water for community uses and it helps to sustain the local environment. Increasing pressures on this groundwater are expected because of anticipated population growth in the area. Experience overseas points to the need to plan before decisions are made which could affect the long-term status of groundwater resources.

When the Hunter Water Board became the Hunter Water Corporation in 1992 responsibility for ensuring sustainability of groundwater in the Tomago/Tomaree/Stockton (Newcastle Bight) sandbeds was transferred to the Department of Water Resources. The Department's Water Policy Division recognised the need for a plan to enable the Department to manage this groundwater in a way that reflects the community's priorities. The plan which will be prepared will help to ensure that land and groundwater resources are managed compatibly for the future.

This technical review of the Tomago/Tomaree/Stockton groundwater aims to provide a comprehensive picture of the groundwater resources, the associated environment and the various human activities which affect groundwater. Its purpose is to enable interested individuals, institutions and corporations to assess the issues and propose directions for the management of the groundwater. It will also provide the Department of Water Resources with a basis for some decision-making about the groundwater, following consultation with the community.

The review was compiled between August 1993 and February 1995, as a joint project by the Department's Water Policy Division and Hydrogeology Unit of the Technical Services Division. It brings together information concerning groundwater quantity and quality from a range of both published and unpublished sources.

Copies of this publication are available from:

Water Policy Division
Department of Water Resources
12th floor
10 Valentine Avenue
Parramatta 2150.

The 1:100,000 suite of maps (see figures) is preserved on Autocad-Hyddraft file and is available on disk. It can be used to display portions of the maps at various scales and to combine features from individual maps as overlays to assist in decision making.

Copies of the disk are available from:

Hydrogeology Unit
Environment Branch
Technical Services Division
Department of Water Resources
5th floor
10 Valentine Avenue
Parramatta.

The Department would appreciate comment on the information, including the maps, contained in this publication.

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- Jan Gill, DWR* legislative and policy direction; principal authorship of chapter 1, authorship of chapter 4, extensive liaison regarding Hunter Water Corporation licensing policy.
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This report is based on information supplied by the Newcastle Bight community and those responsible for its future; governments, local councils, service organisations, interest groups, defence services, industry, corporations, consultants and individuals.

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ABBREVIATIONS USED IN THIS REPORT

AHD - Australian height datum

BOD - biological oxygen demand

BP - before present

CaLM - Department of Conservation and Land Management

COD - chemical oxygen demand

DC - development control

DoP - Department of Planning

DWR - Department of Water Resources

EP - equivalent persons. This is based on a figure of 240 litres of flow per day per person

EP & A Act - Environment Planning and Assessment Act 1979

EPA - Environment Protection Authority

GL - gigalitre (1,000 megalitres or 1,000,000,000 litres)

GWEC - groundwater extraction complex

HWB - Hunter Water Board (which became the Hunter Water Corporation in 1992)

HWC - Hunter Water Corporation

HDWB - Hunter District Water Board (which became the Hunter Water Board in 1988)

LEP - local environmental plan

LG - Local government

ML - megalitre (1,000,000 litres)

NPWA - National Parks and Wildlife Act 1974

NPWS - National Parks and Wildlife Service

PS - pumping station

PWD - Public Works Department

REP - regional environmental plan

SEPP - state environmental planning policy

SPCC - State Pollution Control Commission (which was replaced with the Environment Protection Authority in 1992)

STW - sewage treatment works

SWI - salt water intrusion

TOC - total organic carbon

TCM - total catchment management, as defined in section 4 of the Catchment Management Act 1989.

TDS - total dissolved solids

WHO - World Health Organisation

WQ - water quality

GLOSSARY OF TERMS USED IN THIS REPORT

Aeolian

Relating to, or produced by, the wind.

Alluvial

Fine soil particles (such as sand, clay or silt) deposited on land adjacent to a stream, usually during flooding.

Anions

Negatively charged ions.

Aquifer

Geological formation or formations capable of transmitting and yielding significant quantities of water.

Aquitard

Aquifers which have a very low capacity to transmit water.

Arcuate

Shaped like an arc.

Bore

A hole sunk into the ground, used to pump water or for observation purposes.

Carboniferous Period

The geological period during the Palaeozoic era when the Earth's coal deposits were formed, commencing about 355 million years ago and ending about 265 million years ago.

Cations

Positively charged ions.

Diagenesis

Early stages of rock formation.

Effluent

Waste products that are discharged into the environment.

Embayments

Coastal bays.

Erosional horizon

Rock level representing a period of erosion.

Facies

A body of rock or sediment distinguished from other bodies (often of a related kind) by appearance or composition.

Groundwater

Water stored below the earth's surface in water bearing zones called aquifers.

Humate

A salt or ester of humic acid, an acid derived from humus. Complex decomposed and decaying plant or animal matter in the soil. Humus is the natural, essential fertilising agent in ecosystems. It imparts a characteristic dark colour to the topsoil and determine to a large extent the capacity of the soil to hold water and its ability to retain the nutrients released by decomposition.

Hydraulic gradient

The change in static head per unit distance in a given direction. (Head = energy contained in a water mass, produced by elevation, pressure or velocity).

Hydrochemical

Pertaining to the chemistry of water and substances in it.

Hydrogeology

The study of groundwater.

Hydrostratigraphic analysis

Assignment of groundwater related characteristics to geological formations.

Inliers

Small bodies of bedrock protruding through younger sediments.

Leachate

That which is leached from a source.

Lithology

The scientific study of rocks, in particular their appearance and physical properties.

Morphological

Relating to the external appearance of an organism, such as size, shape, colour and number of structures.

Palaeochannels

Ancient channels now buried and obscured by younger sedimentary deposits.

Permeability

The capacity of a rock or sediments to transmit fluid.

Permian Period

The last of the six geological periods of the Palaeozoic Era, commencing about 265 million years ago and ending around 240 million years ago. During this period the reptiles rose to dominance, and many modern insect families became established.

Petrology

The scientific study of the nature and history of the Earth's crust, and the rocks that are found within it.

Ph

A measure of the acidity or alkalinity of a solution, numerically equal to 7 for neutral solutions, increasing with increasing alkalinity and decreasing with increasing acidity.

Physiography

The study of the Earth's surface features and the way in which they have developed.

Piezometer

A slimline bore hole for measuring changes in groundwater pressure and/or velocity.

Planimetrically

Measured with a planimeter to determine area.

Pleistocene

The earliest geological epoch of the Quaternary Period immediately following the Pliocene, between about 1.8 or 1.5 million and 11,000 years ago. During the Pleistocene four great ice ages occurred. These ice ages produced most of the major non-volcanic features now seen on the Earth's surface. The level of the oceans

rose and fell with these ice ages, and climates, fauna and flora also varied greatly. The epoch also saw the rise to dominance of modern humans.

Podsol

Soil consisting of a thin layer of decayed or decaying organic matter.

Progradation

Advancement of the shoreline in a seaward direction by addition of sediment, usually over a long time.

Quaternary Period

The most recent of the periods of the most recent geological era (the Cenozoic Era) commencing about 1.5 and 1.8 million years ago. The Quaternary consists of two epochs, the Pleistocene and the Recent. During the Quaternary Period the human species rose to prominence throughout the world.

Seismicity

Relating to earthquakes.

Sink

An area bonded by a closed contour on the watertable.

Spearpoint

A device with a pointed end which is driven into soft ground to collect groundwater from shallow depths.

Swale

A linear depression formed by wind erosion, or by the build-up of ridges either side of an area of land.

Transgressive

Relating to the advance of the shoreline into the landmass.

Yield capacity

The average annual amount of groundwater that could be extracted from a bore over a long period of time without causing permanent reduction of groundwater quantity, quality, and other undesirable effects.

1. INTRODUCTION

1.1 Background to this study

Groundwater makes up around 10% of the water used by people each year in NSW, mainly for urban supply, irrigating crops, stock use and industry. It is certain that this use will increase because surface water is heavily committed. Groundwater is also important in sustaining rivers and other ecosystems such as wetlands.

Australia's aridity and growing dependence on groundwater makes conservation and protection of groundwater resources imperative. The groundwater in the Tomago/Tomaree/Stockton aquifers is a significant community asset because it is generally high quality water and is located close to Newcastle. Elsewhere in Australia it is uncommon to find high quality groundwater close to a major city.

The process of developing a Groundwater Management Plan for the Tomago/Tomaree/Stockton aquifers and associated groundwater began in October, 1993. The Minister for Land and Water Conservation, the Hon. G. Souris, MP, announced that a study would be carried out, as the first step in developing a management plan for the area's groundwater resources. Mr Souris called for information and views from the community on groundwater issues in the area. Submissions were received from various organisations and individuals (see Appendix 1).

1.2 The study area

The study area is located on the central coast of New South Wales immediately north-east of the City of Newcastle as shown in Figure 1.1. The aquifer system which forms the study area covers an area of 275 km² along a coastal strip some 10-15 km wide extending from from the Hunter estuary near Stockton to Tomaree Head at the entrance to Port Stephens. The boundaries of the study area are described in Chapter 2 of this report.

Within the study area, the key feature is an extensive series of sand deposits from which groundwater is drawn mainly to supply Newcastle and the surrounding district. These deposits, which are referred to in this report as part of the Newcastle Formation, are defined and described in section 2.2.

1.3 The objectives of this study

If aquifer systems are to be sustainably managed, it is essential to have an understanding of their characteristics and of the characteristics of the land systems in which they occur. The Department of Water Resources (DWR) has carried out a study of the aquifer system in the area and now, with the help of the community, aims

to develop a plan for sustainably managing this system, and the associated groundwater and ecosystems.

This study:

- assesses the Tomago/Tomaree/Stockton aquifer system and identifies areas where data are insufficient for proper conclusions to be made;
- identifies the current and potential human and ecosystem demands on the aquifer system and the likely impacts of these demands;
- assesses the likely impacts of present and future land use on the aquifer system and its associated groundwater;
- identifies areas of risk requiring attention to ensure the long-term use and protection of the aquifers and their associated groundwater and ecosystems, based on current knowledge.

1.4 Groundwater and aquifers

Groundwater, in its broadest sense, includes all water stored below the ground surface. Only 2.7% of world water resources are freshwater (the rest is ocean) and nearly all of it is groundwater. In New South Wales groundwater resources are estimated at 5110 million megalitres* - 200 times more water than is stored in dams. Groundwater use by humans currently represents about 10% of total water use in the State. It is certain that this use will increase because surface water is heavily committed. At the same time groundwater is important in sustaining valuable ecosystems, such as wetlands (NSW Government 1994).

The term 'aquifer' is used to describe the groundwater and the earth materials (including the overlying unsaturated zone) that provide both the underground storage space and the medium through which the groundwater moves. The term 'aquifer system' is used to describe a series of earth materials which include more than one aquifer as well as intervening aquitards.

These systems, like other natural systems, can be subjected to a number of alternative and often conflicting uses as the population, industry, and agriculture of an area develop. Competition for available groundwater resources and the use of aquifers, together with a growing understanding of the effects the different uses of groundwater systems can have on the environment, has increased the awareness of the need for effective management.

*1 megalitre equals the volume of a cube 10 m by 10 m by 10 m.

1.5 The role of the Department of Water Resources in groundwater management

NSW Government policy is to ensure the sustainable use of natural resources. Under the *Water Administration Act 1986* the control and management of groundwater resources in New South Wales is the responsibility of the Minister for Land and Water Conservation. The Minister carries out his responsibilities through the DWR. The Act requires the Department to manage groundwater in a way that balances social, economic and environmental needs.

The DWR aims to manage water resources in ways which:

- slow, halt or reverse any degradation in groundwater resources;
- ensure long term sustainability of the system's biophysical characteristics; and
- maintain the beneficial use of these resources.

To achieve these objectives, the DWR attempts to:

- ensure the sustainability of both the quality and quantity of groundwater resources for the present population and future generations;
- ensure the needs of environmental systems dependent on groundwater are met;
- ensure groundwater management is consistent with other natural resource management strategies;
- provide a mechanism to allocate the resource and resolve conflicts over competing claims;
- provide effective, cost efficient and acceptable enforcement provisions;
- recognise differing perceptions of groundwater problems or values;
- integrate the management of surface and groundwater sources where appropriate; and
- make provision in regulatory arrangements for scientific uncertainty.

The DWR develops and administers water resource policies for the State. These policies broadly address the economic benefits of water use, the importance of the water to local people and communities and to the environment.

Further details of the legislative, policy and institutional factors relating to groundwater in the Tomago/Tomaree/Stockton area are set out in Chapter 4.

1.6 Managing groundwater licensing

The DWR also issues entitlements to extract groundwater to a range of users from government authorities, business and industrial users through to individuals in the community. These entitlements are usually in the form of bore licences. A bore licence enables the licence holder to construct a bore and use an amount of groundwater for a specific purpose. They are issued under Part V of the *Water Act 1912*.

These licences usually have conditions designed to protect groundwater resources and reflect the availability of groundwater, the quality of the water, vulnerability of the aquifer system to damage from further extraction or pollution and both existing and future uses. The conditions attached to each licence should be derived from a Groundwater Management Plan for the aquifer in question.

Management effort is concentrated on areas of greatest groundwater demand and use. These are usually areas that have high quality and high volume aquifers where there is considerable demand placed on the resource. The management challenge is usually to achieve an equitable sharing of the resource among competing demands and users and the overall objective is to ensure that the groundwater use is managed in an ecologically sustainable way. To achieve sustainability, both the quantity and the quality of groundwater need to be managed, ie groundwater resources need protecting from both overuse and damage through pollution.

More details of the licensing systems are given in Chapter 4 of this report.

1.7 The effects of land use on groundwater

In aquifers where the watertable is not separated from the land surface by impermeable layers the quality of water in them is vulnerable to contamination by some land uses.

This is particularly the case with the Tomago/Tomaree/Stockton groundwater because the watertable is shallow and the unsaturated zone above it is highly permeable and can easily transmit contaminants from the land surface to the watertable.

Where groundwater pollution is a major problem, such as in parts of the United States, experience has shown that remedial works for groundwater pollution can be very difficult, costly, time-consuming and not always successful. Many aquifers are so polluted that they are now of little value to the communities they once supported.

It is clear that prevention is better than cure. Therefore, a holistic groundwater study for the Tomago/Tomaree/Stockton area needs to consider land use.

1.8 The history of groundwater management in the study area

Unlike most aquifer systems in NSW, the aquifers of the study area do not have a history of management by the DWR. From 1892 until the end of 1991 the former

Hunter Water Board (HWB) and its predecessor organisations managed these groundwater resources and regulated their use.

The former HWB first used the groundwater resources of the study area in January 1939, when water was drawn from the Tomago Sandbeds (Fig. 3.5) to supply Newcastle. Since then, the Board (now the Hunter Water Corporation) has made increasing use of the groundwater resources of these sandbeds to supply water to Newcastle and the surrounding district. Growth has also occurred in the use of the groundwater by other users, such as commercial users and households with spearpoint access to the aquifers.

The former HWB also had powers within defined special areas to issue permits for the extraction of groundwater and to regulate activities and developments on land above the groundwater that might cause a decline in groundwater quality. These special areas cover the parts of the aquifer systems in the Tomago and Tomaree area used by the Board (see Fig. 5.1). Groundwater quality in the sandbeds has remained generally quite high throughout the special areas. Also, part of the Crown land at Stockton has been declared a water reserve, which has helped to protect the quality of the groundwater resources in the Stockton area.

On 1 January 1992 the Board was corporatised, becoming the Hunter Water Corporation (HWC), a state-owned corporation. It has continued to use the area's groundwater resources, but its responsibilities towards the resource have changed.

1.9 The consequences of corporatisation of the Hunter Water Board

Corporatisation of Hunter Water in 1992 gave it much stronger commercial objectives than it had as a Board. For this reason, it is inappropriate for it to continue to hold regulatory powers, because of the potential for conflicts of interest to arise between its objectives as a commercial organisation and broader State water resource management objectives, which require balancing economic, social and environmental needs.

Under the *Hunter Water Board (Corporatisation) Act 1991*, the Director-General of the DWR was given statutory responsibility for the care, control and management of land overlying a large portion of the groundwater in the study area.

Although under current legislation the HWC has a statutory right to water resources, in the future the Corporation's water use will be controlled by a licence issued by the DWR. The Department will have overall responsibility for management of the groundwater resources of the Tomago/Tomaree/Stockton Sandbeds, while the HWC will retain day-to-day responsibility for its operations in the sandbeds.

1.10 The users of groundwater in the study area

Many people associate the groundwater resources of the study area with the former HWB because of its long history of extracting large amounts of groundwater from the area to supply Newcastle and the Nelson Bay area. Public water supply by HWB has

been the primary use of the groundwater in the area. Groundwater is a much more reliable source than surface water for public water supply. Unlike the water drawn from the Williams River system, it does not suffer from blue-green algae outbreaks and is relatively immune from drought.

There are many other users of the area's groundwater ranging from golf courses, light industry, small farms and orchards to individual households. Many local residents have backyard spear points and have come to regard the aquifer system as a source of water for outdoor use. The residential development around Salt Ash is not supplied with reticulated water and, for this reason, residents in this area rely quite heavily on spearpoint water.

A major feature of the study area is the dependence of some ecosystems, such as wetlands and some forests, on shallow groundwater.

Groundwater users in the area include:

- native plants and animals
- the HWC and its customers
- government authorities
- industry
- mining interests
- local farms and light industry
- golf courses and recreational users
- small area farms
- the RAAF
- recreational users
- individual households (with & without reticulated supply)

In summary, the groundwater of the area is important to many components of the local community. It is also important to local ecosystems, particularly the wetlands and creeks.

1.11 The objectives of the Groundwater Management Plan

The DWR, in co-operation with the community, will develop a Groundwater Management Plan for the Tomago/Tomaree/Stockton aquifers.

The broad objectives of the proposed Groundwater Management Plan are to provide a framework for decision making that will ensure the sustainability of groundwater resources in the Tomago/Tomaree/Stockton area for future generations by:

- providing a structure for making decisions to license groundwater extracted by Hunter Water and other users; and
- providing guidelines which, if followed, will ensure the long term protection of groundwater quality to ensure its viability as a potable water source.

The plan will aim to:

- identify all the issues that impact on the quality and quantity of the aquifers as well as the impact of the aquifer on the environment in the region studied; and
- address all these issues considered important and assess how they might be resolved.

1.12 The process for developing the Groundwater Management Plan

The DWR plans to make available to the community both this study and a booklet that discusses groundwater management issues. The Department is consulting with the community on the issues raised in this study, and holding public workshops.

Comments received from the community will shape the final Groundwater Management Plan.

1.13 The relationship between the Groundwater Management Plan and other projects related to management of water resources in the region

This groundwater management study is part of the work required to be carried out as a consequence of the corporatisation of Hunter Water. This study will guide the preparation of conditions in the Corporation's water licence. As a result of Hunter Water's corporatisation, the DWR is also involved in:

- studies under a water use agreement between the DWR (as the water resource manager) and the HWC (as the commercial water supplier);
- developing a surface water allocation plan for the Williams River;
- developing a regional environmental plan for the Williams River. developing [This statutory plan will aim to protect and enhance the water quality of the Williams River through land use planning. This process is being led by the Department of Planning and involves the DWR, the HWC, the Hunter Catchment Management Trust and the Environment Protection Authority.];
- developing new catchment protection regulations.

These projects are discussed further in Chapter 4.

There is also an environmental study and management plan being co-ordinated by the Department of Conservation and Land Management for Stockton Bight. This project aims to develop strategies for managing land use of the Stockton Beach sand dunes and area inland as far as Fullerton Street/Nelson Bay Road/Marsh Road. A number of government agencies, community interest groups and individuals are involved.

1.14 The structure of this report

The various uses of aquifer systems recognised in this report are classified as direct or indirect. The principal direct use has been the abstraction of groundwater for agricultural, individual, municipal, and domestic consumption. Information on this practice has been drawn from various sources. Other direct uses include mining of sand and heavy minerals, and the disposal of liquid wastes into aquifers. The available data on this practice is summarised.

The groundwater system has also been used indirectly, and often unwittingly, as a sink for other wastes. These include aerosol from industrial and refining plants, leachate from surface dumps, effluent from septic tanks, and agricultural wastes. Data on this type of use is very limited and highly variable in quality, however such information as exists on the sites of past and present use has been gathered. An assessment of the other indirect uses has been made only in general terms.

This chapter sets out the study methods, lists previous studies and gives a detailed description of the study area. Chapter 2 of this report describes the physical, chemical and biological features of the study area that influence or are influenced by groundwater. Chapter 3 describes the features of the groundwater resources of the study area. Chapter 4 describes the policy, legal and institutional considerations in groundwater management. Chapter 5 describes the present development and activities in the study area which influence or are influenced by groundwater. Chapter 6 describes the current uses of groundwater in the study area and the physical, chemical and biological impacts of that use. Chapter 7 describes the impacts of present land use on the groundwater. Chapter 8 sets out options for future management of the aquifers. Chapter 9 identifies issues for future management of the groundwater. More detail concerning some topics referred to in the main text have been provided in appendices.

1.15 The study methods

Proper planning for development and management of aquifer systems requires identification of the aquifer and the available groundwater, followed by quantitative resource evaluation. In addition, alternative strategies need to be formulated considering the various competing uses of aquifer systems. The various alternatives then need to be debated by the community and their relative merits assessed taking the consequences of such strategies into account.

The procedure followed in assessing the resources of the aquifer system in the study area and its actual and potential uses are listed below:

- All relevant data held in the database of the DWR and reports (both published and unpublished) on various aspects of the hydrogeology of the region held by the HWC have been studied.
- Background information on the natural characteristics and human activities in the area were studied, with emphasis on future development.

- Hydrostratigraphic analysis of bore logs of both government and private bores was used to identify the principal aquifer in the area. Results of this analysis together with geological maps prepared by the Geological Survey, were then synthesised to delineate outcrop areas and the subsurface extent (both lateral and vertical) of these aquifers.
- Hydrochemical data from the DWR and HWC database was assigned to the identified aquifers and an initial estimate of the salinity pattern of groundwater in the area was made.
- Past and present uses of aquifer systems in the Tomago/Tomaree/Stockton area, obtained mainly from the HWC, as well as local government, were summarised.

In addition to the presentation of data on the occurrence of these practices, the study includes an analysis of their effects on the groundwater in order to:

- identify any constraints that these effects might have on the future use of the resource and,
- suggest what might be the consequence of continuing the practices in the future.

The result of these analyses provide an indication not only of the conceivable uses of the resource, but also the likelihood of a demand arising for each use in various parts of the Tomago/Tomaree/Stockton area.

1.16 Previous studies

1.16.1 *Geology and mining*

Early descriptions of the study area's geology focused on basement rocks, including an outline of the Permian coal measures (David, 1907) and Carboniferous volcanics (Osborne, 1950). The Eastern Myall Block was set in regional context by Scheibner (1993).

The geology of the Port Stephens district was described by Engel (1962). Humate cementation in the Tomago sands, producing a hardpan described under various local names which have been summarised in Thom (1965), who also noted that the distinctive layering was a giant groundwater podsol (also in Dorman and Vernon, 1993).

Galloway in 1965 commented on the former course of the Hunter River while palaeochannels as much as 50m below sea level were noted in the Tomaree area by Merrick (1980a).

District mapping at 1:250 000 allowed Engel (1966) to summarise regional geology in the accompanying notes.

Descriptions of the Quaternary facies are provided by Chapman et al. (1982).

The principal reference work on the Tomago/Tomaree/Stockton sandbeds is currently the description of the coastal geomorphology and Quaternary geology by Thom et al. (1992). Details include descriptions of the sandbeds in terms of two major cycles of marine advance and retreat, a comprehensive outline of geological and geomorphic processes, and an analysis of the principal depositional environments.

General properties of the Quaternary strata, such as thickness, form, petrology, genesis, and relationships are poorly documented in the wider literature.

1.16.2 *Hydrogeology and groundwater contamination*

The Tomago/Tomaree/Stockton sandbed aquifers have been extensively investigated since the 1930s. However, early hydrogeological comment is mostly contained in the various internal reports of the Hunter District Water Board, relating to the extraction of town water supplies, or to the impacts of sand mining.

The first major report on the Tomago aquifer was a review on the impact of sand mining on groundwater resources for the HWB by Soil Mechanics Limited (1971).

Supplementary investigations, which included large scale pumping tests, were conducted by Herzog and Gerard (1973), and Hindley et al. (1975).

Viswanathan (1979, 1980, 1985, 1990; Hartwell and Viswanathan, 1983; Viswanathan and Evans, 1983) also commented extensively on aquifer properties, while Merrick (1979) conducted geophysical investigations of the sands from Salamander Bay to Anna Bay.

Similar hydrogeological studies were reported of coastal sandbeds at Tea Gardens, to the north of the Tomago/Tomaree/Stockton region, by Drury (1981).

Coffey Partners International Pty Ltd have been involved in assessments of groundwater contamination at the Tomago smelter site (1990) and impacts of the Grahamstown Storage on waterlogging (1992), and have also been involved in the preparation of the environmental impact statement (EIS) for proposed residential subdivision at Fern Bay (1992).

Groundwater conditions at CSR's Masonite Factory waste-irrigation site were examined for the company by Environmental and Earth Sciences (1992, 1993).

Thom et al. (1992) also remarked on aspects of sandbed hydrogeology; however, the major report on the subject was the detailed analysis of the impacts of sand mining on the aquifer by D J Douglas and Partners Pty Ltd (1993b) for the HWC.

2. NATURAL CHARACTERISTICS OF THE STUDY AREA

The area covered by this study and the proposed Groundwater Management Plan is 'all lands underlain by the Newcastle Formation (including areas defined here as the 'Tomago, Stockton, and Tomaree* Sandbeds')'.

The Groundwater Management Plan will cover the whole of the major sandbed bodies that host the groundwater; not just the water that may be present at a point in the aquifer (depending on flow, pumping activity, and the season). It is important to ensure that the total subsurface pore space, whether saturated or unsaturated, is managed, as much as the groundwater itself.

Minor extensions of the sandbed aquifers in fringe areas do extend beneath the sea, eg along the Stockton Beach and other coastal embayments. The contained water is saline and of no obvious economic use. For effective resource management, however, circumstances may arise where, strictly, the area covered by the study is recognised as including these submarine extensions of the sands. More practically, however, the 'mean low water mark' can be taken as the boundary.

In detail, and at the present state of knowledge, the margins of the aquifer are defined as follows (see Fig 1.1 and Fig 2.1):

- **Ocean coast:** From the Hunter River mouth at Stockton, north-east along the beach to Tomaree (South) Head at Shoal Bay.
- **Port Stephens:** From Tomaree Head to Tilligerry Creek, around the Tilligerry Peninsula and into Big Swan Bay at the mouth of Twelve Mile Creek. There is no need to include small islands of bedrock off the Nelson Bay - Tanilba Bay coast, but the various 'mud islands' of the Tilligerry estuary are covered by this study.
- **Northern:** This is a land-based margin, defined geologically as the edge of the Tomago sands. Note, however, that the land to the immediate north provides rainfall run-off which recharges the sand aquifers, and some consideration of this area is necessary (see area C2 on Fig. 8.2).
- **Hunter River:** The western edge of the study area follows the eastern bank of, first, the Williams River north of Raymond Terrace, then that of the Hunter River to its mouth at Stockton. This is mostly the western boundary of Port Stephens Shire which is used for convenience to mark the limit of the study area into Fullerton Cove. Wallis', Bunn's, and Smith's Islands at the cove mouth are included in the area. Small inliers of Permian bedrock (described below), such as at Raymond Terrace and north of Tomago, are also included in the study.

Before any worthwhile management procedures can be developed and implemented for any natural resource, and particularly for a renewable one, some knowledge of the characteristics

* (known as the Anna Bay/Nelson Bay sands)

of the resource and its role in the natural environment is essential. The occurrence, movement and quality of groundwater is dependent on many factors, but the most important is usually the geology of the region because this determines the type of framework in which the water is stored and moves and the consequent matters of storage capacity and quality. Climate is also critical, because replenishment of water in the aquifer is dependent on rainfall. The shape and character of the land surface is important, because they will influence what happens to rain when it reaches the land - for example, whether it will run off to surface streams, concentrate in local pools and evaporate, or infiltrate into and past the soil. The type of vegetation in a region will, in turn, influence the proportion of infiltrating rain water which will be returned to the atmosphere by transpiration and the residual amount which is left to infiltrate to the aquifer.

There are also parts of the natural environment which are dependent or inter-dependent on groundwater, either directly or indirectly. Native fauna may depend on natural outlets of groundwater (springs, for example) as a source of water, or on vegetation which is in turn dependent on a shallow watertable. Many wetlands, and consequently their associated fauna and flora, are dependent on groundwater for their long-term stability.

The parts of the natural environment which are of importance when considering the management of groundwater in the Tomago/Tomaree/Stockton area are discussed in the following paragraphs.

2.1 Physiography

The study area is readily divided into two main morphological provinces that reflect the distribution of sand, and also the types of bedrock. They are named here as the Tomago-Stockton Province and the Tomaree Hills Province and described in the following sections. The main difference between them is that landforms in the former are formed entirely from young, unconsolidated coastal sediments, while in the latter the topography is dominated by hills of hard bedrock which are partly obscured by a veneer of sand.

2.1.1 *The Tomago-Stockton Province*

This province encompasses all the project area west of a line from Birubi Point near Anna Bay village to the mouth of the Tilligerry Creek (Fig. 2.1). There are several elements in the landscape of this province:

- **The Stockton Dune Ridge.** This feature, running parallel to the coast between the villages of Stockton and Anna Bay generally has an elevation above sea level of 15-20 m. It is composed of a series of parallel smaller dune ridges, with intervening lowland swales tending to swamps, located between the Pacific coast and Tilligerry Creek. These land forms have been produced by aeolian and marine forces and there is little evidence of fluvial modification. This dune system is also known as the 'Outer Barrier Dune System' (eg Thom et al. 1992).
- **The Tomago Dune Ridge.** This is the 'Inner Barrier Dune System' (eg Thom, op.cit.) It resembles the Stockton province in character and origin but it is older, wider, and more complex. As the first sands to be laid against the ancient coast it has been more influenced

by bedrock form, and by fluvial processes in the adjacent hinterland. The maximum elevation is 59 m at Duckhole Trig but the ridge crest is mostly below 10 m, with scattered 10-20 m ridges.

- **The Tilligerry Valley.** This is a typical example of an interbarrier depression, separating the Tomago and Stockton sand ridges. The valley is shallow, broad, and flood prone, its flat floor dominated by poorly-drained waterlogged soils and dark muds. It is an estuary or back-barrier lagoon that has been almost completely filled and abandoned by the sea. Fullerton Cove and the so-called Tilligerry 'Creek' (an extension of the Port Stephens Estuary) are interpreted as the last remnants of a tidal waterway that once extended along the back of the Stockton Dune Ridge.
- **Minor landforms.** The northern part of the study area contains the remnants of several ancient valleys, as at Grahamstown and Medowie, that drained the hinterland before being blocked by the Tomago Sand Ridge. Permian bedrock forms rounded hills at Raymond Terrace.

2.1.2 *The Tomaree Hills Province*

This is the area east of the 'Anna Bay line' and the landscape varies considerably in relief (Fig. 2.1). The form is controlled by the underlying geology and is dominated by a scattering of small conical peaks or inselbergs of hard bedrock that rise to over 150 m above sea level. Irregular narrow valleys that wind between the hills are flanked by alluvial slopes and floored by sand, with some low ridges which reflect an aeolian or bay-beach origin. The Tomaree Hills were a minor archipelago of small near-shore islands that are now surrounded by sand imported by the wind and sea. The process is incomplete and the marine component is documented by the embayed character of the modern ocean coast where sandy moon-shaped embayments alternate with ragged bedrock bluffs. Lowland sandplains pass to swamps in many areas of the hills.

2.2 **Geology**

An understanding of the geology of the study area is absolutely crucial to any proposal for groundwater management. There are two main reasons for this, which relate respectively to quantity and quality aspects. The land of the area is, almost without exception, formed on unconsolidated sand deposits which have a high degree of porosity and permeability. In other words, the sands are good at storing and transmitting water and hence form a very valuable aquifer from which useful quantities of water can be withdrawn. However, the very factor which makes the sand such a good aquifer, renders it particularly vulnerable to contamination. Because the sand is permeable for the full thickness between land surface and water table (the characteristic which enables ready replenishment from rainfall), there is a similarly ready path for contaminants.

The essential elements of the geology of the Tomago/Tomaree/Stockton area, in terms of the present study, are:

- the older basement rocks;
- the younger unconsolidated deposits of coastal and estuarine origin; and
- the erosional surface between them.

The erosional horizon developed as a land surface on the older rocks during the Quaternary Period of geologic time, beginning one million years ago. It is now mostly obscured by coastal deposits formed during recent periods of elevated sea levels. The most prominent of these deposits are three sand bodies which are here referred to as the Tomago Sandbeds, the Stockton Sandbeds and the Tomaree (Nelson Bay/Anna Bay) Sandbeds (see Fig. 2.1). The sandbeds are an important part of the coastal deposits which now cover most of the study area, and form the aquifers which are the focus of this study. Marine clay and silt deposits occur beneath and between the sand bodies, and their geometry controls the way groundwater occurs in the area. The following paragraphs explain these aspects of the Tomago/Tomaree/Stockton area in more detail. Distribution of the surface exposure of the various units is illustrated in Figure 2.1.

2.2.1 *Basement rocks*

These rocks form a hard and rigid platform on which the younger coastal and estuarine sediments have been deposited. Compared to the coastal deposits they are quite ancient, those in the eastern area being of Carboniferous age and those in the west being of Permian age. The two areas are separated by a major north-trending fault (the Hunter-Mooki Thrust) in the vicinity of Oyster Cove (see Fig. 2.1) which marks the margin of the Sydney Basin.

The Carboniferous rocks are of volcanic origin, and are exposed in the Tomaree Hills. The Permian rocks are not well exposed in the study area, being completely obscured by the younger coastal deposits. Some low undulating country near Medowie is probably highly weathered Permian. These rocks are part of the Sydney Basin sequence of generally flat bedded or gently dipping sedimentary rocks (sandstones and siltstones). The youngest unit represented (which immediately underlies the younger coastal deposits) is the Tomago Coal Measures.

The basement rocks do not contribute directly to the major groundwater reserves of the Newcastle Bight, since they are relatively impermeable, but they are an important part of the groundwater system as a whole because they form an impermeable limit to the aquifer. In some parts of the area, they comprise the floor of the aquifer, and in other parts they form a lateral boundary.

2.2.2 *The erosional surface on the basement rocks*

Following the geological processes which created the basement rocks and established their structure, there was a very long period during which they comprised a land mass. During this period, the land surface was sculpted by normal erosional forces and attained a shape

characterised by hills and valleys, with relief of several hundred metres. The main feature of the landscape which had evolved by the beginning of Pleistocene time was apparently a valley occupied by an early precursor to the Hunter River, and a land surface with an overall slope towards the east, with the shore being much further east than it is today. Exploration drilling for water, minerals and general scientific purposes has provided a considerable amount of information about the shape of the surface, but no compilation of this data into a comprehensive contour set appears to have been attempted.

2.2.3 The coastal deposits

The land surface was submerged by a rise in sea level concurrent with the waning of the polar icecaps, and the deposition of sediments of marine and estuarine character has been continuous in the Newcastle Bight area since early Pleistocene time. These deposits include the sandbeds referred to here as the Tomago, Stockton and Tomaree sandbeds. The relationships between these and related clay deposits is quite complex at a detailed level. They can be described in a superficial way as the visible remnants of coastal deposition resulting from two periods of sea level rise of about 100 m, with an intervening fall of about the same magnitude. They form a mantle which covers the older land surface except for small areas in the vicinity of the Tomaree Hills where the higher parts of what were islands now appear as outcrop areas surrounded by the younger sand deposits.

The complexities of these coastal deposits have been studied over a period of many years by numerous workers and the results of these endeavours have been integrated and reported in a recent major monograph by several of the main workers (Thom et al. 1992), and the following description of the deposits is largely based on that report.

A six-fold subdivision of Quaternary time, together with the identification of eight principal depositional environments provides a useful way of describing the coastal deposits and the sequence in which they occurred. Table 2.1 details these age subdivisions.

TABLE 2.1: Quaternary time subdivisions and prevailing conditions (adapted from Thom et al. 1992, page 350)

Stage	Years before present	Sea level conditions	Sedimentary processes
Q6	< 3000	Late stillstand	Second & third stages of aeolian transgression & foredune development
Q5	3000 - 6500	Early stillstand	Initial progradation of Outer Barrier; first phase of aeolian transgression
Q4	6 500 - 10 000	PMT within embayment (3)	Marine transgression & backbarrier deposition
Q3	10 000 - 120 000	LG low and oscillating (2)	Aeolian reworking of Inner Barrier; entrenchment of Hunter River.
Q2	c. 120 000	LIG high	Inner Barrier pro-gradation & back barrier infill
Q1	> 140 000	Pre LIG high (1). (Lower than present sea level)	Periods of mud infill behind "proto-barrier"

(1) LIG - Last Interglacial; (2) LG - Last Glacial; (3) PMT - Postglacial Marine Transgression

The eight depositional environments are:

1. Hunter River floodplain-delta;
2. Inner Barrier shoreface;
3. Drowned alluvial valleys;
4. Meadowie bed-rock hinterland;
5. Tilligerry-Fullerton Interbarrier Depression;
6. Outer Barrier shoreface and mobile dunes;
7. Proto-lagoon and tidal estuary; and the
8. Tomaree Hills windfield.

The distribution, form, and relationships of the sedimentary units formed in these basic environments are illustrated in Figures 2.1 and 2.2. These figures also briefly outline the lithology of each unit.

The age subdivision, together with the generalised cross section of the Quaternary deposits in the Newcastle Bight area shown at Figure 2.4, is the basis for the following description based on the work of Thom et al (op.cit.). It is important to emphasise at this point, however, the major difference between the rocks in the underlying basement and the overlying coastal deposits. The basement rocks are hard, rigid, and relatively impermeable, having been subject to rock-forming and earth-deformation processes over a long period of time. The overlying coastal deposits are soft, very young and have not yet been subject to rock-forming processes. They have little or no inherent strength for the most part, and contain a large proportion of sand layers which are even-grained, porous, and permeable. They were deposited during two major cycles of sea level change during the past 140,000 years, and are the remnants of coastal deposits formed during that time.

A further point of note is the nomenclature applied to the coastal deposits. Traditionally, the terms 'Tomago', 'North Stockton', and the 'Nelson Bay-Anna Bay Sandbeds' have been applied and mostly in reference to areas of sand outcrop (eg Fig. 2.1). This usage is awkward, and does not appear to have formal stratigraphic status.

Furthermore, the terms have failed to recognise the three-dimensional form of the sandbeds and the fact that they overlap in places. Figure 2.2 illustrates how the seaward edge of the Tomago aquifer extends under the Stockton Sandbeds at depth, yet no mention of this relationship has been found in references to the Outer Barrier. It is here suggested that the Quaternary coastal deposits of the Newcastle Bight area be named the Newcastle Formation and that the three main areas of sand be referred to as the Tomago Sand Member the Stockton Sand Member and the Tomaree Sand Member. These names conform to geological nomenclature principles, and will be used where appropriate in this report.

2.2.4 *Basal clay, here referred to as the Meadowie Clay*

The basal unit of the sequence of formations in the coastal deposits is a widespread clay formation, deposited as an accumulation of estuarine muds and sand behind a 'proto-barrier' in Pleistocene time prior to the high sea levels of the Last Interglacial (Roy and Crawford 1980). This is Stage Q1 of the Quaternary subdivision shown in Table 2.1. The unit is described as 'Estuarine - lagoonal mud; sand lenses' in Figure 2.2. It is extensive and

lithologically homogeneous (Thom et al 1992, p. 158) and its upper surface has a relatively uniform seaward slope (Ly 1976). The importance of this unit to the Newcastle Bight aquifer system is that it forms the floor, or impermeable base, of the aquifer where the aquifer does not rest directly on the older basement rocks in the Tomaree area. The base of the aquifer system, in other words, can be described by contours drawn on the composite surface of the clay, and of the bedrock where it projects above the upper surface of the clay. A composite contour set, compiled from data supplied by the Hunter Water Corporation, is shown in Figure 2.3.

Some intersections of coarse grained fluvial sand and gravel have been reported beneath the clay ("Fluvial sand and gravel" in Fig. 2.2). Such occurrences might be of some importance, because they could be useful aquifers, but there is insufficient data to enable any reliable attempt to delineate the extent of the occurrence to be made. Exploration of these areas would also be difficult. Nevertheless, these areas should be kept in mind as a possible extension of the main aquifer system.

2.2.5 *Inner Barrier Sand, here referred to as the Tomago Sand Member*

Overlying the Medowie Clay Member, with a disconformable (erosional) contact, is the sand body referred to as the Inner Barrier. It was deposited during a period of high sea level (Stage Q2 of Table 2.1) and subsequent regression (sea level fall) during Stage Q3, when there was aeolian re-working of the exposed deposits. The area is shown in Figure 2.2 as 'Inner Barrier marine and dune sands'. As indicated in Figure 2.2, the sand of the Inner Barrier constitutes a body of sand which slopes towards the sea and which is overlain by younger sand of the Outer Barrier.

It is the exposed part of this sand body which has been called the Tomago Sandbeds. From a strict geological and geomorphological perspective, however, the continuation of the sand body to the east is part of the same structure and warrants the same name. It is proposed, therefore, for the purpose of the present report and pending the establishment of a formal nomenclature, to use the term 'Tomago Sand Member' for the sand body created during Stages Q2 and Q3 (see Table 2.1). Differentiation between the Tomago Sand Member and overlying sand bodies might not be readily possible in all places, however, as indicated in Figure 2.2.

The Tomago Sand Member is an accumulation of beach, dune, and near-shore shelly sands. There are coarser zones and clayey zones in the lowest part, deposited during the transgressive when the sea was encroaching over the Medowie Clay Member.

A soil profile was extensively developed on the upper surface of the Tomago Sand Member following regression of the sea, and prior to the next sea level rise. Where present, this profile is a distinct marker between the Tomago Sand Member and overlying formations. A further major aspect of the lithology of the Member is the occurrence of accumulations of humate material, known variously as 'Woolloomoolo Rock' or 'Coffee Rock'. A possible mode of formation of this material is suggested by Thom et al 1992 (Fig. 4-18, page 140) who regard it as a giant podsol. After deposition of the Inner Barrier sand during Stage Q2, the watertable declined during the following period of declining sealevel (Stage Q3, Last Glacial). Because of the free draining nature of the sand body, humate material moved down with infiltrating

water until it reached the watertable where it accumulated. As sea level rose again during the Postglacial Marine Transgression (Stage Q4), the watertable also rose, and the level of accumulation of the humate rose with it. The zone of humate accumulation now occupies a zone extending between the lowest elevation of the watertable during Stage Q3 and the present watertable, with a thin leached zone above it. The presence of these organic materials is an important distinguishing feature of the Tomago Sand Member but has the adverse effect, in terms of the usefulness of the formation as an aquifer, of significantly reducing the porosity and permeability of the sand.

No adequate description of the lithology of the sandbeds has been found in the published literature, but the classification shown in Table 2.2, based largely on colour and partly on lithology was introduced by Soil Mechanics Ltd (1971). Note that it is partly based on the presence of humate material, which is a secondary feature.

TABLE 2.2: Classification of the sandbeds

Sand classification	Av. depth range, (m)	Description
Upper Light Sand (ULS)	0-2; to 5+ on high dunes	Light brown m-fine sand; also, white, pale yellow, lt grey.
Dark Sand (DS) f-med.-("Woolloomooloo Rock; Podsol B-Horizon)	3-10, to 20 on dunes	Dark brown to black, sand (humic cements in part)
Lower Light Sand (LSS)	2-13	Med-fine sand, tr. coarse; light brown, to yellow and white.
Grey Sand (GS) grey to brown	3-21	Fine-med. sand; light green or light brown.

Not all layers occur everywhere in the sandbeds, there being substantial variation between sites.

The dimensions of the surface exposure of the Tomago Sand Member are:

- length: 32 km;
- width: av. 4 to 14 km;
- area: 152 km²;
- thickness: gen. < 18 m;
- clay base: gen. 9-18 m subsurface (Meadowie Clay);
- highest point: Duckhole Trig; 59.2m asl.

2.2.6 *Outer Barrier sand, here referred to as the Stockton Sand Member and back barrier deposits, here referred to as the Tilligerry Mud Member*

During the period of sea level rise (Postglacial Marine Transgression, Stage Q4), a further body of transgressive marine sand was deposited over the older units (ie deposited over, and obscuring, the sand of the Tomago Sand Member), as shown in Figure 2.2.. There was also substantial deposition of backbarrier sand and muddy sand, and remnants of them are preserved between the Inner and Outer Barrier sands, as shown in Figure 2.2. Following the cessation of sea level rise, during the succeeding stillstand (Stage Q5) there was shoreline progradation, and the sand dunes of the Outer Barrier were formed. The sand bodies associated with these events, ie the Outer Barrier marine and dune sands (see Figure 2.2), will be referred to in this present study as the 'Stockton Sand Member'. Note that this definition implies that the term 'Stockton Sands' as used in the past, and which refers to the full thickness of sand deposits in the Stockton area, consists of two separate entities. The upper part is the Stockton Sand Member, and the lower part is the Tomago Sand Member where it underlies the Stockton Sand Member (see Figure 2.2).

The marine and estuarine sand and mud unit will be referred to in this report as the 'Tilligerry Mud Member'. Its importance from a groundwater perspective is that it partly separates the Stockton Sand Member from the Tomago Sand Member. Its seaward extent is limited but the limits are uncertain. Where it is not present, there is presumed to be hydraulic continuity between the Stockton Sand Member and the Tomago Sand Member.

There is even less recorded lithological information for the Stockton Sand Member than for the Tomago Sand Member, but their similarity of origin suggests that their lithologies will be similar. One important difference, however, is the degree to which humate material has accumulated in the sand. The process of downward movement of humate, and accumulation at the watertable continued to operate after deposition of the Stockton Sand Member and in fact continues to the present day (Thom et al., op. cit.). There are, however, reasons to suppose that the extent of the accumulation, and hence the overall effect on permeability of the sand, is much less than it is in the Tomago Sand Member. There are two main reasons. First, the process has been in operation for a much shorter time. Secondly, there has been substantially less variation in the elevation of the watertable during this period, and any accumulation of humate material will therefore be confined to a much thinner zone.

The dimensions of the surface exposure of the Stockton Sand Member are:

- length: 32 km;
- width: 2-3 km;
- area: 78 km²;
- thickness: 10-40 m.

2.2.7 *Estuarine mud flats along Tilligerry Creek, here referred to as the surface expression of the Tilligerry Mud Member*

During Stage Q6 of the Quaternary Period, ie during the last 3,000 years, the continued high and stable sea level resulted in modification to the dunes of the Outer Barrier, and in the extensive deposition of marine and terrestrial sands and mud in tidal estuaries and bays. The estuarine mud along the Tilligerry Creek alignment, shown as surface deposits between the Inner and Outer Barriers in Figure 2.2, would seem to be part of this depositional sequence. It will be referred to here as the surface expression of the Tilligerry Mud Member.

2.2.8 *Tomaree Sand Member, formerly referred to as the Nelson Bay-Anna Bay Sand Member*

The sand deposits in the eastern part of the area, in the Tomaree Hills physiographic province, have a different origin to those of the Tomago-Stockton Province. As outlined in section 2.1 , the Tomaree Hills Province is west of a line between Birubi Point and Soldiers Point (following Thom et al., op. cit.). This area is characterised by a cluster of prominent hills, which are formed of the Carboniferous age bedrock exposed where the old land surface still projects above the mantling sand. The bedrock surface is complex, resulting from the erosion of strike ridges into a series of hills by fluvial (rather than marine) processes during periods of low sea level (Thom et al., op.cit., p.186). The present land surface, formed by the mantling sand, has a much more subdued relief. Consequently, the thickness of the sand deposits is highly variable. The greatest thickness of sand (and consequently of aquifer) occurs in three main channels radiating from a central area, generally in southerly, easterly and northerly directions.

The sand deposits are thought to have originated from aeolian activity during the Last Glacial Period (Stage Q3, 10 000 - 120 000 years B.P.). An upper unit (2 - 20 m thick) is a uniform dune sand, and it overlies a lower unit which is commonly more than 40 m thick and which is characterised by the localised presence of clay lenses, charcoal fragments and peat (Thom et al., op. cit.). The thicker parts of the lower unit appear to be largely infill of pre-existing channels.

The sand deposits are consistently underlain by a dark grey to black organic clay, whose upper surface does is nowhere above -20 m AHD. This is presumed to be the Medowie Clay Member.

In this report the sand deposits in the Tomaree Hills area, ie east of a line between Birubi Point and Soldiers Point, are referred to as the Tomaree Sand Member. The dimensions of the surface exposure are:

- length: 13 km;
- width: 3-6 km;
- area: 45 km²;
- thickness: 18 m.

2.2.9 *Geological history*

The pattern of distribution of geological formations in the Newcastle Bight region (Fig. 2.4) suggests the following history:

- General uplift of the continental margin initiated following the opening of the Tasman Sea about 80 million years ago. This caused a retreat of seas after high levels during the Cretaceous Period.
- Extensive erosion during the Tertiary Period and extending to the Late Pleistocene (1-65 my BP) leaving hilly landscape on basement rocks of Permian to Carboniferous age. Sharp valleys, cut by streams, extended to submarine canyons on the continental shelf. Alluvial gravel and sand were deposited in these valleys.
- The Late Pleistocene ('Flandrian') sea level rise of about 100m, drowned the coast; and stream channels filled with sand and clay. A proto-lagoon known as 'Tomago Bay' formed.
- A minor sea level fall (3-7 m) initiated 'protobarrier' and extensive lagoon; and the Medowie Clay was deposited extensively.
- With the onset of the 'Last Interglacial' sea levels rose, and marine transgression reworked the upper surface of the basal clay. The Tomago Inner Barrier was initiated; at approximately 120,000 yr BP.
- During the 'Last Glacial' the sea level fell and the shoreline retreated. The Inner Barrier was 'topped' and prograded seaward, following the regression. Podsolis were initiated on Inner Barrier sands. Major aeolian reworking of Tomaree and Tomago Sand Member sands took place.
- Towards the end of the 'Last Glacial' the Outer Barrier was initiated (8-9000 yr BP) as an offshore bar at lowest sea level. Sand of the Stockton Sand Member accumulated as the glacial period waned. Tomago-Tomaree Sands were reworked by wind. The shoreline was at -120 m and 30 km seaward from the present shore.
- During the Postglacial Marine Transgression (10,000 - 6,500 years B.P.) the sea level continued to rise, and the coast advanced. The Outer Barrier accumulated in its present form during the transgression and the Tilligerry-Fullerton Estuary formed in the inter-barrier depression: 'Tomago Bay' became a basin. Fringing dunes and swamps formed at Tomaree. Extensive washovers and tidal deltas occurred as rising seas over-ran earlier sands. Some shoreline erosion occurred around Tomaree, Port Stephens, and the Hunter River.
- During the last 6,500 years, following a minor fall, the sea level has remained stable and there has been aeolian modification of the exposed sand bodies, with anthropogenic deposits and, more recently, disruption of natural systems by European settlement.

2.3 Climate

The climate of the Port Stephens Peninsula is warm humid temperate with important maritime influences from the east contributing to marked seasonal and daily variability (Tweedie 1963, Thom et al., op.cit.).

Three types of air-pressure system dominate the weather, varying in intensity, seasonal incidence, and duration:

- **southern maritime air:** dry, cold, with strong westerly winds;
- **coastal depressions:** low-pressure on-shore maritime air blocked by inland highs; February to September. Cold, wet south to southeast winds; often strong with heavy coastal rain and local floods; and
- **coastal tropical cyclones:** moist warm air in the late summer to autumn. Strong winds and high rainfall with flooding along the coast.

Average daily maximum temperatures range from 21° to 27° in summer, and from 10° to 15° in winter, with an extreme range of 4° to 44°. Rainfall is fairly evenly spread through the year, and mean annual rainfall varies from 1089 mm to 1257 mm in the Bight area. Evaporation is poorly documented but appears to exceed rainfall for much of the year. Figure 2.5 summarises rainfall, temperature, and evaporation data at Williamstown.

Winds are important for dispersing air pollution that may reach groundwater. Descriptions of wind systems in the area vary widely, but the main trends generally recognised are:

- Summer: humid and onshore-maritime, from the south through to SE, east and ENE; some NW, 11-30km/hr 'southerly busters'; and
- Winter: dry continental, funnelled down the Hunter Valley, west to especially northwest; from SE, S, to W in afternoons, 11-50km/hr, autumn - winter - early spring.

Climatic data for the Bight region are widely quoted in the literature, and have been used to prepare the summary presented in the preceding paragraphs. Figures vary between authors and locations, however, and better characterisation of climatic factors and the impact on groundwater recharge might become an important part of the Groundwater Management Plan.

Another climatic factor to be considered is the potential effect of climate change and sea-level rise associated with the phenomenon of global warming. There is at present much scientific debate on this topic and it is therefore difficult to anticipate and plan for changes. However it is anticipated that should it occur, sea-level rise will decrease the capacity of the aquifer to supply water because of the loss of head difference between the aquifer and the ocean. A further consequence of sea-level rise could be the overtopping of the protective embankments and tidal floodgates on drains at each end of the lowlands (section 5.2.3).

2.4 Hydrology: surface water

Most of the study area has a land surface developed on the sand of the Newcastle Bight Sandbeds, with permeable sandy soils underlain by permeable sand. Consequently, there is rapid and effective infiltration of rainfall with very little run-off and no defined drainage pattern except in the areas of bedrock in the inselbergs of the Tomaree Hills geomorphic province.

Topography in the sandbeds area is dominated by marine and aeolian depositional landforms. Elongate dunes and arcuate beach ridges form subparallel sets, separated by linear valleys or swales (see Thom et al., op. cit.). Fields of complex dune forms also contribute to this characteristically hilly dune terrain. Some run off does occur during intense storms and is guided by this rugged landform to converge on the low point of each depression. Swamps or ephemeral wetlands are a common feature of the sandbed landscape (see Fig. 2.6), marking the floors of the largest and lowest depressions.

This process may be described as 'compartmentalized flow and infiltration'. It is a subject that needs further study as it relates to the behaviour of surface pollutants in sandbed terrains and their passage to underlying groundwaters.

Tilligerry Creek is the most prominent surface drainage but for much of its it is broad and flanked by mangrove mudflats length (see Fig. 2.6). Here it is clearly a tidal estuary, part of the larger Port Stephens complex. Above Salt Ash village the 'creek' narrows and merges with an extensive network of agricultural drains that continue along the floor of the Tilligerry lowlands, past Long Bight Swamp, to join with Fullerton Cove (Fig. 2.1). The system forms an axial drain for the Tilligerry interdunal depression, the water flowing to outlets at either the Cove (SW) or the Tilligerry Estuary (NE).

Unlike the dune areas, soils along the Tilligerry trend are clay rich and infiltration is expected to be very low. Also, the watertable is shallow. A large proportion of rainfall will run off under these circumstances, but the floor of the depression is barely above sea level and almost flat. Surface water movement is therefore sluggish with negligible erosional power. Extensive waterlogging and floods can therefore follow intense rainfall, and is only gradually relieved by the agricultural drainage network.

Groundwater discharges from the adjacent Tomago Sandbed and Stockton Sandbed aquifers to the agricultural drains. This enhances the gradient of the watertable away from the sand ridge crests, as indicated by the watertable contours shown in Fig. 3.2.

There is an area of established natural surface drainage in the low bedrock hills just beyond the northern boundary of the sandbeds (Fig. 2.1). Several minor streams of ephemeral character have cut shallow valleys from north to south across the hinterland. The pattern can be traced back to times of low sea level in the Pleistocene when the streams were open to the sea (Thom et al., op.cit.). Deposition of the Tomago Sand Member across the trend (Fig. 2.1) blocked the outflow, damming the surface flows to be dissipated by infiltration into the barrier ridge. Of the original stream systems, Nine Mile Creek now flows into Grahamstown Storage and another (consisting of Pipeclay and Twelve Mile Creeks) flows into Oyster Cove. However, several small watercourses throughout the Medowie area remain barred by the sands and have no outlet to the sea. Drains have been constructed in this area but much of the surface runoff from the region is thought to enter the sandbed aquifers via Moffats Swamp (Fig.2.6). Further

investigations are required, but this mechanism is suggested as a way of transferring urban and agricultural contaminants from the Medowie area to the northern edge of the Tomago aquifer. Some of this groundwater may then discharge into drains which lead to the Grahamstown Storage (see flow lines in Fig. 3.2 and drains in Fig. 5.3).

Other significant surface water movement can be expected after intense rain on the impermeable clays of the extensive floodplains that border the Hunter River south of Raymond Terrace (eg Fig. 2.6). However, all drainage from this area is to the River, with little or no backflow into the sandbed aquifer where groundwater flow lines are directed against the trend (Fig. 3.2).

Flooding in the Newcastle Bight project area is attributed to two major causes:

- high flows in the Hunter River that transgress the flood plains, breaking into Fullerton Cove and extending along the Tilligerry lowlands past Williamtown. This may be termed exogenic flooding and is related to heavy rainfall caused by travelling depressions.
- high rainfall on impermeable rocks and soils, generating high local runoff on areas such as:
 - the Tilligerry estuarine plain;
 - the Hunter River floodplain;
 - clay-based wetlands and swamps; especially the Murrumburrimbah Swamp near Anna Bay (Fig. 2.6); and
 - bedrock inliers as in the Tomaree Hills and around Raymond Terrace to Tomago.

This is termed endogenic flooding and is most common between January to August when coastal cyclonic rains occur.

One body of surface water that is profoundly important in its influence on the Bight's groundwater systems is the adjacent South Pacific Ocean and its estuarine extensions into the Hunter River - Fullerton Cove, Tilligerry Creek, and Big Swan Bay. All three main aquifer systems, Tomago, Stockton, and Tomaree have major portions of their sand margins overlapped by estuaries or the sea, typically mangrove mudflats or wave-swept ocean beaches. As the flow lines in Figure 3.2 show, it is only the elevated head of groundwater stored in the dune ridges that keeps the sea water from moving landward and invading the aquifer sands.

Sea spray carried by onshore winds must be a major source of salt in the groundwaters of the Bight area, although part of the load is being re-exported to the sea by groundwater discharge along the Tilligerry lowlands and into the various bays where the aquifers extend to the coast.

2.5 Native flora*

The dominant vegetation types in the region are well described (eg Shortland Wetlands Centre 1993; Department of Environment and Planning 1983b) the most recent vegetation assessments being completed in 1993 for the Port Stephens Shire Council to delineate an important koala habitat. This survey determined the extent of broadly-classified vegetation groups across the project area. Several more detailed surveys have been conducted for environmental impact studies throughout the area, focussing on individual sites.

The physiography of the study area has a primary influence on vegetation type. There are four distinct landforms of relevance to floral groups in the study area:

- **Inner Barrier Dunes:** the Tomago sandbeds - dominantly free-draining quartz sands with scattered marshlands;
- **Estuarine Interbarrier Flats:** waterlogged lowlands between the inner and outer dunes extending from Fullerton Cove to the Tilligerry Estuary;
- **Outer Barrier Dunes:** the Stockton Sandbeds - clean, highly permeable wind-blown sands and beach ridges;
- **Tomaree Hills:** aeolian sand sheets and beach deposits (Tomaree Sandbeds) amongst scattered bedrock peaks.

Vegetation is dependent on geology, soil characteristics, micro-climate and surface/groundwater drainage patterns for each landform type. It follows that landform boundaries can be used to divide the vegetation into ecologically distinct zones. Ecological links between each landform are provided through the influence of vegetation on local climate, migration patterns of fauna, human activities, and seed dispersal.

The broad vegetation types for the project area include (eg Shortland Wetlands Centre 1992, Department of Environment and Planning 1983b):

- **Dry Sclerophyll Eucalypt Forest** - in protected areas on well-drained soils and coastal sands.
- **Dry Sclerophyll Eucalypt Woodland** - in exposed areas associated with low nutrient soils on coastal sands.
- **Casuarina - Melaleuca Forest** - freshwater swamps bordering coastal sands and associated with dune depressions within sclerophyll forests.
- **Melaleuca Shrubland/Heath** - freshwater swamps on poorly-drained and frequently inundated areas.

* Sections 2.5 to 2.7 which describe the natural biological environment of the Newcastle Bight region, are based on a contribution by M. Sheather-Reid of the Environmental Studies Unit, DWR (March, 1994), which was reviewed by G. Winning of the Shortland Wetlands Centre in October 1994.

- **Grassland/Regenerating Forest** - on land previously cleared for pasture or sand mining.
- **Littoral Grassland** - dense wet grasslands associated with temporary inundation.
- **Littoral Swamps** - shallow aquatic herblands associated with temporary inundation.
- **Sedge Swamps** - shallow semi-permanent to permanent wetlands with regular inundation.
- **Spinifex Foredunes** - associated with open ocean beaches consisting of a variety of sand-binding grasses, succulents, and mat plants. Behind the open beaches the foredune tops are usually covered in Wattles (*Acacia longifolia* var. *sophorae*) forming dense sprawling shrubs.
- **Wooded Hind Dunes** - protected beach dunes dominated by *Leptospermum laevigatum*, *Banksia integrifolia*, and Smooth-barked Apple (*Angophora costata*).
- **Mangroves** - highly salt tolerant vegetation in tidal areas dependent on freshwater recharge from groundwater and surface runoff.
- **Saltmarshes** - sedges and succulents in estuarine areas favouring highly saline areas.

A 1983 study by the Department of Environment and Planning found the above areas within the Hunter Region; vegetation communities similar to those of the project area also occur at Myall Lakes. However, the Newcastle Bight dune forests appear to be distinctly different from those of the Lakes. Particular vegetation occurrences such as *Eucalyptus robusta* and *Melaleuca quinquinervia* on the dunes appear to be unique to the project area. The wet heaths and fringing *Eucalyptus gummifera* woodlands in the dune swales do not occur at Myall Lakes. The occurrence of very old *Eucalyptus grandis* trees probably represents the southern limit of the species range. Mangrove and saltmarsh areas around Fullerton Cove are a highly significant habitat for waterbirds, as well as supporting a complex marine fauna. Larger areas of dune swampland and heath are considered important as they are of limited extent and are unique to the Bight area (Department of Environment and Planning 1983b).

Extensive areas of undisturbed contiguous vegetation exist particularly along the Stockton dunes and the mangrove areas of Fullerton Cove. These areas are highly significant as wildlife habitat. Even the disturbed areas have additional value as faunal corridors between areas used for hunting, breeding, and foraging.

The predominant factors influencing vegetation structure and species composition vary between each landform type. Vegetation of the Tomago, Stockton, and Tomaree sandbeds is predominantly dependent on surface and groundwater drainage patterns, micro-climate created by varying topography, and nutrient characteristics of the soils. During drought periods vegetation may draw on deeper aquifers, but generally tends to have a high drought tolerance through inducing physiological changes throughout the plant.

Many plants in the Newcastle Bight area tend to rely on the local watertable to some degree. In the case of dry sclerophyll forests and woodlands, trees have been known to extend their roots over fifty metres to the watertable and to depend largely on groundwater during

drought. Shrubs, grasses, and other ground covers rely much more on local rainfall, but shrubs often extend their roots into shallow aquifers for drought protection.

The vegetation in permanent to temporarily inundated wetlands is highly dependent on the local watertable, relying heavily on soil moisture during dry periods. The plants have specialised water requirements, depending on the duration of inundation and fluctuations in the watertable. For example, a decreased frequency in the inundation of Melaleuca Forest may result in a gradual shift to plant species that prefer dryer soils, such as Casuarinas and Eucalyptus. Other factors, such as exposure to drying winds, airborne salts, concentration of soil and groundwater salts, and nutrient status tend to have a secondary influence on plant mixes. The sensitivity of wetlands to changes in water levels makes them a good indicator of the initial impacts of groundwater abstraction. Wetlands are discussed in more detail in section 2.8.

The vegetation in all the sandbed areas where the watertable is shallow, say less than two to five metres from the surface, is likely to be highly dependent on the local aquifers as the major source of freshwater. It is likely that most plants would tolerate natural fluctuations in water level of about one to two metres with roots extending into the watertable. The effect of greater fluctuations would require study before conclusions could be made with confidence.

Over an extended period, say ten to fifty years, increased water stress on the vegetation might result in any or all of:

- thinning of eucalypt forest to eucalypt woodland;
- the increased dominance of drought-tolerant grassland and shrub species;
- reduction of overall vegetation height; and
- contraction of wetlands.

There is no validated evidence that groundwater withdrawals over the past fifty years have had a discernible impact on the vegetation of the sandbeds area. It is possible, perhaps, that some less common plants dependent on the specific climatic, nutrient, and soil moisture conditions could suddenly disappear from the area. Any future proposals to extensively lower the water table through groundwater abstractions should be preceded by appropriate investigation of the system so that withdrawals can be planned and managed in accordance with desired outcomes and, if approved, significant stands of vegetation sensitive to groundwater fluctuations should be monitored.

2.6 Native fauna

The fauna of the project area is highly dependent on the natural vegetation communities to provide diverse and extensive areas for food, shelter, nesting sites, and social interaction. It tends to be opportunistic, invading areas dependent on the quantity, type, and diversity of available food. It follows that any cumulative or individual change in vegetation will affect the health and behaviour of the fauna of the study area.

The sensitivity of organisms to vegetation changes is often expressed as an animal's tolerance to stress, rather than to the impacts of environmental catastrophe. It is these subtle changes which determine the degree to which natural systems can be manipulated for beneficial uses such as water supply. Common fauna are usually more adaptable to changes in habitat as the most important habitat requirements (for example, water, food, and shelter) have not deteriorated to the extent of endangering the species. They may modify their feeding behaviour (for example, longer feeding hours), migrate to better areas, become more aggressive, or produce less young. Cumulative changes, such as those which can be speculated upon as a response to groundwater abstraction, need to be monitored carefully to avoid more subtle changes such as a reduction in the size of a population or a reduction in its resistance to disease.

Endangered species of the study area are listed to focus further studies and monitoring as to which species might be affected by groundwater abstraction. G. Winning from the Shortland Wetlands Centre has listed endangered fauna that occur around the Grahamstown Storage (Fig. 2.6). This area includes a wide variety of habitats found within the Bight's sandbed areas and may be used as a preliminary list of species to focus monitoring (Winning March 1993, pers comm.). The endangered species of the Newcastle Bight region include:

- the Koala (*Phascolarctos cinereus*);
- the Squirrel Glider (*Petaurus norfolcensis*);
- the Spotted-tailed Quoll (*Dasyurus maculatus*);
- the Common Bent-wing Bat (*Miniopterus schreibersii*);
- the Little Bent-wing Bat (*Miniopterus australis*);
- the Greater Broad-nosed Bat (*Scoteanax rueppellii*);
- the Yellow-bellied Sheath-tail Bat (*Saccolaimus flaviventris*);
- the Eastern Chestnut Mouse (*Pseudomys gracilicaudatus*);
- the Powerful Owl (*Ninox strenua*);
- the Masked Owl (*Tyto novaehollandiae*);
- the Glossy Black Cockatoo (*Calyptorhynchus lathami*);
- the Regent Honeyeater (*Xanthomyza phrygia*);
- the Bush Thick-knee (*Burhinus magnirostris*);
- the Green and Golden Bell Frog (*Litoria aurea*).

Further investigation into the habitat requirements of these endangered species is required to prioritise monitoring.

2.7 Wetlands

2.7.1 Wetland types

A wetland is an ecosystem which is transitional between terrestrial ecosystems and truly freshwater aquatic or marine ecosystems. The generally accepted determining characteristic of wetlands is the influence of waterlogging on soil and on biological processes. Whilst there are

many approaches to defining wetlands, it is reasonable to describe wetlands as being areas of land covered by shallow water (permanently or intermittently) and/or which support vegetation that is adapted to growth in waterlogged soils.

The combination of the particular geological and geomorphological features in the Newcastle Bight area has resulted in a landform in which wetlands are an important feature (Fig. 2.6). The wetlands of the area can be grouped into two broad classes - estuarine wetlands and dunal wetlands.

Estuarine wetlands:

Along Tilligerry Creek and along the north channel of the Hunter River, land subject to tidal inundation supports mangrove and saltmarsh wetlands, as well as extensive mud flats. These wetlands are important fisheries and waterbird habitat. The shallow waters of Fullerton Cove are important habitat for migratory waders. This value has led to the wetlands of Fullerton Cove and those of nearby Kooragang Island being included in Kooragang Nature Reserve, as well as being listed on the 1971 Convention on Wetlands of International Importance (Ramsar Convention).

The dominant hydrological influence on these wetlands is the tidal estuarine water. The influence of groundwater would be limited, although any surface breakout of groundwater discharging through estuarine wetlands would affect the overall salinity of the water in these wetlands, and therefore influence the vegetation.

Dunal wetlands:

The extensive dunes and sand plains of the Newcastle Bight area support a large number of wetlands, many of which owe their existence to the influence of groundwater. In swales between dunes, the watertable is shallow and, in some cases and under suitable conditions, is at or above ground level. Wetlands establishing in these situations are often referred to as 'water-table window wetlands' because they occur in places where the land surface intersects the groundwater.

The water level in watertable window wetlands rises and falls with the groundwater. The water regime in any particular wetland is therefore determined by the depth of the swale or the degree to which it intersects the groundwater. Some deeper swales are permanently inundated, and support vegetation dominated by sedges (Family *Cyperaceae*) and restiads (Family *Restionaceae*), although no emergent vegetation occurs in deeper parts of the wetlands (>ca. 1m).

Areas which are inundated when the groundwater level is high but otherwise support no surface water, often allow the establishment of swamp forest vegetation. The dominant tree species in swamp forests in the study area is Broad-leaved Paperbark (*Melaleuca quinquenervia*), but Swamp Mahogany (*Eucalyptus robusta*) is also common. Swamp forests are important habitat for koalas and other fauna in the study area, due to the high moisture and nutrient content of the leaves relative to other forests on the dunes. In some low-lying areas the groundwater level rarely rises above the ground surface, but is typically close to the surface (within ca. 1.5-2m). These areas often support a mix of Broad-leaved Paperbark,

Swamp Mahogany and some of the more typically dryland species, such as Smooth-barked Apple (*Angophora costata*) and Scribbly Gums (*Eucalyptus haemastoma* & *E. signata*).

The swale running along Nelson Bay Road in the vicinity of Fern Bay coincides with an interface between the sands of the Holocene outer barrier dune and estuarine deposits of silts and clay. The swamp forests occurring along this swale have Swamp Oak (*Casuarina glauca*) intermixed with the other tree species as a result of the influence of the estuarine soil.

A swale east of Medowie has developed along the interface between bedrock and the Pleistocene inner sand barrier. This swale dips below the groundwater in this area, forming a 'dune-upland contact wetland', called Moffats Swamp, which is a complex of sedgeland and swamp forest. The northern part of Moffats Swamp is a Nature Reserve.

In a few locations where groundwater lies (on average) approximately 2 metres below the soil surface in larger swales, the interaction between the groundwater and organic matter from decomposing plant material has resulted in the formation of a semi-permeable soil layer called an organic pan. Temporary waterlogging of the soil above the organic pan after heavy rain prevents the establishment of trees in these areas, and the vegetation is instead dominated by shrub species, such as Paperbark Tea-tree (*Leptospermum attenuatum*), Ball Paperbark (*Melaleuca nodosa*) and saw-toothed Banksia (*Banksia serrata*). Water rarely ponds on the land surface in these *wet healthlands*. Although groundwater does not directly influence the vegetation of these areas, its influence on soil formation is an indirect determining factor on the character of the vegetation.

'Perched wetlands', so named because they are perched above the regional water-table, can occur in dunes in places where an impermeable or semi-permeable soil layer impedes percolation of rainwater and results in permanent or temporary inundation of a topographical depression in the dunes. Perched wetlands are uncommon in the Newcastle Bight area. A number of shallow ephemeral ponds develop in wind-formed depressions along the beach between Cox's and Lavis Lanes. A thin layer of sand accreted by salts forms a semi-permeable base in these ponds, but inundation is too temporary to support wetland vegetation although they do support briefly lived communities of aquatic invertebrates.

Two larger wetlands with perched watertables occur within the grounds of the Hunter Region Botanic Gardens, where the western edge of the Pleistocene sands is underlain with impermeable silt and clay soils of the Hunter River floodplain. These 'floodplain-dune contact wetlands' support typical dunal wetland vegetation due to the influence of the overlying sands, although the presence of some Swamp Oak is indicative of the presence of the underlying fluvial deposits.

2.7.2 *Values and threats*

The importance of wetlands has been recognised only recently. Many wetlands in New South Wales have been drained or severely damaged by flood mitigation, agriculture and other development since European settlement. The values of wetlands include:

- flora and fauna habitat;

- breeding and nursery habitat, especially for fish;
- nutrient recycling;
- sediment trapping;
- flood water retention;
- agricultural uses, especially for grazing during droughts;
- landscape quality; and
- recreation and education.

Although the pressure on wetlands has lessened now that their value has been recognised, they are still threatened by human activities. In urban areas, there is still pressure to fill or drain wetlands on private land to allow development, and stormwater runoff which carries many pollutants is often directed into wetlands. Artificial wetlands are now often constructed as part of large urban developments to filter stormwater run-off before it flows into natural waters. In rural areas, wetlands are seen as valuable drought-refuge grazing land, some wetlands are seen as a source of irrigation water, and in inland New South Wales, larger wetlands are used for cropping when they dry out. Many of these agricultural uses of wetlands can be compatible with other wetland values provided there is some balance between competing uses. Most wetland types are also at threat from animal and plant pests, such as pigs and noxious weeds.

Because they occur on generally low nutrient soils, dunes and dunal wetlands have traditionally been seen as being of little value for human activities, especially agriculture, and many have remained largely intact. However, with the increasing urbanisation of our society, there are increasing demands for residential development in coastal areas, with previously undeveloped dunal areas becoming the focus of development interest. Apart from the potential clearing and filling of wetlands that may accompany urban development, because of their location low in the landscape, wetlands are often targeted as discharge points for stormwater run-off and, less often, for treated sewerage effluent. Such discharges can result in localised changes in the groundwater regime and/or the water regime of the wetland, thus affecting the vegetation of the wetland.

Many of the wetlands in the Newcastle Bight area have been provided a degree of protection through gazettal under *State Environmental Planning Policy 14 - Coastal Wetlands* (NSW Department of Planning 1993), which requires that any development proposal in these areas be accompanied by an environmental impact statement. A 1990 Land and Environment Court decision - *Myall Koala & Environment Support Group v Great Lakes Shire Council*, 17 Oct.1990, (unreported) - confirmed the role of SEPP 14 in protecting coastal wetlands, strengthening the role of this statutory planning instrument. This case involved a third party appeal against a decision by the Council granting consent to its own construction of a boat ramp which involved clearing, draining and filling land. The proposal was seen by the Court as incompatible with the aims of SEPP 14, and Council failed to justify the development in terms of the need and lack of feasible alternative sites.

The mapping for SEPP 14 excluded several wetland types, including Swamp Mahogany swamp forests, which are locally valuable as fauna habitat.

3. GROUNDWATER RESOURCES IN THE TOMAGO/TOMAREE/STOCKTON AREA

Groundwater is present in many types of geological formation in the upper part of the earth's crust. There is a very great range in the ability of the various formations to store and transmit water, depending on the character of the formation. Large masses of hard crystalline and essentially impermeable rocks may be capable of storing and transmitting water because of a network of fractures through them caused by earth movements since their formation. Some sedimentary rocks, such as sandstone, formed by individual sand grains cemented together, may retain sufficient pore space between the grains to provide a small, moderate or even a high level of porosity and permeability. Some younger deposits, which have not yet been consolidated by the lengthy process of rock formation, can retain a high degree of intergranular porosity. Fluvial sand and gravel deposits, and coastal sand deposits are important examples of such deposits. The water-bearing sediments of the study area constitute a classic example of a coastal sands aquifer, and the groundwater resources contained in them comprise a water resource of national significance.

Information on attributes and uses of aquifer systems is set out in Appendix 2. Further information on groundwater occurrence, and particularly on its occurrence in New South Wales, is provided in the publications *Groundwater In New South Wales* 1984(Water Resources Commission,) and *Our Water* 1994(Department of Water Resources, second edition).

The following sections provide an outline of the aquifer system in the Newcastle Bight area, including the mode of occurrence of the water, its quality, the storage capacity, and the relationships with adjacent water bodies.

3.1 Hydrogeology

The occurrence of groundwater in the Newcastle Bight area is related very closely to the geological features of the area as described in Chapter 2. Although groundwater is stored in, and moves through, all geological units in the area, the older basement rocks can be regarded as an impermeable floor for the younger, unconsolidated deposits which contain the most useful amounts of groundwater. These younger deposits are themselves highly variable in their capacity to store and transmit water, and the geometry of the various member units of the Newcastle Formation exerts a controlling influence on groundwater occurrence and movement.

3.1.1 *The water cycle*

In its simplest terms, the water cycle commences with rainfall, part of which can be returned to the atmosphere by evapotranspiration, some forming runoff to creeks and rivers, and some lost as infiltration to groundwater. The proportion of rainfall which infiltrates to groundwater varies with the type of land surface, and can be very low or even zero where the land is formed of impermeable formations with little soil cover. Conversely, where the land surface is underlain by permeable material it is possible for runoff to streams to be practically zero, and

the proportion of rainfall infiltrating to groundwater can be high. The runoff to rivers returns rapidly to the ocean, where it is again subject to evaporation and precipitation as rain. The water which infiltrates to groundwater also moves back towards the ocean but may return to the ground surface to either evaporate, or to join the surface stream system before it reaches the coast. These concepts are illustrated in Figure 3.1.

The study area is, in general, land with a high proportion of rainfall infiltration and very little or no runoff. Infiltrating water from rain reaches the watertable rapidly and fills some of the empty pore space in the sand above it. That is, the watertable rises. This increases the hydraulic gradient between the recharge area and discharge area, and causes an increase in the rate of outflow. Outflow, or discharge, is concentrated in the lower parts of the land area, and in the context of the Bight area this means around the base of the dunes, in the swales, or direct to the ocean or an estuary. Thus, rainfall on the sandbeds infiltrates to the watertable where it is added to the groundwater storage, and then drains either to the low-lying parts of the land surface or to the ocean or estuary. The aims of a Groundwater Management Plan will be to determine how to skim some of this water from the system without a long term impact on natural systems which depend on it, and how to protect water in the cycle from the effects of human development and activities in and around the area.

3.1.2 Newcastle Formation sand members

The most important parts of the Newcastle Formation, in relation to the storage of groundwater, are the three sand members, namely the Tomago Sand Member, the Stockton Sand Member, and the Tomaree Sand Member. These sand members dip seawards, as shown in Figure 2.2, reflecting their deposition as coastal dunes on an advancing and retreating shoreline. In simple terms, the Newcastle Bight aquifer system can be thought of as a single entity, bounded below either by impermeable bedrock or by the relatively impermeable Medowie Clay Member, and with discontinuities and less permeable zones of limited extent represented by zones of humate accumulation in the sand bodies and by the interlayering of discontinuous clayey, less permeable zones. Movement of water within the main aquifer is controlled by the geometry of the sand body and of the bounding impermeable material, the amount and location of recharge from rainfall, and the location of discharge zones. The storage capacity is controlled by the volume and porosity of the sand below the watertable.

The geometry of the sand body as a whole is defined by the present land surface above and by the Medowie Clay Member together with the areas of shallow bedrock below. Figure 2.3 is an integration of these, based on data supplied by the Hunter Water Corporation, using computer contouring techniques. It is subject to revision as additional data are obtained. The distribution of less permeable zones within the main sand body is less well known, particularly along the Stockton-Anna Bay area where there is little information on the Stockton Sand Member and the underlying Tomago Sand Member.

3.1.3 Groundwater movement

Movement of water within the aquifer system can be described by contours drawn on the watertable. In some parts of the area, there are sufficient data points to enable this to be done with some degree of confidence, but in other parts (including most of the Stockton Sand Member outcrop area) there is very little. Figure 3.2 shows a compilation of watertable contours from various sources. There are some gaps in the plot, in particular the large

proportion of the Stockton Sand Member outcrop area, and the Anna Bay-Salamander Bay area of the Tomaree Sand Member, where there is apparently no data on groundwater levels. There are also some discrepancies between the D J Douglas contours and, respectively, the Coffey Partners International contours in the Tomago Smelter area and the Environmental and Earth Sciences contours at the CSR Masonite Factory, but these three data sets are from times separated by about three years. There are also some areas where contours appear to have been extended beyond the area occupied by the aquifer (e.g. south-west of Medowie), and this probably results from extrapolation in areas of sparse data points. Additional observation points in some of these areas may become necessary, as part of the implementation of a Groundwater Management Plan.

The important feature of groundwater movement, as indicated by these contours, is that water moves from the most elevated part of the aquifer in the Tomago area towards discharge zones at or near the shoreline. It can reasonably be assumed that the similar pattern shown by the contours in the Fern Bay area can be extrapolated along the whole of the Stockton Sand Member area, with a similar pattern of groundwater flow. Since it is also reasonable to assume that rainfall is evenly distributed over the whole area, and that the potential for recharge is similarly evenly distributed, it is clear that the major control on the natural pattern of groundwater flow is the location and elevation of the discharge zones. This is perhaps stating the obvious, but it is a first step towards a more analytical study of the system. Factors requiring further study and/or additional data, are the large areas where no groundwater levels are available, the historical pattern of water level change and its relationship with rainfall pattern and groundwater withdrawals (if any), and an analysis of the detail variations in the contour pattern.

There are several aspects of the pattern of groundwater movement suggested by the contours of Figure 3.2 on which some comment is warranted. Firstly, there appears to be very little distortion to the contours by the groundwater pumpage at that time (May 1993), with the exception, perhaps, of some irregularities associated with the CSR site on Masonite Road (Fig. 3.2, Fig. 7.1).

Secondly, there is an apparent sink south-west of Medowie, with closure of the 6 m and 5 m contours. There is apparently no groundwater pumped from the vicinity, but the feature coincides with the Grahamstown Drain which conducts water from periodically flooded land near Medowie to a discharge point into the Hunter River near Raymond Terrace. It appears that there is a substantial groundwater discharge to this drain. Some of the water table contours in this area appear to have been drawn beyond the limit of the aquifer boundary and further analysis is needed in this area.

In the Tomago Smelter area, there is a difference of interpretation between the Coffey and Douglas representations of the watertable, in addition to the difference in elevation (which is presumably due to the time difference between measurements). Both show a local recharge zone, with groundwater flow radiating from the area, but the shape and extent are different. The Coffey interpretation has some advantage, because it shows what appears to be a realistic interpretation of groundwater flow into the North Channel (Fig. 3.2). Further analysis of the groundwater system in this area might be warranted as part of the Groundwater Management Plan.

Some quantitative aspects of groundwater movement are discussed below, on the basis of limited published data.

The rate of movement between two points in an aquifer is controlled by the difference in hydraulic head between the two points and by the hydraulic conductivity of the aquifer between them. Hydraulic conductivity is the term used to formally describe the capacity of the aquifer to transmit water through a one square metre area, and is a more specific way of describing the characteristic commonly referred to as permeability. It can be measured directly by observations in specially constructed piezometers, but is more usually determined from controlled pumping tests which sample a larger part of the aquifer. Analysis of pumping tests initially provides a value for transmissivity, which is equivalent to the conductivity multiplied by the thickness of the aquifer.

The value of transmissivity for the Tomago Sand Member is reported to range from 100 to 4000 m²/d, with a general increase from west to east (DJ Douglas and Partners P/L 1993). The average value has been reported as 400 m²/d and 500 m²/d by Viswanathan (1990a and 1990b). The reported range of values for hydraulic conductivity is mostly in the range 10 to 20 m/d, although DJ Douglas and Partners used a range of 30 to 100 m/d for the purposes of computer simulation of the aquifer.

Because hydraulic conductivity controls the rate at which water moves through the aquifer, it will control the rate at which recharge water moves through the aquifer system. If the rate of recharge exceeds the rate of the aquifer to transmit water for any significant period, the water table in the lower parts of the area will rise until it reaches ground level and water is discharged to the land surface. In the study area context, this means that there could be short term spring discharges along the toe of the dune ridges after heavy rain.

The storage co-efficient and hydraulic conductivity values of the various parts of the aquifer control many aspects of the way the aquifer works. These include the height to which the watertable will rise after rain and, more significantly, the rate at which water can be withdrawn by pumping and the effect that any particular pumping schedule will have on the aquifer. Considerable effort to determine these factors is therefore warranted for the Groundwater Management Plan.

A further aspect of the aquifer which influences groundwater movement is the layer of humic cemented sand (Woolloomooloo Rock) which is prominent within it. Because of its lower permeability it will inhibit groundwater movement, and this may be of particular importance in the recharge process.

Estimates for hydraulic conductivity in the Stockton Sand Member indicate a range of 12 to 20 m/d, and for transmissivity a range from 480 m²/d to 600 m²/d. An important factor in groundwater movement within this part of the aquifer system is the relative absence of the less permeable Woolloomooloo rock, such as occurs in the Tomago Sand Member.

The direction of movement of groundwater in the Tomaree Sand Member aquifer is indicated by the watertable contours in Figure 3.2. It moves down the gradient from the elevated area south of Nelson Bay, south towards discharge zones along the shore, or by subsurface flow to the ocean. Although not shown because of lack of data, there must be a comparable, but steeper, gradient to the north with groundwater flowing into Port Stephens. The watertable

gradients are quite steep, and the rate of groundwater movement is expected to be relatively high. No data on hydraulic conductivity has been found, but values are unlikely to be much smaller than those for the Tomago or Stockton Sand Member aquifers and hence groundwater could be expected to drain rapidly from the higher parts of the aquifer.

3.1.4 Natural groundwater discharge

The location and rate of natural groundwater discharge is a further aspect of the aquifer system which requires attention. There are no quantitative estimates available for total groundwater discharge rate from the Tomago/Tomaree/Stockton aquifers, but in the long term it will be in balance with recharge. Some water will be lost through evapotranspiration, especially in the lower lying land where the watertable is shallow, and in total the volume of this loss might be greater than direct discharges to swamps, estuaries, and the ocean.

The critical areas will be where vegetation is dependent on the shallow watertable (wetlands, mangroves in particular). The rate of groundwater discharge at these locations will be determined by the local hydraulic gradient. In order to maintain an acceptable rate of groundwater discharge in these locations, groundwater withdrawals will have to be managed in such a way that these gradients are not disturbed. Quantitative studies will be necessary if the aquifer is to be used in such a way as to maintain the current discharge conditions or, alternatively, the consequential effects of using the aquifer in such a way that they are changed.

3.2 Groundwater quality

The quality of groundwater is determined by all processes and chemical reactions that have acted on the water from the moment it is condensed in the atmosphere to the time it is finally discharged from the sub-surface flow system. These factors are outlined in Appendix 2, which includes a flow diagram as a model for hydrochemical interpretation.

There has been a considerable amount of information obtained about the quality of groundwater in the Newcastle Formation aquifer system, but there appears to be no comprehensive report available on this aspect of the aquifer. The following information is taken from various sources and provides a summary of the overall pattern, with some reference to specific aspects.

Quality of groundwater is measured by several factors, some of which are inter-dependent, and which vary in relative importance between locations and depending on the use to which the water is to be put. The main factors are:

- **total salinity:** depends on the total concentration of dissolved (ionic) sodium, potassium, magnesium, calcium, sulphate, chloride and bicarbonate (which are the most common constituents of natural groundwater);
- **acidity:** measured by the pH value;
- **alkalinity:** determined by the bicarbonate content;

- **hardness:** determined by the calcium and magnesium content;
- **sodicity:** an index of the imbalance of sodium compared to calcium and magnesium concentrations (important for agricultural uses);
- **dissolved gases:** commonly carbon dioxide, oxygen, hydrogen sulphide;
- **minor ions:** dissolved constituents which contribute a negligible amount to the total salinity, but which may be objectionable or undesirable because of the effect of very small concentrations (most commonly iron, manganese, fluoride, nitrogen in various forms, phosphorous);
- **colour:** various methods of measurement;
- **turbidity:** various methods of measurement;
- **temperature;**
- **microbiology:** for example, *Thiobacillus*, *Gallionella*,

All these are, or can be, factors influencing the quality of any naturally occurring groundwater. Contaminants such as pesticides, fertilizers, petroleum products and so on which may also be present in amounts that affect water quality, are discussed later in this report. Contamination may also lead to high values of chemical oxygen demand, biological oxygen demand and TOC, and to microbiological problems (for example *E. coli*).

3.2.1 *Quality of water pumped by Hunter Water*

Water pumped from the Newcastle Formation aquifer system by Hunter Corporation and its predecessors has been uniformly of low salinity, both in total and in terms of the concentrations of the individual ions. Total salinity has been referred to as in the range 60 - 112 mg/L (Viswanathan 1990a), generally about 135 mg/L (Australian Water and Coastal Studies 1990), and generally less than 200 mg/L (Coffey Partners International, 1990). These totals are all very low, and well within WHO limits. The concentration of each of the individual commonly occurring ions is also low or very low (see for example Viswanathan 1990, Australian Water and Coastal Studies 1990, DJ Douglas 1990). Hardness (with a possible exception at Pump Station 14) and alkalinity are low and well within WHO limits (Corlette, 1944, Australian Water and Coastal Studies 1990), as is fluoride with a background level of 0.3 mg/L (Australian Water and Coastal Studies 1990, Coffey Partners International 1990). Little information is available on nitrogen concentration, but it appears to be low. Nitrogen as ammonia has been reported as generally less than 0.5 mg/L (Environmental and Earth Sciences 1993).

There are several aspects of the water pumped, however, which are less satisfactory. The pH level is low (that is, the water is acidic), with a range of pH 4 to pH 6 (Soil Mechanics Limited 1971, Australian Water and Coastal Studies 1990, Coffey Partners International 1990, Viswanathan 1990). Dissolved carbon dioxide is very high, usually in the range 100 -150

mg/L but ranging up to 240 mg/L (Corlette 1944, Australian Water and Coastal Studies 1990). It causes the water to be corrosive, but can be removed relatively easily and cheaply by aeration. Hydrogen sulphide is nearly always present, with a concentration of 0.5 to 1.0 mg/L reported by Corlette (1944) and Australian Water and Coastal Studies (1990). It has an objectionable smell, but can be removed by aeration at the same time as the carbon dioxide.

The concentration of dissolved iron is high to extremely high, and this aspect of water quality is the worst aspect of the quality of groundwater from the Newcastle Formation aquifer system and has received much attention. Records and comments from several sources are listed below:

- **Corlette (1944):** Average, Tomago groundwater: 6 mg/L (range 1.2 -7)
Average, pumping stations 1 and 2: 0.8 mg/L (max. 2)
- **Soil Mechanics Ltd (SML) (1971):**
 - Iron is the most serious pollutant and concentrations vary widely in space and time;
 - Concentration increases with pumping;
 - Oxidation of sulphides produces soluble iron, and sulphate, with a decline in pH.
- **Hunter District Water Board records, 1940 - 1970** (as tabulated below, values in mg/L):

Iron Concentrations (mg/L)

	Min.	Mean	Max	Std.dev. ; n	Location
1940-1970	<1	6.4	80		P.S. 1 - 20
1941-1942		2.4	28		P.S. 7
1946-1949	0.5	3.9	8.5	2.5 , 10	
1946-1970	0.5	5.2	20	4.4 , 33	
1957	Marked increase to high values				
1965-1966	0.5	5.8	20	6.3 , 9	
1967-1970	0.2	4.0	7.7		
1969-1970	0.5	5.8	115.1	4.1 , 14	

- **Evans and Viswanathan 1983:** Average Tomago iron concentration 'is about 3 mg/L.'
- **Johnson (1988):** 'There is a wide spatial and temporal variation, large fluctuation.'
- **Australian Water and Coastal Studies (1990):** 'HDWB studies place the average iron content at 6 mg/L.'
- **Viswanathan (1990):** Tomago varies from 0.1 to 10 mg/L, - usually 1.5 - 3.5
- **D J Douglas and Partners (1993):** Average background iron is 1.5 - 3.5 mg/L, range is from about 1 to 100 mg/L.
- **D J Douglas and Partners (1993):** Tomago average is 4 mg/L (1.5-3.3 in top aquifer; 0.7 - 8.3 in basal aquifer. Scatter plots show an average of 10-16 mg/L pre-mining.

The pattern of dissolved iron is clearly complex, incompletely understood, and the most important aspect of water quality. It is not feasible to provide a comprehensive discussion in this report, but studies of dissolved iron levels will be a continuing aspect of aquifer management. The limit for dissolved iron concentration in water for domestic use is 0.3 mg/L, so it is clear that most water pumped from the Tomago/Tomaree/Stockton aquifers exceeds the limit. The iron can be removed by relatively simple procedures, but the treatment is an added cost to the water supply authority and increases as the concentration increases.

Removal of dissolved iron from groundwater by in situ treatment has been investigated, and field trials in the Lemon Tree Passage area have been reported by Viswanathan (1990) who concluded that the method was feasible. While not conclusively established as a suitable alternative, the method warrants further consideration because of the major treatment costs imposed by iron concentration in water from the Newcastle Formation aquifers.

3.2.2 Quality of water in the whole system

The pattern of water chemistry of the aquifer system as a whole (rather than just the part used by Hunter Water Corporation for water supply purposes to which most of the data in the preceding paragraphs refer) has been examined using data from records of the Department of Water Resources which include sixteen full chemical analyses. This is a small sample, and although it may suffice for a preliminary examination, the conclusions drawn from it cannot be regarded as conclusive. Further detailed work on the regional pattern of groundwater chemistry would be essential to verify these conclusions.

The data from records of the Department of Water Resources is listed in Table 3.1, and plotted in Figures 3.3 and 3.4. The hydrochemical types of regional groundwaters have been assessed by using the system of classification developed by Szuzukariew and Priklonksi (Alekin 1970), and these are summarised in Table 3.2. The chemical type of groundwater is based on the occurrence of those anions and cations which constitute 20% or more of the total anions and cations, calculated in milliequivalents per litre. These ions are listed in order of anionic dominance, followed by cationic dominance. The very limited number of full chemical analyses inhibit interpretation of groundwater hydrochemistry and its evolution, and only generalised observations about the hydrochemical nature of the region's groundwater are possible.

The groundwater chemistry data have been used to assign the water to four geochemical provinces, shown geographically in Figure 3.5 and described below.

1. Tomago Sand Member aquifer

The high recharge co-efficient, high hydraulic conductivity and consequent rapid flow of groundwater through the aquifer, and the short distance to discharge zones, result in groundwater in the Newcastle Formation sandbeds aquifers having a very low salinity. Data from the Tomago Sand Member indicate that the groundwater in it has a salinity ranging up to about 200 mg/L, and mostly less than 150 mg/L. This level of salinity is highly satisfactory for a public water supply, and none of the main contributors to total salinity is individually too high.

Table 3.1 GROUNDWATER HYDROCHEMICAL TYPE, NEWCASTLE BIGHT

GEOCHEMICAL PROVINCE	BORE	TYPE
1 TOMAGO SANDBEDS	17544	Cl-Na-Mg (Cl-SO ₄ -Na-Mg)*
	47309	SO ₄ -Cl-Na-Mg
	47438	HCO ₃ -Cl-Na-Ca
	47439	Cl-Na-Mg
	54682	SO ₄ -Cl-Na
2 STOCKTON SANDBEDS	47490	Cl-HCO ₃ -Na-Ca
	56098	Cl-Mg-Ca
	60010	HCO ₃ -Cl-Ca-Na
	60358	SO ₄ -Cl-Na-Ca-Mg
3 TOMAREE SANDBEDS	39308	Cl-Na
	39309	Cl-SO ₄ -Na-Mg
	47491	Cl-Na
	53762	Cl-Na-Mg (Cl-SO ₄ -Na-Mg)*
	53763	Cl-Na-Mg
	59151	Cl-Na
	60734	Cl-Na-Mg
4 FULLERTON-TILLIGERRY		No Data

*Bore tested again at later date.

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Area	Bore No.	Date	Top (m)	Bottom (m)	CO3 (mg/L) (epm)	HCO3 (mg/L) (epm)	SO4 (mg/L) (epm)	NO3 (mg/L) (epm)	Cl (mg/L) (epm)	F (mg/L) (epm)	Ca (mg/L) (epm)	Mg (mg/L) (epm)	Na (mg/L) (epm)	K (mg/L) (epm)	SiO2 (mg/L)	Fe (mg/L)	B (mg/L)	pH	TDS (mg/L)	Cond (uS/cm)															
TOMAGO SANDBEDS:	13359	28/07/57	48.80	48.40			0.00	0.00	#####	36.58									6.30	2637															
	17544	24/11/77		9.10		12.20	0.20	12.01	0.25	0.28	0.02	39.00	1.10	0.11	0.01	2.81	0.14	3.77	0.31	21.15	0.92	3.52	0.09	7.00	0.75		6.00		200						
	17544	24/04/78																																	
	17544	17/07/78																																	
	17544	25/01/79																																	
	17544	23/07/79																																	
	17544	25/09/85		9.10	0.00	0.00	1.22	0.02	35.06	0.73	0.98	0.07	29.78	0.64	0.00	0.00	4.81	0.23	4.50	0.37	18.85	0.82	5.47	0.14	5.20	0.21		5.71		213					
	17544	25/09/85																																	
	35926	13/03/72	7.80	8.20																														6.50	201
	35926	4/05/73	7.80	8.20																														5.75	210
	35926	22/05/74	7.80	8.20																														7.10	220
	35926	10/09/74	7.80	8.20																														8.40	280
	35926	10/12/74	7.80	8.20																														9.00	320
	47309	9/04/79		5.50			0.00	0.00	148.89	3.10	0.00	0.00	90.41	2.55			9.62	0.48	20.88	1.70	81.38	2.87	0.39	0.01	42.00								3.35	780	
	47438	15/02/80	9.50	20.70	0.00	0.00	72.00	1.18	0.00	0.00	0.01	0.00	28.94	0.78			15.03	0.75	3.65	0.30	18.16	0.79	1.17	0.03							0.08	6.59	210		
47439	6/03/80	9.50	21.40	0.00	0.00	3.68	0.06	3.38	0.07	0.01	0.00	25.68	0.73			2.00	0.10	2.07	0.17	11.95	0.52	0.39	0.01							0.26	5.40	120			
47973	2/07/86		14.00	0.00	0.00	68.47	1.45	8.85	0.18	2.10	0.15	33.68	0.95	0.19	0.01	27.68	1.38	2.43	0.20	25.52	1.11	3.13	0.08							0.10	7.82	301			
53044	14/10/81											120.00	3.38																			4.90	380		
53048	30/10/80											175.00	4.94																			5.50	2040		
54682	28/09/80	2.00	13.00			0.60	0.01	117.00	2.44	0.00	0.00	57.00	1.81	0.18	0.01	8.80	0.34	1.77	0.15	41.50	1.81	1.10	0.03	12.00	12.00					4.85	400				
STOCKTON 2	47490	28/10/80	10.10	11.90	0.00	0.00	94.58	1.55	30.74	0.64	5.80	0.40	58.14	1.64	0.19	0.01	32.26	1.81	7.41	0.81	37.47	1.63	3.13	0.08	6.70						7.60	450			
	54683	5/02/82											73.00	2.08																		5.00	0.30	4.50	
	58098	10/11/82					17.27	0.26					70.00	1.97			18.02	0.90	26.98	2.22												0.00	5.50	180	
	60010	9/08/84	9.90	11.70	0.00	0.00	144.00	2.36	34.10	0.71	3.08	0.22	82.04	1.75	0.19	0.01	55.51	2.77	5.83	0.46	30.81	1.34	1.17	0.03	7.40	0.00	0.00	7.72			0.00	0.00	7.72	505	
	60358	26/06/86	8.90	8.50	0.00	0.00	2.44	0.04	161.68	3.37	0.00	0.00	32.26	0.91	0.00	0.00	18.04	0.90	10.45	0.68	22.07	0.98	2.35	0.06	6.60	11.38	0.00	5.79				0.00	5.79	517	
TOMAREE SANDBEDS:	39308	15/03/83	16.40	19.80	0.00	0.00	13.42	0.22	70.80	1.47	0.00	0.00	666.52	18.80	0.57	0.03	8.82	0.43	18.84	1.55	418.18	18.19	16.38	0.47	8.10	4.40					5.69	2250			
	39308	16/03/83	13.00	16.30	0.00	0.00	29.68	0.47	38.42	0.60	0.14	0.01	426.15	12.02	0.00	0.00	3.41	0.17	9.11	0.75	256.34	11.15	12.51	0.32	11.40	2.99					5.87	1530			
	39308	17/03/83	10.00	11.00	0.00	0.00	28.07	0.46	8.17	0.17	0.00	0.00	60.12	2.26	0.00	0.00	3.61	0.19	6.08	0.50	50.12	2.18	2.74	0.07	10.50	0.93					6.01	381			
	39309	24/03/83	16.30	18.00																													0.52		
	39309	25/03/83	8.30	10.00																														2.48	669
	39309	25/03/83	8.30	10.00	0.00	0.00	14.64	0.24	107.11	2.23	0.00	0.00	64.38	2.38	0.19	0.01	8.42	0.42	23.82	1.99	54.72	2.38	3.52	0.09	6.40						5.43		567		
	39309	11/04/83	16.70	18.70																															588
	39309	11/04/83	16.70	18.70																															595
	39309	12/04/83	16.70	16.70																															592
	39309	12/04/83	16.70	16.70																															593
	39309	13/04/83	16.70	18.70																															599
	39309	19/01/85	12.00	19.00									183.00	5.16																			0.35	8.40	625
	47491	4/02/80											60.00	2.26																			5.30	104	180
	47491	28/10/80	12.00	13.50	0.00	0.00	15.25	0.25	7.20	0.15	0.00	0.00	41.13	1.16	1.14	0.06	3.21	0.18	3.04	0.25	24.37	1.06	1.17	0.03	7.30							5.51	178		
	53762	23/03/83	15.50	21.80	0.00	0.00	0.00	0.00	12.01	0.25	0.00	0.00	35.81	1.01			0.80	0.04	3.04	0.25	21.15	0.92	1.17	0.03							0.30	5.39	180		
53762	13/12/83	15.50	21.60	0.00	0.00	8.54	0.14	6.65	0.16	0.00	0.00	41.13	1.16	0.95	0.05	1.60	0.08	4.25	0.35	21.61	0.94	3.91	0.10	16.60	0.39	0.00	4.99					165			
53762	15/09/87	15.50	21.80	0.00	0.00	485.30	7.83	866.20	18.03	0.42	0.03	605.50	22.72	1.07	0.06	#####	8.32	246.20	20.42	544.10	23.67	20.41	0.52	20.06	0.00	0.01	7.67					4430			
53762	15/09/87	15.50	0.00	0.00	0.00	465.30	7.83	866.20	18.03			605.50	22.72	1.07	0.06	#####	8.32	246.20	20.42	544.10	23.67	20.41	0.52	20.06	0.00	0.01	7.67						4430		
53763	23/03/83	15.20	21.30	0.00	0.00	1.22	0.02	10.09	0.21	0.14	0.01	41.13	1.16	0.19	0.01	0.80	0.03	3.65	0.30	22.99	1.00	1.17	0.03							0.10	5.82	191			
53763	13/12/83	15.20	21.30	0.00	0.00	7.32	0.12	7.68	0.16	0.00	0.00	41.48	1.17	0.95	0.05	1.00	0.05	3.89	0.32	26.87	1.16	0.00	0.00	16.10	0.34	0.00	4.90					164			
53763	15/09/87	15.20	21.30	0.00	0.00	6.10	0.10	7.91	0.16	0.31	0.02	40.73	1.15	0.07	0.00	0.48	0.02	3.64	0.30	24.42	1.06	0.60	0.02	7.38	0.02	0.00	5.21					165			
53763	15/09/87	15.20	0																																

The water in the Tomago Sand Member aquifer has a mixed ionic character, with no particular ion generally dominant. There is very little apparent difference between this water and that in the Stockton Sand Member aquifer, but more detailed sampling may lead to a more specific characterisation of chemical type and this may help in assessing the way the aquifer would respond to changes in recharge and discharge consequent on changes to aquifer management procedures.

Because the permeable sand of the Tomago Sand Member forms the land surface in its outcrop area, the aquifer is highly vulnerable to contamination by substances which may dissolve and be transported through the aquifer. Some analysis for particular elements has been conducted in relation to particular sites, and some contamination may be occurring in some places. An aquifer management plan should incorporate the establishment of background levels of a range of indicator elements and compounds, including nitrogen in its variety of forms, phosphorous, metals, BOD, COD, pesticides, herbicides, and appropriate microbiological indicators.

2. Stockton Sand Member aquifer

Figures 3.3 and 3.4, referred to previously, illustrate the chemical character of water from this aquifer as represented by chemical analyses of a small number of water samples. There is little, if any, difference in character between water from the Stockton Sand Member aquifer and the Tomago Sand Member aquifer, with no particular ionic domination apparent. The water has a low total salinity, generally less than 500 mg/l, except near formation boundaries where there is some impact from saline water in adjoining aquifers (the Tilligerry Mudstone Member) or near the saltwater/freshwater interface along the shoreline. There is some suggestion that the iron content of water in this aquifer is less than in the Tomago Sand Member aquifer, but there is little data and this conclusion needs verification.

There are no data on other aspects of groundwater quality in this unit. Baseline data, of a similar range to that suggested for the Tomago Sand Member aquifer, will be required as an essential part of any aquifer management plan.

3. Tomaree Sand Member aquifer

The chemical character of the water from a small number of sources in the Tomaree Sand Member aquifer is indicated in Figures 3.3 and 3.4. The most apparent feature is the high proportion of sodium and chloride, which comprise a higher proportion of the total salinity than in the Tomago and Stockton Sand Member aquifers. In an aquifer of this nature, in which the storage/flow ratio is small (ie the residence time is small) and which is adjacent to the coast, the most likely reason for the high sodium chloride content is windblown salt from the ocean.

Total salinity of water from the aquifer ranges from less than 200 mg/L to over 4000 mg/L, but no systematic pattern is apparent. There is no information available on other aspects of water quality.

4. Anna Bay and Tilligery Mud Members

Water is moderately to highly saline, with chloride concentrations up to 12 000 mg/L in water from bores which appear to have penetrated the Anna Bay Member (Viswanathan and Evans, 1983). A more detailed assessment of the role of these units within the Newcastle Formation aquifer system would be a necessary part of a Groundwater Management Plan. In particular, the seaward extent needs definition, and the extent to which the overlying Stockton Sand Member and the underlying Tomago Sand Member are separated by less permeable material.

3.3 Estimates of storage capacity and yield potential

3.3.1 Storage

The storage capacity of the aquifer system of the Newcastle Formation is determined by two factors, namely the total volume of the aquifer between its base and the watertable, and the storage co-efficient. The volume between the base and the watertable can be determined by calculating the volume between the contours on the base of the aquifer as shown in Figure 3.2, and the watertable contours. It should be noted that this gives an estimate of the volume stored at the date represented by the watertable contours, and the volume would be different on different dates. There is, however, no consistent set of watertable contours for the whole area. Figure 3.6 is an approximation for the Tomago and Stockton provinces, based on the May 1993 data of Figure 3.3 and extrapolated using professional judgement. The total volume of saturated material between the two surfaces is $8.061 \times 10^9 \text{m}^3$. Note that this does not include the saturated aquifer volume from the Tomaree Province.

The volume of water in this volume of aquifer is dependent on the average value of the storage co-efficient, which is related to the porosity, and to the grain size, of the aquifer material. Since these are quite variable it is not possible to determine a unique value. Estimates can be made, based on controlled aquifer pumping tests, or laboratory tests of the aquifer material, followed by extrapolation of the value across the whole formation. The accuracy of the estimated average will depend on the accuracy, number, and distribution of the field tests.

There are numerous values quoted in the literature, but most of them relate solely or mainly to the Tomago Sand Member. The value for the better parts of the sand units is between 30% and 40%, but the value in the humate cemented layers (Coffee Rock or Woolloomooloo rock) will be very much less than this. Average values of around 10% have been quoted, and this is probably a reasonable value to adopt for an initial estimate. It results in a volume of some $8.061 \times 10^8 \text{m}^3$ (806 GL) for the watertable conditions of May 1993.

The estimated value is an indicator of the magnitude of the total storage, and can be used for general planning purposes, but it must be treated with some caution. For example, the average value for storage co-efficient which was adopted (0.1) may be in error. If 0.11 was a better estimate, the estimated volume of water stored would then be $8.87 \times 10^8 \text{m}^3$ (887 GL). Note also that the calculated volume assumes a vertical cut-off at the shoreline, and will therefore include an amount of saline water.

An alternative approach to estimating the volume of water stored in the aquifer is to estimate the average thickness of various parts of the aquifer, use the measured area occupied by that part to obtain an estimate of aquifer volume, and then apply the best estimate of storage coefficient for it. This approach has been used for each of the three sand members of the Newcastle Formation. Average thicknesses have been estimated from Figure 3.7 which is based on unpublished Hunter Water Corporation data. The resulting estimates are no more accurate, and probably less accurate, than the preceding estimates for the total volume, but serve to indicate the relative importance of the various parts of the aquifer.

3.3.2 Yield capacity

The yield capacity of the aquifer system is a much more complex concept and is dependent on both physical constraints and on choices about what impacts on the groundwater system are acceptable. There are two clear-cut management goals influencing these choices. Firstly, water levels in the aquifer should be maintained at a level sufficient to ensure that wetlands and other ecosystems are maintained. Secondly, unacceptable salt water intrusion must be prevented, by maintaining appropriate water levels.

As a first approximation, the long term average annual recharge rate could be regarded as the highest withdrawal rate which would not result in long term depletion of the aquifer storage, and hence as a satisfactory annual pumpage (providing the long term average annual recharge rate can be determined). There are two important points in this regard. Firstly, there may be other factors which require that the withdrawal rate be smaller, in particular the effect of groundwater withdrawal on wetlands in the study area. Secondly, the recharge is evenly distributed over the whole aquifer, and pumpage of an equivalent amount from a small area would lead to localised depletion and consequent problems of saline water intrusion. Annual pumpage at the long term average recharge rate may require a very widespread pumping network.

Selection of a rate at which water can be withdrawn from the aquifer is therefore a matter of deciding what limits are to be placed on the impact that pumping will have on the groundwater system (apart from the avoidance of long term depletion, which is assumed as a given). The implication is that a comprehensive understanding of the aquifer system is necessary, so that the impacts of selected pumping regimes can be predicted and decisions made as to whether or not they are acceptable.

For the purpose of the present discussion, the acceptable annual pumpage can be regarded as a proportion of the long term annual average recharge rate. The discussion in the following paragraphs gives an indication of what the long term average recharge rate might be for the three main parts of the aquifer system, based on data and reports which are currently available.

The proportion of rainfall which infiltrates to groundwater in the Newcastle Formation aquifer system will vary with time, season and location. Changes in vegetation pattern may increase or decrease the infiltration rate. Agricultural, urban, commercial and industrial development will change the pattern of infiltration. The estimates in the foregoing paragraphs are then clearly only an initial attempt, and the volume of recharge which actually occurs will depend on particular circumstances in each area.

Tomago Sand Member

There have been several studies aimed at determining the recharge co-efficient (i.e. the proportion of rainfall which infiltrates to groundwater). Estimates range from less than 20% to over 80% of mean annual rainfall, but most are in the range 25-30% and this seems to be the most likely range of values. An important point, however, is that the co-efficient appears to vary with seasonal conditions, and may be lower in dry years than it is in wet years. Also, the infiltration characteristics will vary across the area, depending on topography and current conditions. For example, infiltration will be restricted in swale areas when the watertable is at a high elevation because of wet antecedent conditions, and recharge may be rejected if the watertable is shallow enough. Extrapolation of any estimated rainfall co-efficient across the whole outcrop area of the Tomago Sand Member in order to determine the total annual recharge must therefore be done with some caution. As an indication, adoption of a coefficient of 20% of mean annual rainfall (240mm) (as used by DJ Douglas 1993b, for example) over the 152km² of the exposed Tomago Sandbed Member leads to an estimate of 36GL/year. The estimate is sensitive to the estimate of mean annual rainfall, to the rainfall co-efficient, and to the estimation of the total area of the sandbeds, but it is of fundamental importance in assessing the capacity of the aquifer system. For comparison, Kinhill (1992) reporting to HDWB, estimated annual recharge of 45GL by using a rainfall co-efficient of 30% and an area of 100 km² for the sandbeds.

One further aspect of recharge to the Tomago Sand Member aquifer is that of run-off from the area to the north. While much of this is captured by the Grahamstown Reservoir, some run-off does enter the sandbeds, and there is probably still some leakage from the storage reservoir to the sandbeds (substantial leakage identified in earlier years has been largely eliminated along a section where a grout curtain placed along the dam wall) (Figure 3.2).

Stockton Sand Member

On the basis of the limited data available, the recharge characteristics of the Stockton Sand Member are presumed to be similar to those of the Tomago Sand Member. In this case, the recharge co-efficient is expected to be in the range 25-30%. Assuming an outcrop area on land of 78 km², as indicated in Chapter 2, and the same rainfall and recharge co-efficient as for the Tomago Sand Member aquifer recharge estimate above, the mean annual recharge would be about 21 GL/year.

Tomaree Sand Member

The outcrop area of this unit, as determined planimetrically for this study, is 45 km², including small areas of the basement rock outcrops. In the absence of any more specific data, a recharge estimate has been based on the same rainfall co-efficient and storage co-efficient values adopted for the Stockton Sand Member. The total area has been reduced to 35 km² to allow for the rock outcrop areas (conservative, since much of the run-off from these areas will infiltrate into the surrounding sand body), and the resulting mean annual recharge estimate is 8 GL/year.

3.3.3 Preliminary conclusions on storage/yield relationships

The volume of stored fresh water is clearly very large. The estimate based on the contours on the base of the aquifer and the 1993 water level contours is probably the most accurate available. Using a conservative value (10%) for storativity, the volume of water is estimated to be some 800 GL. This includes a salt water fringe around the shoreline margin of the area, but even if this accounted for 25% of the water in storage (probably a gross over-estimate) the volume of fresh water is still about 600 GL, excluding the water stored in the Tomaree Sand Member.

This volume is about ten times the estimated long term average annual recharge, which is large enough to provide a useful buffer between constant annual withdrawals and varying annual recharge. It is not, however, so large that the system would be unaffected by excessive withdrawals over a period of a few years during a time of below average recharge. The effects of such over-pumpage could be minimised by effective management based on comprehensive knowledge of the system and close monitoring. It could, on the other hand, lead to long term and possibly irreversible damage, if conducted in ignorance without monitoring.

Annual withdrawal limits should be set at a conservative level until the aquifer system and its responses to pumping are well known and responses to increased pumping can be accurately predicted. Determination of the proposition of long term annual recharge which can be withdrawn by pumping will be a key part of a groundwater management plan.

3.4 Interaction with adjacent water bodies

3.4.1 Aquifers adjoining the study area

The only aquifers which adjoin the study area are those in the basement rock, which underlies the Newcastle Formation and forms the land surface to the north of its outcrop area. There is very little interaction between these aquifers units, mostly because of the major difference in permeability between them. It is possible that there could be a small amount of drainage from the rock aquifers into the sand along the northern part of the study area, and because the water in the basement formations is likely to be brackish or saline, there could be localised impacts on salinity of water in the sand bodies. There may also, in particular circumstances, be small areas where water from the sand aquifers enters the basement aquifer system. If those circumstances occur in an area where the groundwater in the sand aquifer is contaminated, there could be a small impact on the basement aquifer. The relative positions of the two aquifer systems, however, and their differences in permeability, indicate that such occurrences are most unlikely. Further, the basement aquifer is not used as a water source, so any small impact on its quality which does occur will be inconsequential, and restricted to the secondary problem of the impact which drainage from the basement aquifer into the estuaries might have. The risk of such drainage being a problem is very small compared to the risk of drainage direct from the sand aquifers into the estuaries.

3.4.2 Wetlands

There are two general types of wetlands in the study area, namely those that border the shore (generally along the Tilligerry Creek estuary), and those at higher elevations in the swales of the dune areas.

The wetlands in the dune swales have a very high degree of interaction with the sand aquifers of the Newcastle Formation. These wetlands are essentially swamps which are maintained by drainage from the aquifers, or are windows in the watertable where the watertable is locally at a higher elevation than ground level. They will be subject to seasonal variation, as the watertable rises and falls in response to seasonal changes, and the fluctuations will be accentuated in particularly dry and particularly wet years. It is quite possible that some of these fluctuations would be accentuated by pumpage from the groundwater store, and that some of the smaller swamps could be dry for quite long times. A pumping schedule to keep this impact within acceptable limits is necessary.

The shoreline wetlands are also subject to changes brought about by seasonal variations, but are less subject to these impacts than the high level wetlands because they are further down the flow path at a position where the sea creates a stable base level. Seasonal fluctuations of water levels are less than they are further up the flow path. The most apparent problem here would be a landward movement of the salt water/fresh water interface, which will happen if the dynamic balance maintained by the fresh water flow through the sand aquifer is upset. The impact of a decline in the flow of fresh water into these areas is also a factor which requires attention, because of the possibility of an increase in the salinity level and consequent effects on the ecosystem. Management of the aquifer to take account of these factors is essential.

An important aspect of the interaction between the sand aquifers of the Newcastle Formation and the wetlands they support is that of water quality. Salinity is not, in general, the problem here but other quality aspects could be. In particular, if contaminants from waste disposal (intentional or unintentional, authorised or unauthorised) enter the groundwater system, they will move towards the discharge zones with the groundwater flow. Apart from any attenuation which may occur, they will be present in the discharge flow which maintains the wetlands, and might become concentrated in the ponded surface water of the high level wetlands. A change in water quality in the wetlands could have an impact on the vegetation and animal communities they support, and that impact could be substantial or fatal, depending on the type of contaminant and the concentrations reached.

The impact of contaminants on the shoreline wetlands is less certain, because in these areas there is potential for great dilution. Nevertheless, concentrations could become unacceptable in restricted parts of the estuaries.

Maintaining the quality of the water discharging to the wetlands, and to the estuaries either directly or via the wetlands, is one of the most important matters to be addressed by a management plan for the Newcastle Formation sand aquifers.

3.4.3 Surface streams

Because there are no permanent surface streams, this aspect of the interaction between the aquifers and surrounding water bodies need not be considered separately. The comments regarding the high level wetlands in the previous section would apply to any ephemeral streams in the area maintained by groundwater drainage.

3.4.4 *Estuaries and the sea*

Water from the sand aquifers which does not drain to dune swale wetlands, and is not withdrawn from the aquifer by pumping or evapotranspiration, will either drain into the sea, into Port Stephens, or into one of the estuaries. The drainage path might be via the shoreline wetlands, as discussed above, or direct to the receiving water body. In either case, the end result is that if the groundwater carries contaminants they will enter the sea or estuary. If they enter a part of the coastal system in which tidal circulation is restricted, there is potential for concentration. It is therefore imperative, if such areas of concentration are to be avoided, that strict control of groundwater quality is maintained. The implication of this is that land use needs to be properly managed over the entire area in which the Newcastle Formation occurs, and over any adjoining area from which run-off might enter the sand aquifers.

4. LEGISLATION, POLICY AND ORGANISATIONS

4.1 Background

The Hunter Water Board and its predecessor boards had a long history of withdrawing groundwater from the Tomago Sandbeds and the Tomaree Sandbeds for public water supply. In 1992 the Board became a state-owned corporation, the Hunter Water Corporation (HWC), through the enactment of the *Hunter Water Board (Corporatisation) Act 1991* ('the Corporatisation Act').

The main objective of corporatisation is to increase overall efficiency, so the new Corporation has a much stronger commercial focus than the Board it replaced. In accordance with NSW Government corporatisation policy, regulatory powers and functions exercised by the former Board in relation to water resources became the responsibility of government. The Corporatisation Act, therefore transferred the statutory responsibility for protecting both groundwater and surface water resources, including the groundwater resources of the Tomago/Tomaree/Stockton sandbeds, to the Department of Water Resources (DWR), the State's water resource manager.

The NSW Government is committed to ensuring the ecologically sustainable use of natural resources, including water resources. There are demands on groundwater resources to meet a wide range of community needs and values, including water for the environment. Therefore, there needs to be a balance struck between social, economic and environmental needs when dealing with increasing competition between interested parties. This means that the DWR (as an arm of Government) needs to:

- ensure that there is a regime in place that will protect these groundwater resources and their associated water environments from degradation;
- license the Corporation's groundwater (and surface water) use; and
- establish the rights and obligations of other groundwater users.

This technical review is part of the work involved in developing a Groundwater Management Plan which, in turn, will help the Department to achieve these goals. The proposed Groundwater Management Plan, to be developed in conjunction with the community, other government authorities and industry, will aim to address both quality and quantity aspects of groundwater management in the Tomago/Tomaree/Stockton sandbeds.

Currently, under the Corporatisation Act, the Department does not have clear power to license the Corporation's groundwater extraction and use, nor clear power to license other groundwater users within the special areas. However, amendments to this Act which will give the Department these licensing power, are expected to occur in 1995. The Department does have a clear power to license groundwater users outside the special areas.

4.2 NSW Government's responsibilities in groundwater management

International law:

Australia has signed numerous international agreements relevant to the protection of environments associated with groundwater in the Tomago/Tomaree/Stockton sandbeds. These agreements aim to protect a range of environmental values including wetlands, migratory birds, wildlife habitat and biological diversity. They include the Convention on Wetlands of International Importance (Ramsar Convention) and migratory birds agreements with China and Japan (Farrier 1993).

Ecologically sustainable development:

The Commonwealth Government does not have any direct powers under the Constitution to manage groundwater. The *National Strategy for Ecologically Sustainable Development* (ESD) was adopted by the Council of Australian Governments (which includes all state governments) in December 1992. The ESD strategy has three core objectives:

- to enhance individual and community well-being by following a path of economic development that safeguards the welfare of future generations;
- to provide for equity within and between generations; and
- to protect biological diversity and maintain essential ecological processes and life-support systems.

The *Intergovernmental Agreement on the Environment* (signed in February, 1992) was negotiated by all levels of Australian government, and sets out the environmental policy and management responsibilities of each level of government. It aims to create a more co-operative approach to managing environmental issues, and it recognises that responsibility for most environmental issues lies at State level. A National Environment Protection Authority with Ministerial representatives from all States, Territories and the Commonwealth, is in the process of establishing national ambient water quality standards (Coastal Committee 1992; Farrier op. cit., p12).

Under both the *National Strategy for Ecologically Sustainable Development* (1992) and the *Intergovernmental Agreement on the Environment* (1992), DWR, on behalf of the NSW Government, aims to sustainably manage its groundwater resources. As well as adopting the three principles stated above, ESD requires:

- taking a precautionary approach where there are threats of serious or irreversible environmental damage and a lack of full scientific certainty; and
- limiting the use of natural resources so that use matches the supply of renewable resources and the ability of the environment to cope with degradation and waste.

In 1994 the Council of Australian Governments (the Prime Minister, State Premiers and Chief Ministers and the President of the Local Government Association) agreed that where they have not already done so, States are to give priority to formally determining allocations to the environment (Council of Australian Governments, 1994).

The proper management of groundwater requires that both its quantity and quality are preserved for future generations. This is difficult in the case of coastal sandbed aquifers, such as the Tomago/Tomaree/Stockton aquifers, for two reasons. First, it is at risk from pollutants from all forms of human activities that occur on the surface (NSW Government, 1994). Secondly, demand

for groundwater is likely to increase as population increases in the Tomago/Tomaree/Stockton area, which could result in depletion of the resource if it is not properly managed.

State policies:

NSW Government policy on Total Catchment Management (TCM) aims to involve the community in natural resource management and to ensure co-ordination of State Government, local government and community policies, programs and activities relating to natural resource management. In accordance with TCM objectives groundwater management should therefore be integrated with management of land, water, vegetation and other natural resources.

Under the *Catchment Management Act 1989* trusts and committees have been established in most parts of NSW to promote positive resource management through the voluntary co-operation of members of the community. These trusts and committees focus on managing river catchments, including their associated groundwater. The Hunter Catchment Management Trust is responsible for co-ordinating activities relating to natural resource management within the Hunter River catchment, which covers only part (the south-western part) of the Tomago/Tomaree/Stockton sandbed area.

The NSW Government's *State Rivers and Estuaries Policy* (1993), which aims to provide objectives and principles for the sustainable management of rivers and estuaries, was developed under the TCM framework. The Policy also identifies a suite of more detailed policies that are being developed to provide clear guidance on wise use, best management practice and effective restoration of rivers and estuaries.

There are already several draft state policies which will have implications for the Tomago/Tomaree/Stockton sandbeds and related environments. A draft framework for a state groundwater policy was released in 1992 to complement other policies being developed under the TCM framework. Six component policies are to be prepared focusing on groundwater quality protection, resource allocation, resource assessment, environmental protection, inter-governmental management, and pricing. Under statewide natural resource policies currently being introduced, state and local government authorities will be ensuring that groundwater contamination and pollution are minimised. A key aspect of the management process is that the beneficial value or attributes of aquifer systems must be recognised and their vulnerability as well as the level of protection should be established (NSW Government, 1994).

There are wetlands throughout the Tomago/Tomaree/Stockton sandbeds area (see Fig. 2.6). Wetlands are not comprehensively protected by any single legal mechanism. Existing legislation, however, is sufficient to require that explicit consideration is given to wetlands in planning and operational decisions (NSW Government, 1994). To protect and manage wetland systems requires mechanisms and guidelines which address a wide range of land and water practices. Consequently, a wetland management policy must be consistent with the objectives and operations of many other policies and legislation which deal with the management of natural resources. A NSW Wetlands Working Group is presently revising its draft wetlands management guidelines after extensive consultation with groups interested in wetland management, and once completed the draft will be widely released for further review.

4.3 The history of groundwater management in the Tomago/Tomaree/Stockton sandbeds

The Hunter District Water Supply and Sewerage Board was set up in 1892 to meet the urban water supply and sewerage needs of Newcastle and adjacent towns. It was a government authority with statutory powers that existed as a Board for nearly a century.

Throughout this period the Board had powers aimed mainly at protecting the quality of groundwater from the areas where it pumped for public supply - now known as the two 'special areas'. The current boundaries of both special areas are shown on figure 5.2. (There is also a Williams River Special Area for the protection of surface water supply that is not shown on figure 5.2.) By-laws or regulations have applied to the land in the 'Tomago Special Area' since 1941 and in the 'Nelson's Bay/Anna Bay Special Area' since 1949.

The most recent regulation made by the Hunter Water Board is the *Hunter Water Board (Special Areas) Regulation 1989* (the 'Special Areas Regulation 1989'). This Regulation gave the Hunter Water Board control over development (especially agricultural) and day-to-day activities (mainly those that might pollute water) in the special areas.

4.4 Changes to groundwater management resulting from corporatisation

The Hunter Water Board was corporatised on 1 January, 1992. The Hunter Water Corporation (HWC) is a state-owned corporation under the *State Owned Corporations Act 1989*. Consistent with NSW's corporatisation legislation and policy, it has a business-oriented board and is a commercially oriented provider of water supply and sewerage services. It is shedding its traditional government functions, including regulatory powers and functions in water resource management, to enable it to focus on its commercial operations.

Under Division 8 (ie. sections 52-62) of the Corporatisation Act the control of the special areas was transferred to a Government agency - the Director-General of the Department of Water Resources (s. 52). The Special Areas Regulation 1989 was renewed for five years (s. 58).

The transfer of regulatory powers and functions to the Department as a result of corporatisation gives the Department the responsibility for both surface water and groundwater management in HWC's area. However, pending legislative reform, authority to exercise powers under the Special Areas Regulation 1989 has been given by DWR to HWC under s. 60 of the Corporatisation Act.

Work currently being carried out by the Department to meet its new responsibilities (apart from the development of a Groundwater Management Plan) includes:

- scientific and technical studies to be carried out and plans to be developed under a water use agreement between the DWR and HWC. This work is designed to provide information concerning the behaviour of critical elements of water resources and the impact of HWC's operations on these water resources. The information derived from these studies will shape the conditions in the Corporation's water licence which will be issued when legislation permits. The development of a Groundwater Management Plan is one of the plans to be developed in accordance with the water use agreement;
- development of a surface water allocation plan for the Williams River. This plan will aim to develop strategies for allocating water from the Williams River equitably, to meet both human and environmental needs;

- development of a regional environmental plan (REP) for protection of the water quality of the Williams River. The REP will aim to protect and enhance the water quality of the Williams River through land use planning. This process is being led by the Department of Planning and also involves the DWR, the HWC, the Hunter Catchment Management Trust and the Environment Protection Authority];
- development of new catchment protection regulations for the special areas - the Special Areas Regulation 1989 expires in September, 1995.

4.5 DWR's other groundwater management powers

Water Administration Act 1986:

Under the *Water Administration Act 1986* the Water Administration Ministerial Corporation, operating through the Department of Water Resources, has the right to use, flow and control of the State's groundwater and surface water resources (ss 7 & 12). Under section 4, the objects of the Act are to:

- (a) ensure that the State's water and related resources are allocated and used in ways consistent with environmental needs and provide the maximum long-term benefit for the State and Australia; and
- (b) provide water and related resources to meet the needs of water users in a commercial manner consistent with the overall water management policies of the Government.

The Department is therefore required to allocate water for environmental needs (such as water for wetlands), to ensure that a balance is struck between meeting human and environmental needs.

Under section 11 of the *Water Administration Act* DWR may carry out a broad range of management functions relevant to both groundwater and its related surface water (eg wetlands), including:

- evaluating the State's present and future water needs;
- planning and carrying out the development of water resources;
- collecting, recording and assessing information about water resources and publishing it;
- co-ordinating the activities of people with water resources functions;
- reviewing and monitoring the efficiency of proposals and projects relating to the use and development of water resources;
- integrating water resources management with management of other natural resources; and
- managing water catchment areas as sources of water supplies and co-ordinating the management of water catchment areas.

Under section 12(3) of the Water Administration Act the Department can take a number of measures relevant to the exercise of its rights and functions, including measures for:

- the conservation, replenishment and supply of water;
- the equitable distribution of water;
- the beneficial use of water;
- the protection of water from pollution and the improvement of its quality;
- preventing unauthorised interference with the flow or availability of water;
- preventing unauthorised erection or use of works;
- flood control and mitigation; and
- environmental protection.

Water Act 1912:

The Department also has power to allocate groundwater by licensing bores under Part 5 of the *Water Act 1912*. These licences apply to the overlying land, irrespective of changes in land ownership or occupation. Licences usually have conditions attached to them. The licence conditions usually cover:

- the location, design and construction of the bore;
- bore testing and other information requirements;
- the purpose of the bore and volume entitlement. In the case of irrigation users, a condition covering the area within which the water can be used may be included;
- requirements for the licence holder to report to the Department on volumes used, crop areas and types and bore condition; and
- environmental protection, including protection of aquifers from pollution.

In heavily used groundwater areas, the Department monitors aquifer water levels regularly. Use by licensed users is also monitored to make sure licence conditions are followed. The Department has power to take action where groundwater is being wasted or used improperly.

Under section 117A the Department can declare a groundwater basin or any part of it as a 'restricted sub-surface water area'. Bore licensees can then be:

- restricted in their pumping or other activities that affect water quantity;
- required to take specified action to protect water quality from pollution or contamination;
- metered; and/or
- required to give water quantity reports.

The whole of NSW is covered by restricted sub-surface water areas declared under section 117A.

Under section 117B the Department can declare a subsurface water area to be a 'prescribed area'. Differential charges (as well as the licence fee) can then be fixed depending on bore location, quantity extracted and the purpose for which the water is to be used (Farrier, 1993). There are no declared 'prescribed areas' in the Tomago/Tomaree/Stockton sandbeds area.

It is well recognised that water abstraction has an important effect on water quality; however for convenience groundwater quality and quantity are considered separately below.

4.6 Managing groundwater quantity

Table 4.1 below lists the major statutes relevant to managing groundwater quantity in the Tomago/Tomaree/Stockton Sandbeds, the government authority responsible for administering each statute and the relevant provisions.

TABLE 4.1: Tomago/Tomaree/Stockton groundwater: legislation, administering bodies and functions relevant to water allocation

Statute	Principal administering authority	Relevance of statute to groundwater quantity	Implications of statute for allocation of Tomago/Tomaree/Stockton groundwater
Water Administration Act 1986	Department of Water Resources (DWR)	Control, use and flow of NSW's water resources vested in a Water Administration Ministerial Corporation and administered by DWR. This includes surface water, groundwater and water in wetlands.	Section 12 gives DWR broad powers to take action for: <ul style="list-style-type: none"> •the beneficial use of water, •equitable distribution of water, •water conservation and replenishment.
Water Act 1912	DWR	Sets up a system for licensing water use in NSW and for floodplain control.	Requires groundwater extraction to be licensed. However, this power is not currently applied in the HWC's area of operation, because there are overlapping powers in HWC's legislation.
Hunter Water Board (Corporatisation) Act 1991	Hunter Water Corporation Limited (HWC)	The Water Administration Ministerial Corporation's right to control, use and flow of the water in HWC's area is vested in HWC for the purposes of water supply, sewerage and drainage services.	<ul style="list-style-type: none"> • HWC is given a <u>statutory</u> right to use water, rather than a right given in a <u>licence</u>. Neither this Act nor the Operating Licence issued by the Governor put any limitations on this right eg a volumetric allocation • Under current administrative arrangements, a permit from HWC is required for water abstraction by other users in the HWC's area of operations.

In NSW the primary mechanism for managing groundwater quantity is the licensing of abstraction. In the special areas, HWC is currently authorised under s. 60(1) of the Corporatisation Act 1991 to issue abstraction permits to other groundwater users under Part 4 of the Special Areas Regulation 1989. This is a temporary arrangement, pending the legislative reform referred to above in section 4.1. Outside the special areas, DWR has power to license groundwater users.

Hunter Water Corporation's groundwater use:

The major user of groundwater in the sandbeds is HWC. Before corporatisation, the Hunter Water Board had an implied statutory right to the use, flow and control of groundwater and surface water that it needed to supply water to its customers. For this reason, it did not need to be licensed itself.

The aim of the corporatisation legislation was to properly separate government functions from HWC to enable it to concentrate on meeting its commercial objectives. For this reason, it has been intended since the time of its corporatisation that the primary mechanism for defining the conditions under which it could extract water would be a licence issued by the DWR, as delegate of the Ministerial Corporation (see Second Reading speech, 12.11.91, Hansard, pp. 4244-4251). However, section 12 of the Corporatisation Act 1991 gives HWC the Water Administration Ministerial Corporation's right to the use, flow and control of water (subject to some limitations). This provision, therefore, effectively excludes the Department from regulating major facets of the HWC's operations related to water use. Retention of a statutory right to use, flow and control of water, however, is considered to be at odds with its status as a quasi-private body. It is expected that following legislative reform HWC will, like other waters users, be licensed.

As an interim measure, a water use agreement was signed in October 1994. Under this agreement work is being done to enable conditions to be formulated for a future water use licence that will regulate both surface water and groundwater use by the HWC.

The water reserves in HWC's area of operations (see section 4.8 below) enable the Corporation to gain access to groundwater for public water supply purposes.

Groundwater use by others:

There are many other commercial and private users of groundwater in the Tomago/Tomaree/Stockton sandbeds. The Special Areas Regulation 1989 - and the primary legislation upon which it was based - enabled the Hunter Water Board to regulate groundwater extraction and use by others. Similar legislation has existed for many decades.

Under Part 4 of the Special Areas Regulation 1989 it is an offence for others to abstract or use groundwater in the special areas without a permit. Permits may have a charge or payment attached to them. These permits are still issued by HWC (as a temporary measure). All charges or payments for water abstraction under the regulations are currently paid to HWC in accordance with s. 59 of the Corporatisation Act 1991. The reform to the Corporatisation Act 1991 expected in 1995 should lead to the phasing out of these permits and their replacement with licences issued by DWR.

Outside the special areas, the Department of Water Resources can license groundwater users under Part 5 of the Water Act 1912.

4.7 Managing groundwater quality

A major aim of the proposed Tomago/Tomaree/Stockton Groundwater Management Plan will be to try to ensure that groundwater quality is protected, because of the importance of this water in meeting future human and environmental needs. Because of the vulnerability of the groundwater to contamination and pollution from activities on the land above, it is important that both state and local government authorities with land management powers are aware of the effects their decisions will have on groundwater quality.

There is a strong link between land use and groundwater quality in the sandbeds. This means that land use planning is a key factor in minimising water quality degradation. Commonwealth, state and local government legislation that relates to land use in the area is, therefore, relevant. Table 4.2 below lists the major statutes which affect groundwater quality in the sandbeds, the role of government organisations in administering these statutes and the relevant provisions.

TABLE 4.2: Tomago/Tomaree/Stockton groundwater quality: legislation, administering bodies and functions relevant to protection of groundwater

Statute	Principal administering authority	Relevance of statute to groundwater quality	Implications of statute for protection of Tomago/Tomaree/Stockton groundwater
Water Administration Act 1986 ('WA Act')	Department of Water Resources (DWR)	Right to control, use and flow of the State's water resources vested in a Ministerial Corporation and administered by DWR. This includes surface water, groundwater and water in wetlands.	Section 12 empowers DWR to take action for <ul style="list-style-type: none"> •the beneficial use of water, •water conservation and replenishment, •protection and improvement of water quality, •environmental protection. The Act gives the Department power to make policies and plans for groundwater protection.
Hunter Water Board (Corporation) Act 1991 ('Corporatisation Act')	Hunter Water Corporation Limited (HWC)	Water Administration Ministerial Corporations' right to control, use and flow of the water in HWC's area is vested in HWC for the purposes of water supply, sewerage and drainage services.	<ul style="list-style-type: none"> • HWC is given a <u>statutory</u> right to use water, rather than a right defined in a <u>licence</u> with conditions such as environmental flows or groundwater quality monitoring conditions. • Under current administrative arrangements, water abstraction permits issued by HWC under the Hunter Water Board (Special Areas) Regulation 1989 can include water quality protection conditions.
Protection of the Environment Administration Act 1991	Environment Protection Authority (EPA)	Established the EPA.	EPA has general environmental protection responsibilities in the area ie to protect, restore and enhance the quality of the environment in NSW, having regard to ESD.
Pollution Control Act 1970	EPA	Procedure for seeking a 'pollution control approval'.	Pollution control approval needed before projects that will pollute (eg industry) can go ahead.
Clean Waters Act 1970;	EPA	Creates offences for pollution of the environment without a licence.	Day-to-day operations that pollute (eg industries) can only pollute in accordance with a licence (powers have been applied only with respect to point-source pollution in relation to Tomago/Tomaree/Stockton groundwater).
Environmental Offences and Penalties Act 1989	EPA	Creates offences for spillage and escape of pollutants.	High penalties and strict controls on corporations and individuals for these offences.

TABLE 4.2 (cont.): Tomago/Tomaree/Stockton groundwater quality: legislation, administering bodies and functions relevant to protection of groundwater

Statute	Principal administering authority	Relevance of statute to groundwater quality	Implications of statute for protection of Tomago/ Tomaree/Stockton groundwater
Environmentally Hazardous Chemicals Act 1985	EPA	Allows the EPA to assess existing chemicals and make a chemical control order.	Chemical control orders are made only after an assessment that measures are necessary to prevent or minimise any adverse effects on the environment arising from the manufacture, use or disposal of the chemical. The chemical can be banned or special conditions put on its use.
Environmental Planning and Assessment Act 1979	Department of Planning (DoP) & Port Stephens Shire Council	Specifies: <ul style="list-style-type: none"> • environmental impact assessment requirements and procedure; and • environmental planning control system. 	<ul style="list-style-type: none"> • Requires environmental impact assessment before some development can proceed, ie mainly development likely to have a significant effect on the environment (which includes groundwater, land overlying it and wetlands). • S. 90 requires council to take a number of specific environmental factors into account when deciding a development application. • Development control can also occur through SEPPs, REPs and LEPs. Those most likely to affect Bight's groundwater are SEPP 14 - wetlands, the Hunter REP and the Port Stephens LEP.
Local Government Act 1993	Port Stephens Shire Council & Public Works Department (PWD)	Allows Council to undertake a range of functions and responsibilities.	Requires Council to: <ul style="list-style-type: none"> • have regard to to the protection of the environment when carrying out its responsibilities (s. 7), • to properly manage, develop, protect, restore, enhance and conserve the environment (s. 8), • annually plan and report on its environmental management.
Public Works Act 1912	PWD	Responsible for most government coastal engineering projects allows for works to be carried out.	Drainage works could affect groundwater quantity. Responsibility for floodplain management in estuarine areas.
Crown Lands Act 1989	Department of Conservation and Land Management (CaLM)	Provides a regime for management and sale of Crown land (including reserves).	Water reserves at Tomago, Tomaree and Stockton (currently controlled by DWR and managed by HWC) created and managed in accordance with Part 5 of Crown Lands Act.

TABLE 4.2(cont.): Tomago/Tomaree/Stockton groundwater quality: legislation, administering bodies and functions relevant to protection of groundwater

Statute	Principal administering authority	Relevance of statute to groundwater quality	Implications of statute for protection of Tomago/Tomaree/Stockton groundwater
National Parks & Wildlife Service Act 1974 (NPWA)	National Parks & Wildlife Service (NPWS)	Provides a regime for managing national parks, nature reserves, areas of significance for Aboriginal culture etc. as well as responsibility for conserving and managing cultural and natural heritage (including flora and fauna).	Flora & fauna are protected by: <ul style="list-style-type: none"> • requirement for permits to take native fauna • controls on taking native flora • specific endangered species provisions; and • conservation orders. Aboriginal relics are protected by: <ul style="list-style-type: none"> • restrictions on searching for, possessing or removing relics (NPWA s.86.) Places of Aboriginal significance may be protected by: <ul style="list-style-type: none"> • restrictions on access (NPWA s.66) and penalties for offences (LMR cl. 11(1)(h))
Coastal Protection Act 1979	DoP & PWD	Creates responsibility for planning (DoP) and public works (PWD) in the coastal zone.	<ul style="list-style-type: none"> • Coastal Committee (established by the DoP under s. 22 of the EP & A Act) produced a draft coastal policy in 1993 • engineering projects, eg coastal hazards projects can occur in sandbeds overlying the groundwater.
Catchment Management Act 1989	Hunter Catchment Management Trust & CaLM	Provides a framework for co-ordinating land and water resource management in conjunction with the community.	Not yet tested as a mechanism for co-ordinating natural resource programs in a groundwater 'catchment'. Trust covers Hunter River catchment, ie SW part of the Tomago/Tomaree/Stockton groundwater area.
Fisheries Management Act 1994	NSW Fisheries	Creates responsibility for management and protection of fish resources and their habitats.	The Minister for Natural Resources must always be notified of a proposed land reclamation or dredging in order to prevent damage to fisheries.
Mining Act 1992	Department of Mineral Resources	Creates responsibility for development, management and use of mineral resources.	Mining in sandbeds overlying aquifer is subject to approval under this Act.
Drainage Act 1939	DWR & PWD	Enables landowners to join together to carry out drainage works to mitigate the effect of floods where land is being 'injured' by the accumulation or flow of water.	Drainage unions have broad powers to construct and maintain works financed by rates levied on their members.
Native Title (New South Wales) Act 1994	Premier's Department	May change current land use above aquifer	Future water use may need to take into account water rights accompanying any land rights granted under the Native Title Act

TABLE 4.2(cont.): Tomago/Tomaree/Stockton groundwater quality: legislation, administering bodies and functions relevant to protection of groundwater

Statute	Principal administering authority	Relevance of statute to groundwater quality	Implications of statute for protection of Tomago/Tomaree/Stockton groundwater
Forestry Act 1916	State Forests of NSW	Forestry activities/practices can affect groundwater quality (and quantity)	State forests are located outside the Tomago/Tomaree/Stockton area, to the north.
(Commonwealth) Endangered Species Protection Act 1992	Director of Commonwealth National Parks & Wildlife Service	Protects endangered flora and fauna species on land owned or leased by Commonwealth agencies.	Applies to Department of Defence occupied land (RAAF Base, Williamtown).
(Commonwealth) Native Title Act 1993	National Native Title Tribunal	May change current land use above aquifer	Future water use may need to take into account water rights accompanying any land rights granted under the Native Title Act

EPA licensing powers:

Some developments require a licence for both their abstraction of water (see section 4.5 above) and/or their discharges into receiving waters, which include groundwater.

The NSW Environment Protection Authority (EPA) has responsibility for environmental protection in the State. The EPA is responsible for licensing wastewater point-source discharges into waters (including groundwater). Under the *Pollution Control Act 1970* a 'pollution control approval' is required from the EPA for any proposed development (including modifications to existing premises) likely to result in the discharge of pollutants into waters.

For day to day control of projects (once construction is finalised), it is an offence under section 16 of the *Clean Waters Act 1970* to pollute water (including groundwater) except under the terms and conditions of a licence issued by the EPA under s. 16. A licence may also be required under s. 17 for those responsible for drains or who occupy land on which there is a drain.

There is groundwater in the Tomago/Tomaree/Stockton area which, under section 11 of the *Clean Waters Act 1970*, was in 1975 classified as 'Class U - Underground Protected Waters' in the Atlas of Classified Waters. The groundwater in the following areas are so classified:

- Tomago Special Area;
- Nelson's Bay/Anna Bay Special Area; and
- Coastal Water Reserves, part Water Reserve 61307 and part Water Reserve 57573 (see Fig. 5.1 for location of water reserves).

The EPA takes into account the state of particular waters when developing conditions for licences for point-source pollution.

The *Environmental Offences and Penalties Act 1989* specifies the penalties for groundwater pollution offences and other remedies that the EPA can seek to prevent groundwater pollution and pay for clean-up costs (Farrier, 1993).

4.8 Controls on land development

Private land holders are subject to the development control provisions of the *Environmental Planning & Assessment Act 1979* and the Special Areas Regulation 1989 (see below in this section), as well as the licensing legislation administered by DWR, the HWC and the EPA (described in sections 4.5 and 4.6 above).

Special areas:

HWC holds freehold title to about 40% of the land in the Tomago Special Area as well as some land in the Tomaree area (Nelson Bay/Anna Bay Special Areas). There are also Crown land water reserves (see section 4.9) and other privately owned land in the special areas (see Fig. 5.2). Certain types of development in the special areas are not permitted by the Special Areas Regulation 1989, except with HWC's permission and subject to any condition imposed by the Corporation (in accordance with the authority given to HWC under s. 60 of the Corporatisation Act 1991). Specifically, clause 10(2) of the Regulation does not permit the erection, use or maintenance of an intensive animal feed lot, intensive pigsty, intensive poultry operation, trout farm or other concentrated agricultural activity identified by HWC as a hazard to water to be supplied by the Corporation. Under clause 12(1) of the Regulation, HWC may serve notice on owners and occupiers of land within a special area that the Corporation requires structural alterations to a building or other work on the land, subject to any approval required under any Act.

The Special Areas Regulation 1989 also regulates a number of day-to-day activities on land within special areas, including the use of pesticides, or the bringing of pollutants or wastes into a special area.

Some privately owned land within the special areas is also subject to restrictive covenants in HWC's favour.

Environmental impact assessment:

The formal procedures for assessment of environmental impacts of certain projects are set out in the *Environmental Planning and Assessment Act 1979* (the EP & A Act). This process usually applies to development on both public and private land. Part 4 of the Act requires environmental impact statements (EISs) to be prepared for particular types of development. Under Part 5 of the Act projects likely to cause significant environmental effects also require an EIS. The EIS requires the developer to outline the project, examine the nature and extent of anticipated adverse environmental impacts and identify measures to prevent or minimise these impacts. The EIS must be publically exhibited and public submissions must be taken into account in the decision-making process (Coastal Policy 1990).

Environmental planning instruments:

There are several environment planning instruments - ie state environmental planning policies (SEPPs), regional environmental plans (REPs) and local environmental plans (LEPs) relevant to the

groundwater of the Tomago/Tomaree/Stockton area, and to related environments such as wetlands. These include:

- *SEPP 14 1985 - Coastal Wetlands* - which aims to protect many coastal wetlands. It was adopted by the Government in December 1985 with the aim of preserving and protecting coastal wetlands, following a survey of wetlands along the NSW coast. An EIS must be prepared for any proposed development in a SEPP 14 zone. Under the SEPP, developments involving clearing or filling of land, construction of levees or drainage works will only be permitted on designated wetlands with local council consent and with the concurrence of the Department of Planning. In considering whether to grant concurrence the Director shall take into consideration the surface and groundwater characteristics of the site and its surrounding area including salinity and water quality.

SEPP 14 is subject to a continual review process involving amendment of maps and the principal policy. A number of other SEPPs, mainly relating to various aspects of urban development, that can affect the groundwater or its related ecosystems.

- *Hunter REP 1989* - This REP identifies in broad terms where development may occur in the future within the 14 local government areas - including the Port Stephens Shire - that it covers. It is in the process of being revised (Department of Planning, 1994a).
- *Port Stephens LEP 1987* - was adopted by the Government in December 1987 and has been amended since then. This is the principal instrument for the control of land use and development covering nearly the whole of the Tomago/Tomaree/Stockton sandbed area. Land is divided into numerous zones under the plan, so a series of maps which show the zones must be consulted. Under the LEP there are a number of environmental protection zones. In these zones, most types of development require Council's consent. These zones include: 7(a) - Environmental Protection (Wetlands) Zone; 7(c) - Environmental Protection (Water Catchment) Zone; and 7(f1) - Environmental Protection (Coastal Lands) Zone.

The Port Stephens LEP, like all LEPs covering the coastal area in NSW, is required to give effect to the NSW Government's Coastal Policy (1990). This Policy currently applies generally to land extending one kilometre landward from the low-water mark and three nautical miles out to sea (Farrier, 1993). It requires a local environmental study to be done for a proposed development in the coastal area (within one kilometre of the coastline) that requires re-zoning. For example, proposed development at Fern Bay (see figure 7.1) was the subject of a local environmental study. The 1990 Policy is in the process of being revised (Coastal Committee of NSW 1994).

Port Stephens Shire Council has also adopted a number of development control plans and codes to control development within the Shire.

Urban settlement strategies:

A settlement strategy is not a statutory planning instrument. Rather, it provides a guide to the development of REPs and LEPs.

Within the Hunter region, the strongest population growth is occurring in the coastal areas and there is every indication that this trend will continue (Department of Planning, 1992). In August 1994 the Minister for Planning released the *Hunter Coastal Urban Settlement Strategy* after public consultation. This Strategy relates to the coastal area located generally to the east of the Pacific

Highway, including the whole of the Tomago/Tomaree/Stockton sandbeds area (Department of Planning 1994b).

A direction made under s. 117 of the EP & A Act requires the Strategy to be taken into account in managing coastal urban growth. This Strategy is intended to guide councils, government agencies, developers and the community on the future direction of urban growth within the coastal area of the Hunter region. It is intended to be consistent with the State Government Coastal Policy (1990). The Strategy delineates potential urban areas that have been identified after considering planning issues and physical constraints to development. Urban growth in Port Stephens is proposed mainly for the Tomaree peninsular and possibly at Fern Bay (Department of Planning 1994).

The *Port Stephens Shire Council Settlement Strategy* (Port Stephens Council, 1994) states that a continuation of water supply and good quality water requires protection of the special areas. The Strategy identifies a number of areas in the Shire, particularly in the Tomaree area, which could be developed under the existing zoning structure for residential use. It should be noted that there will be impacts on groundwater quality and quantity, whether development occurs within or outside the special areas, although the existing special areas and water reserves provide a considerable degree of protection for groundwater in the Tomago/Tomaree/Stockton area.

4.9 Public land

Most public land in the Tomago/Tomaree/Stockton is Crown land under the *Crown Lands Act 1989*. The Commonwealth of Australia occupies land used as a RAAF base in the Tomago Special Area (see Fig. 5.2).

The Coastal Crown Lands Policy:

The Coastal Crown Lands Policy translates the Government's Coastal Policy (1990) into specific strategies and actions that the Department of Conservation and Land Management intends to implement in relation to coastal Crown land. For the purposes of this policy, 'coastal Crown land' is defined as all Crown land one km landward from the low water mark'. Under this Policy all environmentally sensitive Crown lands and beaches are to be retained in Crown ownership (Farrier, 1993). This Policy, therefore, covers areas such as Stockton Beach, which is the subject of a current environmental study and draft management plan.

Water reserves:

Areas of Crown land listed as 'water reserves' under Part 5 of the *Crown Lands Act 1989* are shown in Figure 5.2. They are areas of land reserved for public water supply purposes. They cover about half of the land in the Tomago Special Area and nearly all of the land in the Tomaree Special Area. There are also water reserves covering much of the groundwater at Stockton (never used by HWC, but held in reserve to meet future water supply needs). The reservation of this land effectively protects the groundwater in these areas. The former Hunter Water Board was the trustee of these water reserves. However, these trustee powers can now be exercised by the Director-General of DWR under section 54 of the Corporatisation Act 1991, which means that this land cannot be sold, leased or licensed without the Director-General's consent.

Preparation of a management plan for the water reserve is the responsibility of the Minister for the Department of Conservation and Land Management, or with his consent, the reserve trust (ie the Director-General of DWR). Land in the water reserves can be sold or leased by the reserve trust

with the Minister's consent (*Crown Lands Act 1989* ss. 102-103). It first has to be assessed under Part 3 of the *Crown Lands Act 1989* to establish the land's preferred use. The assessment must consider the value of the land for environmental protection. The Stockton Bight environmental study and draft management plan (carried out in 1994/95) has included an assessment of Crown land in the Stockton area pursuant to Part 3 of the *Crown Lands Act*.

National parks and nature reserves:

Land (usually Crown land) can be reserved under the *National Parks and Wildlife Act 1974* as a national park or dedicated as a nature reserve. Under section 8(2)(a) national parks are described as 'spacious areas containing unique or outstanding scenery or natural phenomena'. Under section 8(2)(c) nature reserves are 'areas of special scientific interest containing wildlife, natural environments or natural phenomena' (Farrier 1993). Tomaree National Park, Kooragang Nature Reserve and Moffats Swamp Nature Reserve are all either reserved or dedicated under the Act (see fig. 5.6). The National Parks and Wildlife Service (NPWS) is responsible for their care, control and management. Tomaree National Park is currently 896 ha, split over seven separate areas (see Fig 5.6). There has for some time been public interest in this Park being expanded (Dorman and Vernon, 1993).

There are extensive restrictions placed on development in Crown land reserved or dedicated for special purposes in the area (for example, national parks, nature reserves and water reserves). The NPWS is only given power under its Act to build works relating to the management and maintenance of a national park (s. 8(3)) or the protection and care of fauna and the protection of native plants (s. 8(7)). The reservation or dedication of land under the *National Parks and Wildlife Act 1974* effectively protects its associated groundwater from contamination; however, groundwater extraction will usually be excluded.

Environmental planning instruments under the *Environmental Planning and Assessment Act 1979* (see above) also apply and set general constraints. Management plans, which are more detailed, are also required to be developed by the NPWS for national parks and nature reserves (but not for the water reserves reserved under the Crown Lands Act). It must be referred to HWC and any HWC representations considered before the plan is adopted.

State forests:

Under the *Forestry Act 1916* Crown land can be dedicated as a State forest, as a flora reserve, or reserved temporarily from sale as a timber reserve. State Forests of NSW manages some State forests in the Bulahdelah management area, to the north of the Tomago/Tomaree/Stockton area. These State forests are at Wallaroo, Uffington, Karuah and Medowie, which form part of the catchments of Twelve Mile Creek, Reedy Creek, Williams River, Karuah River and Grahamstown storage.

Aboriginal interests:

There is a range of specific Acts and provisions which address Aboriginal interests at national and state levels. The *Australian Heritage Commission Act 1975* establishes the Australian Heritage Commission which creates the *Register of the National Estate* by listing places nominated from all over Australia. Listing on the Register only imposes obligations upon Commonwealth Ministers and authorities and has no ability to restrict the activities of private individuals or companies, nor state and local governments.

Under the *Aboriginal and Torres Strait Islander Heritage Protection Act 1984* (ATSIHA) Aboriginal peoples can apply to the Commonwealth Minister for the Environment to make a protective declaration where certain areas are under threat of damage or desecration from private bodies or individuals.

In NSW provisions dealing with the protection of Aboriginal heritage and culture are found in the the *Heritage Act 1977* and the *National Parks and Wildlife Act 1974* (NPWA). While the former does not include 'relics' and 'Aboriginal places', it is relevant in that it protects sites which are important to both European and Aboriginal history, and provides for immediate protection of 'items of the environmental heritage' of the State. Thus, in cases where the exact details of an Aboriginal site are uncertain it can be protected until further assessment affords it protection under the NPWA. The NPWA protects "relics" and "Aboriginal places" but provides no special role, privileges or rights for Aboriginal people in the management of Aboriginal heritage protection.

Similarly, the *Aboriginal Land Rights Act 1983* (ALR) does not protect sites, nor does it allow them to be claimed by Aboriginal people. It only allows for claims on vacant Crown land not needed or likely to be needed for essential public purposes.

The *Native Title Act 1992 (Cth)* provides for Aboriginal land claims to be made on unalienated Crown land where current usage is not deemed to be incompatible with the continuance of native title. National parks and conservation areas are examples of such current usage that is compatible with the lodgement of claims. The *NSW Native Title (NSW) Act 1994* gives effect to the Commonwealth legislation within the NSW.

4.10 Pricing

There are costs incurred in managing groundwater in the Tomago/Tomaree/Stockton area, especially by DWR and HWC. These include the costs of groundwater assessment and monitoring groundwater behaviour. These costs are currently paid by the community through rates, charges and taxes. It is important, therefore, that these costs be minimised. Accordingly, the level of management should be kept at the minimum necessary to ensure preservation of the resource (Ventriss 1989).

If the community's resources are to be used in the most efficient way, prices should show each customer the costs of consuming water, discharging waste or moving to a particular location (Government Pricing Tribunal 1993). Such costs should include environmental as well as financial costs, because this can help ensure scarce water resources are not wasted.

Environmental costs are also known as 'externality' costs arising from activities that cause groundwater and environmental pollution. In terms of groundwater quality, these costs include both groundwater contamination/pollution and wetlands pollution/loss. There are also externality costs arising from changes in the groundwater level, including saline intrusion and environmental damage to wetlands (Pope 1989).

In the past, the low or zero pricing of natural resources has encouraged the view that unlimited potable water was a right. The result has been ecologically unsustainable levels of exploitation. It is now recognised that nature is not limitless in its capacity to supply water and absorb wastes. The key to achieving ecological sustainability in groundwater management is to ensure that resources are not treated as free in the future (Watson and Johnson 1993).

These costs have important implications for the community of the Tomago/Tomaree/Stockton area, given the importance of groundwater to the public water supply system (especially as considerable urban expansion is anticipated in the area) and the costs and difficulty of 'cleaning up' degraded aquifers. It is important that the community is made aware of the long term scarcity of groundwater and risks of pollution to this valuable resource.

In 1994 the Council of Australian Governments agreed to pricing reform based on the principles of consumption-based pricing and full cost recovery (Council of Australian Governments 1994). The NSW Government Pricing Tribunal is concerned that the structure of water prices should provide suppliers (such as HWC) and customers with signals that reflect the scarcity of water and the true costs of providing it. The Tribunal regards HWC as an industry leader in pricing policy, because since 1982 it has moving towards a pay-for-use pricing structure, mainly by replacing its property based charges with a tariff based on water usage (Government Pricing Tribunal 1993).

HWC is current exempt from paying licence fees. In the past the only costs incurred were by HWC. These included investigating groundwater and monitoring. HWC also incurs costs associated with extracting groundwater and managing the special areas. Since corporatisation, DWR has taken on the responsibility of managing the resource and, therefore, the costs of assessing the resource, defining the conditions on use, ensuring compliance with these conditions, and monitoring the resource, particularly in terms of its use by HWC. It is anticipated that under future licensing arrangements, HWC will be required to pay a licence fee to cover these costs.

4.11 The future roles of DWR and HWC in groundwater management

HWC, as a commercial, quasi-private organisation, is pursuing its commercial objectives of providing water supply and sewerage services, whilst groundwater management functions are the responsibility of DWR, the State's water resource manager. This means that the groundwater use of the HWC will itself need to be licensed. The Special Areas Regulation 1989, which currently incorporate provisions relating to both proposed development (planning powers) and day-to-day activities, is due for revision in 1995. Proposed administrative allocation of division 8 from the Minister responsible for HWC (the Minister for Planning and Housing) to the Water Administration Ministerial Corporation (that is, the Minister for Land and Water Conservation) will enable this Regulation to be replaced by DWR.

The powers currently exercised by HWC over groundwater extraction by other users should be taken over by DWR. Ideally, the development powers in the Special Areas Regulation 1989 (referred to in section 4.6) should be located in an environmental planning instrument, such as an LEP. The overall responsibility for powers in the Regulation that control day-to-day activities that have the potential to affect groundwater quality in the special areas would be better placed with DWR, with some 'on the ground' powers delegated back to HWC. It should also be stressed that proper review of this Regulation does not involve merely splitting the clauses into one of these two categories. The Regulation needs to be updated to reflect current needs, as some powers are outdated and there are issues not presently covered by any powers.

5 PRESENT LAND USE

Land use is a key factor in determining the water quality in any area. For surface water resources, the connections between land use, water quality and water quantity are direct, and are clear for all to see. The relationship between land use and the maintenance of the quality of groundwater resources is less direct and less obvious. Groundwater may travel for a large distance from its recharge area, and is often separated from the land surface by impermeable rocks. The impact on water quality of land use practices in the recharge area can therefore become apparent some distance from the land being affected. This is not the case in the Newcastle Formation aquifers, however, because the sand beds are continuously permeable from the land surface downwards. Land use here has a major and immediate impact on the quantity and quality of water entering, and stored in, the sand aquifers. Comment on land use in the study area is, therefore, an essential part of the study.

Table 5.1, which outlines major land uses in the project area, has been prepared from a wide range of information on the study area. Available data have been collated to form an impression as to the principal activities of the permanent inhabitants of the Tomago-Williamstown-Medowie district (Figs. 1.1, 5.1). Preparation of a more rigorous land use map should be undertaken as part of developing a Groundwater Management Plan.

TABLE 5.1: Major land uses

Land use	Percentage
Industry, manufacturing, construction	32
Commerce, finance, transport, storage	25
Health, administration, education, defence	13
Agriculture	10
Entertainment, recreation	5
Communications	4
Utilities	2
Mining	2
Other	7
	100%

Land uses in the eastern areas of the study area remain unquantified.

5.1 Residential development

Port Stephens Shire (Fig 1.1) has become a major residential and recreational growth centre for coastal NSW. The 'unprecedented expansion is greater than for any other local government area in the Hunter Region' (Hindley 1983a), and is based on a strong tourism industry. The trend is expected to continue.

However, there are major land-use and environmental constraints to further settlement which have generated debate within the community. For example, according to the *Hunter Regional Environment Plan* (1989, Department of Planning and Environment) there are 'clear opportunities for growth in the region', but 'there is a need to take action to overcome factors inhibiting development'. By contrast, the National Parks Association of NSW state that 'the Newcastle Bight area is largely unsuitable for development' (Dorman and Vernon, 1993).

The *NSW Coast: Government Policy* (1990) suggests that 'the challenge in the face of rapidly increasing population pressure' in the region, is to 'balance the legitimate demands on the coastal zone for housing, tourism, industry, mining, and agriculture' while 'recognising the importance of the natural environment'.

Population statistics for the main growth areas are shown in Table 5.2 (see Fig 5.2 for locations).

TABLE 5.2: Population data, Newcastle Bight region

Estimated max. capacity and year max. capacity estimated to be reached		1986	1996 projected	2006 projected	2016 projected
33-44,000/2028	<u>Tomaree Peninsula</u> (Salamander, Nelson, Shoal, Fingal, Anna Bays, Soldiers Point)	11,250	17,000 (rapid inc.)	23,000	29,000
to 12,000	Salamander-Anna Bay	-	-	-	-
8-9,000/2004	<u>Tilligerry Peninsula</u> (Tanilba Bay, Mallabula, Lemon Tree Passage)	3,950	6,000	8,000	8,000
18-25,000/2010	<u>Raymond Terrace</u>	9,420	11,500	14,700	18,000
13,000/2025	<u>Medowie</u>	3,360	6,000	8,000	11,000
~12,000/-	<u>Fern Bay</u>	-	-	-	-
	Salamander Bay; Area 'M'	-	-	+4,000	-
90,000(Max.)	Total Pt. Stephens Shire:	36,000	52,000	66,500	81,000

(Port Stephens Shire Council, 1994)

The availability of abundant clean water has been one of the major attractions of the region.

5.2 Water supply, sewerage and drainage systems

5.2.1 Water supply

Comment on water supply schemes is restricted to the sandbed areas of the study area (Figure 2.1) Much of the groundwater from the aquifers supplies urban and industrial centres outside the region, including Newcastle and the surrounding areas.

Potable water supplies available in the area are of three types:

- surface water drawn mainly from the Williams River catchment;
- small surface storages on rural and urban properties; and
- groundwater, almost entirely from sandbed aquifers.

Water reticulated to the major towns by the HWC includes treated water from groundwater and surface water sources, collected through an interconnected collection grid (Appendix 4).

Figure 5.3 summarises available information on groundwater works within the sandbeds of the study area, however this map is incomplete. Many works on lands subject to the *Water Act 1912* are unlicensed, especially the numerous domestic spearpoints in the Tomaree area.

Officially recognised groundwater-extraction works in the study area divide into two categories:

- those within lands currently owned or managed by HWC (Figs. 5.2 and 5.3), that are used for town-water supply; and
- private works outside HWC lands which are subject to licensing by the Department of Water Resources, under Part V of the *Water Act 1912*.

Appendix 3 is a summary of licensing information for the works within the study area that were registered with the Department of Water Resources as at February 1994.

The history and current facilities of the HWC groundwater withdrawal works are described in sections 6.1 and 6.2 below.

5.2.2 Sewage

Sewage collection and treatment methods in the study area have evolved with increasing population, technology, and urbanisation of rural lands. There has been a steady growth away from basic home-based methods, through to local collective treatment, and to widespread connection into a few major plants. The trend is continuing, but many rural properties will probably always remain unconnected to a scheme. Large organisations have their own treatment plants.

There has been a significant improvement in sewage collection and treatment infrastructure on both the Tomaree and Tilligerry peninsulas in recent years. This work was undertaken by the Hunter Sewage Project on behalf of the Hunter Water Corporation and the State Government. This work represents a major step towards better groundwater protection in the region.

On the Tomaree Peninsula the Boulder Bay Treatment Works (45,000 EP) and extended ocean outfall was commissioned in 1993 resulting in the decommissioning of several smaller plant and the connection of 3200 unsewered properties to date. The plant will be able to handle all future development in the area into the next century.

Groundwater concerns may remain with the following major schemes, not part of the Boulder Bay grid, where treated effluent is discharged into receiving waters or infiltration beds for final disposal (Fig. 7.1):

- **HWC - Medowie Waste Water Treatment Works:**
The present activated sludge plant discharges into Moffats Swamp (Fig. 2.6) where the effluent is estimated to stand for about 120 days before infiltrating into the Tomago aquifer (HWC, unpub 1993). Residence times for effluent in the swamp may be much less in wet weather. The HWC is currently assessing options for augmenting the plant due to significant development in the catchment area. Options for plant augmentation are construction of new plant (7,000 EP) on a different site which will discharge to Moffats Swamp, and pumping sewage to Raymond Terrace for treatment.
- **HWC - Tilligerry Peninsula; Tanilba Bay:**
On the Tilligerry Peninsula a new sewage treatment plant (15,000 EP) was commissioned at Tanilba Bay in 1993. Prior to construction of this plant the townships of Tanilba Bay, Malabula and Lemon Tree Passage were unsewered. Effluent is disposed of via infiltration ponds. Groundwater movement is towards Tilligerry Creek and 7 monitoring bores have been established to monitor any potential contamination.
- **HWC - Raymond Terrace:**
A modern activated-sludge plant south of the city discharges treated effluent into the Grahamstown Canal. Overflow passes into Windeyers Creek and the Hunter River, with an unknown amount leaking into the aquifer. No information has been found on the integrity of the effluent ponds, however the ponds were originally clay-lined to prevent seepage losses.
- **HWC - Stockton:**
Although this STW discharges to the sea, the plant is located on the Stockton dunes and one treatment pond was lost to storm erosion in 1974. Any instability in the remaining lands raises the possibility of groundwater contamination.

- **Tomago Aluminium STW:**
Site waste-water is treated at a modern plant located on the edge of the Tomago sands (Figs. 2.1, 7.1). However, groundwater outflow (Figure 3.2) and effluent discharges pass into the Tilligerry lowlands, away from the main aquifer.
- **RAAF Williamtown STW:**
Although the plant is old, it is located towards the edge of the Tomago sandbeds where hydraulic gradients, flow, and effluent discharges are directed towards the Tilligerry lowlands (Figs. 2.1, 3.2, 7.1), away from the main aquifer.
- **Fern Bay subdivision, proposed STW:**
The sewerage treatment strategy for this proposed residential development (Fig 7.1) includes disposal of treated effluent by infiltration into the Stockton aquifer within Crown Water Reserve 61307 (Coffey Partners International Pty Ltd, 1992). Any potential impacts on groundwater, and alternative options will be assessed in the EIS.

Of greatest concern to groundwater quality protection within the study area is the presence of innumerable domestic septic tanks scattered across the sandbed lands-32% of holdings were unsewered in the Port Stephens Shire in 1977. Septic tank approvals have fallen from 236 in 1991 to 181 in 1992 since the Fringe Areas Sewerage Project started in the shire. However, there is no information as to how many of these units are now located on vulnerable sandbed lands.

5.2.3 Drainage systems*

Extensive networks of shallow drains and embankments cross parts of the Newcastle Bight area. They are most abundant along the floor of the Tilligerry lowlands where they drain waterlogged agricultural land, while exporting salt from the valley (Figs. 2.1, 5.3). Flow in the drains is towards Fullerton Cove in the west, and to the Tilligerry Estuary in the east. Sea water is held back by protective embankments and tidal flood gates at both ends of the lowlands. Drainage water originates both as rainfall within the valley, and in substantial volumes as natural groundwater discharge from the flanks of the Tomago Sandbed and the Stockton Sandbed (Figure 3.2).

Drains west of Anna Bay to Bobs Farm (Figure 5.3) are an extension of the Tilligerry lowlands system, although here the groundwater discharge is from the Tomaree and Stockton Sandbeds. Minor drains at Salamander Bay also are fed by the Tomaree sands, but the pattern may have been disrupted by construction of the Salamander golf course (Figs. 3.2, 7.1). A series of drains along the northern margin of the Tomago sands (Figure 3.2) exports seepage from the flank of the aquifer, as well as run-off from basement hills in the hinterland.

* This section relates to artificially enhanced drainage *from* the sand aquifers or adjacent units.

South of Raymond Terrace, the Grahamstown Drain carries overflow from the Grahamstown Storage Reservoir, via Windeyer Creek into the Hunter River. Apparent leakage from the western margin of the storage may be passing to the drain near Richardson Road (Figs. 5.3, 3.2).

The drain west of Medowie, from which seepage is pumped into the Grahamstown Storage (Figure 5.3), appears to be responsible for a large depression in the Tomago watertable (Figure 3.2). Again, leakage from the eastern flank of the reservoir may be contributing to the flow.

A similar drain east of Medowie which passes into Big Swan Bay (Figure 5.3), limits the water level in Moffats Swamp (Fig. 2.6), preventing overflow to the south onto the Tomago sands. Sewerage effluent being discharged to the swamp (Figure 7.1) contributes to the flow.

NSW Public Works has maintained communal drains on behalf of district 'drainage unions', which represent all local landholders. Decline in the function of these groups has led to the Longlight-Williamstown Drainage Union being replaced by a Steering Committee chaired by the Department of Water Resources (McGlynn, DWR; 1992).

Agricultural drains have not been regarded as licenseable works by the DWR under Part V of the *Water Act 1912*. However, the Newcastle Bight drains significantly limit the volume of water that can be held in storage in the sandbed aquifers. Natural groundwater discharge will be enhanced, and aquifer storage reduced, by any deepening or augmentation of the drains.

Drainage of lands within the study area needs further study. Meanwhile, a firm precautionary approach is recommended towards expansion of these schemes.

5.3 Extractive industries

The mineral resources of an area depend on several factors that are subject to change, including:

- community demand for fuels, metals, and construction materials;
- technology available for exploitation;
- production economics; and
- attitudes to the environmental impacts of production, use, and disposal.

Historical records describe past deposits, but present information is often confidential.

Past, present, and future views as to the significant mineral resources of the study area are summarised in Figure 5.4. Areas of potential mineral resource are indicated, but

these are highly price-dependent and technological developments or changing demand are expected to alter resource boundaries.

Recent re-mining of the Tomago sands for heavy mineral deposits in deeper leads is an example of changing perceptions. Mining companies assign only a limited potential to heavy-mineral occurrences in the Stockton sands, but this view could change with a rise in the price of titanium, or a demand for Monazite rare earths.

Sandy bog-iron (50% Fe) was once extracted by early settlers from a shallow pit in the Hunter Region Botanic Gardens using horses and used for copper smelting (D. Barnett, pers. comm., 1993). The deposit has no value today.

Substantial reserves of high-grade coal occur in the Tomago Coal Measures below the aquifer in the western end of the study area (Figure 5.4). Proximity to Newcastle's industrial areas may lead to pressures for mining, however several factors downgrade the attractiveness of the resource:

- the seams are thin and numerous;
- groundwater in the overlying Tomago and Stockton sands, as well as wetlands, may be affected by subsidence and pollution; and
- open-cut mines would be subject to flooding and slope collapse.

Further definition of mineral potential in the study area would help with groundwater management. Impacts on aquifers should be considered when defining resources.

5.4 Manufacturing industry

Although much of the land in the study area is used for agriculture or tourism, there is an increasing amount of industrial activity in the western areas which lie adjacent to the city of Newcastle.

An industrial corridor appears to be developing across the end of the Tomago sandbeds, linking Newcastle and the major rural centre of Raymond Terrace (Figure 7.1).

No comprehensive survey has been done of manufacturing industries that are sited on outcrops of the sandbed aquifers. However, major activities include the following:

- the CSR wood panel factory south of Raymond Terrace; and
- the Tomago aluminium smelter west of Tomago.

Minor light industry is scattered along the edge of Tomago sandbeds from Raymond Terrace, through Tomago village, and at places along the Nelson Bay Road towards Salt Ash. Activities include metal and electrical fabrication, chemical processing and wood working.

5.5 Agriculture

Agricultural Suitability Classes, as defined by the NSW Department of Agriculture for land in the study area, are shown in Figure 5.5. There is almost no arable land in the main sandbed areas.

Large sections of good farming country along the Tilligerry interdunal area correspond to regions of saline groundwater that are underlain by the Tilligerry Mud Member (Fig. 2.1).

The best farming lands are located on the Hunter River floodplains, with smaller areas beyond the boundary of the Tomago Sandbeds at Medowie.

5.6 Other land uses

Although past land development has affected groundwater, the focus here is on activities of the present population, and current impacts on groundwater which can be addressed by the management plan.

There is an abundance of land use information for the Port Stephens Shire and Lower Hunter Region (see, for example, Figures 5.1, 5.2, 5.4; Hunter Regional Plan 1977; Hunter Regional Environmental Plan, 1989; Port Stephens Local Environmental Plan [LEP], 1987). Categories include population composition, employment, enterprise, land ownership, and land classification.

Locations of existing and proposed national parks and nature reserves are shown in Figure 5.6.

6 THE AQUIFER SYSTEM AS A WATER RESOURCE

Aquifer systems throughout the world are used intentionally and unintentionally in a number of ways. The main use of aquifer systems has been as a source, storage, and distribution system for water and as a receptor for solid and liquid wastes. Less commonly, groundwater systems have been used as natural treatment media for the renovation of wastewater, sources or sinks for thermal energy, mining sources of hydraulic energy, and for the storage of gas and fluids other than water. However, there has been more concern in recent years with the wider environmental aspects of the uses of aquifer systems. A more detailed discussion of the possible functions of an aquifer system is provided in Appendix 2.

Bores or tubewells are common types of access, but other structures such as wells, spearpoints, pits, excavations, and even dams may be dug to the watertable. The NSW *Water Act 1912* refers to any structure, regardless of size, that is man-made and penetrates the watertable as being a 'licensable work'. Use of a natural spring is not captured by the Act; nor are the 'watertable windows' of the Bight's sandbeds, where groundwater crops out at the surface as wetlands. In this report the term groundwater 'work or structure' is used to describe licensable works.

Many works entering an aquifer are not intended to be used for long-term water extraction but are for resource investigation (test bores), water-level or water-quality monitoring, or for appraisal at a construction site or mine. Dredges used for mining in the sandbed areas float on groundwater at the watertable in a window or pit that progresses across the orebody as new ground is excavated at one end and the excavated area re-filled with treated sand at the other. Groundwater is used temporarily by the dredge but it is returned to the pond with no substantial loss of volume. Mining, however, can change the quality of groundwater so the resource has, in a sense, been 'used'.

To cover these activities, the term 'access to groundwater' is adopted in this report, rather than 'groundwater use'. Figure 5.3 records all information available to the project on groundwater works within the study area. The detailed notes on the map are self explanatory and provide a summary of aquifer development in the region. Figure 5.4 shows areas of the sandbeds that have been disturbed, presumably below the natural watertable, by dredging for heavy-minerals. For licensing purposes, the dredge pits could be regarded as 'abandoned and backfilled excavations accessing groundwater'.

It should be noted that Figure 5.3 is incomplete and many works on lands subject to the *Water Act 1912* appear to be unlicensed. Future effort could be directed at recording all functional monitoring bores and especially what are believed to be the very numerous unlicensed domestic spearpoints in the Tomaree area, especially the Nelson Bay-Shaol Bay-Fingal Bay area (see eg. Holroyde, 1990, p.72). A major property survey may be appropriate, to locate and map each work, assess its purpose, the amount of water used, and measure water quality. Basic information on design, construction, and local geology could also be obtained. While details of individual works may seem unimportant, collectively the information is essential for effective management of the resource.

There is little detailed or specific information about groundwater use in the study area, either within the gazetted Tomago Special Area (Figure 5.2), or in other lands controlled by the HWC, or in other areas not under HWC control.

Within the special areas, the right to use, flow and control of groundwater resources has, subject to some limitations, been vested in the HWC (see Chapter 4 above). Large amounts of water have been extracted from the Tomago and Tomaree Sandbeds over many years to supplement other sources of town water for Newcastle and its surrounds. (Figure 6.1, 6.2, see also Appendix 3).

Outside the special areas (Figure 5.2) the HWC has no control over access to groundwater, and 'all works penetrating the watertable' are subject to license by the DWR under Part V of the *Water Act 1912*. Many of these works are unlicensed. Appendix 4 summarises all that is known about registered works in the project area. Many of the licences have been issued 'in perpetuity' for low volume stock and/or domestic bores or spearpoints. Meters have not been required and annual returns on water usage are not submitted to the DWR. Total volumes may be small but remain unknown. Cumulative extractions are of major concern in areas such as Nelson Bay where it is believed that hundreds of unlicensed spearpoints could be taking a significant amount of water from the edge of the Tomaree Sandbeds (see Figs. 2.1, 5.3). The threat of saline intrusion into these areas is also a matter for concern.

Table 6.1 (see over page) summarises groundwater use categories for the study area. The information in Table 6.1 is based on a literature search and on basic field observations (done in July-December 1993), and inferences drawn from the pattern of land uses recorded in Chapter 5 above. The tabulation is partly speculative and is certainly incomplete, but it forms a basis for further investigations for a future Groundwater Management Plan. All the main sandbeds of the project area are considered together. Only direct use of, or access to, groundwater is considered:

As indicated above, officially recognised groundwater extraction works in the study area fall into two categories:

- those structures outside lands controlled by the HWC (see: Fig. 5.2) which have been licensed by the DWR, as required under Part V of the *Water Act 1912*, and
- those within HWC lands, used by HWC for town-water supply.

Groundwater development in the study area is discussed below under these two broad headings, but by far the largest part of the development of groundwater extraction works has been carried out by the HWC.

TABLE 6.1: Tomago/Tomaree/Stockton groundwater use categories

Extraction and consumption:	
Agriculture	Livestock (sheep, beef/dairy cattle, horses, pigs, poultry); irrigation (pasture, fodder, vegetables, fruit, viticulture, horticulture, ornamentals); drainage (waterlogged lands; marshes, swamps wetlands)
Aquiculture	Yabbies, fish, oysters
Recreation	Parks and gardens (esp urban); resorts, hotels, golf courses
Industrial	Heating, cooling, steam, washdown, flushing; engineering (construction, floatation, cement); chemical processing; smelting (aluminium); timber processing (esp Masonite); electrical and metal fabrication; general light-industry
Commercial	General non-residential urban activities, esp. food processing, beverages, fish; tourism
Utilities/Shire	Construction; urban environment - parks and gardens; urban support - town water supply, amenities, sport; sewage transport, treatment, and disposal; firefighting; health support, education; drought/crisis reserve
Mining	Dredge pond top-up; mineral processing; industrial extraction; resource exploration and development
Defence	(RAAF base is a small industrial town)
Environment	Aquatic ecosystem support (swamps, marsh, wetlands); vegetation ecosystem support (sedge, woodlands); faunal support (habitat, water supply); microclimate maintenance

Table 6.1 (cont): Tomago/Tomaree/Stockton groundwater use categories

Future	Saltwater dilution/flushing; coal mining (process support, dewatering, coal washing); synthetic fuels (coal-to-oil); heavy industries; environmental support; resource remediation (pollution clean-up)
Passive access, non-consumptive (but possible water-quality impacts):	
Recreation	Primary contact (swimming); secondary contact (boating, fishing etc.); visual/aesthetic (ponds)
Industrial	Site assessment; drilling; watertable disturbance (earthmoving, boring); waste disposal
Utilities/Shire	Sewerage effluent disposal; town water drought/crisis reserve; rubbish pits (into watertable)
Mining	Dredge floatation; sand excavation, washing, sorting, replacement; exploration drilling
Environment	Dune stabilization (wet sands as deflation base); maintain saline interfaces; other ? (investigations required)
Resource management and exploration (agriculture, industrial, mineral, water, environmental etc.)	Exploration/investigation (test boring); appraisal/development; monitoring (especially water levels, water quality); remediation (pollution clean-up)

6.1 Hunter Water Corporation

Many reports have been prepared, and several published, which describe parts of the aquifer system in the Newcastle Formation, but most refer only to specific matters which were important in relation to issues affecting water management at the time. The following paragraphs outline the history of development of HWC usage of groundwater, and some of the related resource management aspects.

6.1.1 History of development

Construction of the Tomago groundwater extraction facilities can be divided into several stages (eg. Corlette 1994; Holroyde 1990):

- **STAGE I (to July 1939):**

This was an experimental scheme, with two primary pumping stations, one secondary pumping station, a spray basin, and a delivery main. It was commissioned in January 1939, at '2x 10⁻⁶ gpd' (9ML/day).

- **STAGE II (1939-1942):**

This was the main construction phase, and was developed in haste in response to the drought that ended in 1942. Output was increased to '15x10⁻⁶ gpd' (68ML/day) with fifteen primary pumping stations and extended over an area of 48 km² (2-5x23 km). It was based on a battery of spear points at each pumping station, connected by a suction system. Each pumping station was designed to address approximately 5 km² of sandbeds, taking into account:

- aquifer properties and thickness;
- water quality (high iron avoided);
- the need to prevent saline intrusion by location 'as high as possible on the watertable'; and
- by 'using a vacuum system, limiting the draw to about 26ft (7.9m).

Each primary pumping station consisted of 50 to 60 x 102 mm gravel-packed tube wells connected to slotted-brass strainers, 12 m apart along a 750 m common suction line or header that was set parallel to local sand trends. The 600 mm Tomago Main delivered raw groundwater to the Tomago water treatment plant (Fig. 5.3) where it was aerated at a spray basin before being dosed with lime, alum, and chlorine then filtered prior to storage.

- **STAGE III (1943-1994+):**

In this stage there was a trend to fewer but deeper wells, each one being equipped with a submersible pump. Pumping stations' 16-23 were constructed during this time (Fig. 5.3). Many of the Stage II suction systems, from tube wells to pumping stations, were abandoned or replaced because:

- suction from the vacuum pumps was unreliable and required high maintenance;
- priming was necessary, taking 20 minutes;
- vertical lift was limited to 26ft (7.93m), restricting access to deeper water in a drought; and
- water quality (especially iron content) and yield were unsatisfactory in some areas.

The whole Tomago Groundwater Extraction Complex (GWEC), excluding the Tomago water treatment plant, has been unused at times in the past, then refurbished in response to drought.

A typical modern pumping station consists of a number of well points each 300ft (91m) apart on a collector main set parallel to local watertable contours (for example, PS 16/17 consists of 28 bores 300ft (91m) apart, each delivering 100gpm (7.6L/sec) to a common boosting station). Pumps are submerged and driven either by shaft from the surface, or by immersed electric motors of either the wet or dry-stator type. Output varies from 3.5 to 7.6L/sec per pump. For construction, a 22 inch (559mm) steel casing about 65ft (19.8m) long was jetted-in at 1400g/m (106L/sec) and the annulus packed with 3/16inch (5.8mm) pea gravel around at least 15ft (4.6m) of 6inch (152mm) ribbed-brass or, commonly, stainless steel screen.

6.1.2 *Current use and trends*

Appendix 3 is a diagrammatic representation of the whole water supply network controlled by the Hunter Water Corporation, and the location of the various facilities is shown in Figure 5.3.

The HWC groundwater-extraction grid consists of the major 'Tomago Sandbeds' source and three minor resources in the Port Stephens area; 'Lemon Tree Passage', 'Boat Harbour', and the 'Anna Bay/Nelson Bay/Fingal Bay' scheme (in Holroyde 1990; Fig. 5.3). These are combined into two collection, treatment, storage, and delivery systems, namely the 'Tomago Sandbeds' grid (incorporating Lemon Tree Passage), and the 'Nelson Bay/Anna Bay' grid, including the Fingal Bay extension. The Boat Harbour line and water treatment plant have been abandoned. Water is treated at the Tomago water treatment plant, or at the Anna Bay and Glovers Hill plants (Figure 5.3).

A collection system planned for the Stockton sands water reserves would connect to either the Tomago Primary Line, to the Anna Bay water treatment plant, or would be treated in a new water treatment plant and pumped directly to Newcastle.

For simplicity, and to match aquifer terminology, the three main grids are referred to in this report as the Tomago, Stockton, and Tomaree Groundwater Extraction Complexes (GWEC's). The Tomaree GWEC presently includes the Anna Bay, Nelson Bay, and Fingal Bay Borefields.

The Tomago GWEC consists of 23 pumping stations, not all of which are still in service. The pumping stations are serviced by some 120 deep bores and 510 tube wells. There are 21 groundwater extraction points, each equipped with a turbine pump, in the Anna Bay Borefield (Fig 5.3) while no works are in place on Stockton.

An audit and re-classification of the entire HWC groundwater withdrawal facilities is recommended prior to any licensing action by the DWR.

Figure 6.1 shows water pumpage from the Tomago and Anna Bay GWECs, and Figure 6.2 shows total pumpage by HWC from all sources. Since the Grahamstown Storage was commissioned in about 1960, the Tomago GWEC has become an expensive source for the HWC to operate, relative to surface water alternatives such as Chichester Dam. This is because of the 'high labour costs for monitoring and servicing the numerous small pumps' (Holroyde 1990). For this reason, there has been a tendency to use Tomago water only for peak demands in summer, and as a base reserve that can be progressively developed in a

drought or some other surface water crisis. There has been a suggestion that, with the expansion of the Grahamstown Storage, Tomago's only use might be as an emergency reserve; as outlined in HWC's Drought Management Plan (see Holroyde, op cit). On the other hand HWC personnel have said that the installed extractive capacity for the Tomago GWEC was 104ML/day (38 GL/year) in July 1993, with current expansion planned to 206 ML/day (75 GL/year). However, daily extracted volume is said to 'rarely exceed about 65 ML'. The projected future figures appear to be substantially in excess of the acceptable withdrawal rates suggested in Chapter 3, highlighting the need for extensive understanding of the aquifer before there are major increases in pumping rate.

The reported HWC pumpage from all sources, including the Tomago and Tomaree systems, is illustrated in Figure 6.2. The break in upward trend of consumption in 1980, and the relatively stable consumption rate since then might be due to changes in water charging policy, or seasonal conditions, or a combination of both. However, the demand for groundwater is expected to continue to increase because of the anticipated population increase and recent blue-green algal outbreaks in surface water supply sources. Population trends are outlined above in Section 5.1 and summarised in Table 5.2. A doubling of population in Port Stephens Shire by about 2016 is predicted, and a substantial increase of water use by HWC would be necessary to meet the resulting demand. Consumption via private wells and bores might also increase, but the amounts are likely to be small. Industrial and commercial use, however, could be expected to increase in parallel with the population growth. If the trend of increased consumption between 1940 and 1980 shown in Figure 6.2 is repeated for the period from 1990 to 2015, the consumption would increase by 35 to 40 GL per year, which is an increase of just under 50% on current usage. Such an increase is unlikely, because of the effect of demand management strategies introduced during the late 1980s, but a substantial increase in total demand must be expected for the period.

Within the overall water use trend, the consumption of groundwater has changed from an increasing pattern prior to 1965, to an uneven pattern since then (see Figure 6.2). This change was due to the use of groundwater as a drought reserve only following the implementation of the Grahamstown Reservoir in 1965. There has been no year, however, in which no groundwater was used, although very little was used in 1984. It is therefore difficult to forecast groundwater usage, as it will depend very much on decisions taken about how the reserves of groundwater are to be managed.

One aspect which may have a bearing in practical terms, however, is the cost of maintaining a groundwater operating system. If the groundwater system is to be available for use during periods of shortage in the surface storages, there will be a substantial cost involved in adequate maintenance. Given that there is an operable system available, and that it is a cost burden on the HWC and its customers, there will inevitably be pressure to make use of it. Some increase in groundwater use is therefore likely, and the aquifer system is apparently capable of some degree of increased withdrawals. The Groundwater Management Plan will be required to shape limits on that withdrawal in the license to be issued to the Hunter Water Corporation, based on decisions to be made on how much stress can safely be placed on it.

6.1.3 Aquifer system assessment and monitoring

Formal groundwater assessment has mostly been conducted only by the Hunter Water Corporation and a few other larger users. Exploratory drilling and pumping tests to determine aquifer properties and limited hydrogeological and hydrochemical studies characterise these investigations which were all intended to ensure that the user would always have enough water. Factors such as other users or environmental considerations are not considered in these early studies (eg Corlette, 1944). Monitoring of the groundwater system also seems to have been directed mainly at operational requirements, rather than towards developing a comprehensive understanding of the groundwater system (as evidenced by, for example, the lack of metering on individual withdrawal points and the lack of ongoing environmental impact appraisal). Water level monitoring data held by Hunter Water Corporation is summarised in Table 6.2 below (HWC 1994).

TABLE 6.2: Water level monitoring data (after HWC 1994)

Number of points	Date of first measurement	Date of most recent measurement	Frequency of measurement
21	May 1947	Oct 1957	Daily
25	Oct 1957	Jun 1968	Daily
25	Jun 1968	Dec 1974	Twice per week
75	Jun 1972	Dec 1976	Monthly
75	Aug 1979	Nov 1984	Monthly
75	Feb 1985	Feb 1994	Quarterly

The first major need for more detailed monitoring arose when dredging for heavy-mineral sands began along the axis of the Tomago aquifer (Figs. 5.3, 5.4). Extensive assessment of groundwater properties, before and after mining, are required of the mining company. These studies are continuing and the collected data is being analysed by various consultants (eg DJ Douglas).

Prior to corporatisation, the Hunter Water Board had absolute powers to manage groundwater within gazetted Special Areas (Figure 5.2). Although the HWC's primary interest in the sandbeds is groundwater extraction for town water supply, the organisation appears to have a well developed environmental ethic. Activities are guided by an Environmental Management Plan and the Corporation has an Environmental Policy Unit which is active in the field of public education. Potential for conflict may arise, however, between the need for the Corporation to meet its commercial objectives regarding water supply and sewage disposal on the one hand, and the need for protection of the water-related local environment. A proper regulatory regime will therefore be required to govern the HWC's use of groundwater.

A comprehensive re-assessment of the procedures employed for monitoring groundwater pumpage and the response of the aquifer system is necessary, to ensure that the data being collected is satisfactory for the purpose of assessing the long-term capacity of the aquifer system to maintain the desired withdrawal rate within acceptable environmental limits.

6.2 Other users

As indicated earlier in this Chapter, the extent and rate of groundwater use outside the HWC Special Areas is uncertain. It is apparently concentrated in a few village locations and in a small number of industrial/commercial enterprises.

Since the enactment of the *Environmental Planning and Assessment Act 1979* (EPA Act), major developments in NSW must be assessed for their impact on the environment. This includes not only sensitive ecological systems, but also groundwater and related water environments (see section 4.8). Large projects recently approved in the study area subject to an Environmental Impact Statement include the Tomago Aluminium Smelter and subsequent extension, heavy-mineral sand mining, a highway re-alignment south of Raymond Terrace, Stockton Bridge, a golf course at Salamander Bay, and the enlargement and new spillway for the Grahamstown Storage Reservoir (Fig. 7.1). The proposed Fern Bay residential subdivision has not at this stage been approved. This list of major developments is probably incomplete.

The extent and type of monitoring being undertaken in conjunction with licensed and unlicensed uses of groundwater outside the HWC special areas is variable and uncertain. There is a need for a comprehensive assessment of all groundwater monitoring in the study area, as part of a Groundwater Management Plan. The monitoring procedures are properly the responsibility of groundwater users, but the data from the monitoring network must be studied as a whole. Under current and proposed legislative and administrative arrangements, the DWR is the appropriate body to conduct the regional assessment of this body of data. Optimum management of the groundwater resource and the environment in which it occurs can, however, only be achieved if both users and the DWR undertake the task with a commitment of adequate resources.

Table 6.3 summarises all information made available to the project on groundwater monitoring in the study area. Being derived from scattered records in the literature it is certainly incomplete and must be used with caution. Apart from the overview of activities it provides, it can form the basis for future surveys, as a contribution to effective groundwater management. Impressions that can be drawn from this table are that:

- most groundwater monitoring serves corporate interests;
- there is little, if any, environmental monitoring;
- there is no regionally-coordinated approach to water management in the study area;
- there is little coordination within and between industry, government and private bodies;
- collection of monitoring data is very unevenly spread across the study area;
- some existing data has not been analysed;
- a statistical approach could be effective in examination of some of the data in hand;

STATUS	MONITORING:				PARAMETERS:																					
	Organisation	Location	Structure	Frequency	Cations		Anions					Others														
					Iron	Ammonium	Fluoride	Chloride	Nitrate	Sulphate	Cyanide	Oxygen	Sulphide	Total salts	Conductivity	pH	Hardness	Alkalinity	Turbidity	Colour	Fines	BOD	Microbiol.	Waternable		
Concluded	Tomago Aluminium P.L.	Tomago Sb.	Bore network	Extensive			F																			
	Hunter Water Corporation	Tomago Sb.	Bores	Monthly																					W	
	RZM Ltd.	Courtaulds	Spearpoints (21)	NS	Fe											pH						Fn				
	D.J. Douglas & Partners for Hunter Water Corporation	Tomago Sb.	Bores, spears		Fe																					
	Hunter Water Corporation	Stockton Sb.	Obsv. wells	Periodically	Fe			Cl																		
	CPI for Tomago Aluminium P.L.	Tomago Sb.	Obsv. bore	NS				F																		
	Hunter Water Corporation	Al. Smelter	12 bores	1-6 mth; 1981-8				F								EC	pH									
Existing	Hunter Water Corporation	Tomago Sb.	Bore network	Project life			F																			
	Hunter Water Corporation	Tomago Sb.	7 pairs, bores**	NS											TDS											
	Hunter Water Corporation	G. Storage	Piezometers	Monthly																					W	
	Hunter Water Corporation	G. Storage	7 bores	NS				Cl										Hd								
	Hunter Water Corporation	Mined area	Bore	Periodically	Fe			Cl	N			O						pH	Hd	Alk	Tb	C				
	RAAF	Williamtown	Bore	NS																					W	
	CPI	Tomago Sb.	Bores	NS				F																		
	Tomago Aluminium P.L.	Tomago Sb.	Bores (20+)	Monthly +				F										EC	pH							
	CSR Ltd. (Masonite)	Tomago Sb.	Bores, spears	Random											TDS			pH						B		
	RAAF	Williamtown	Bores, Spears	Long term																						W
	NS	Stockton Sb.	Bores	Periodically					Cl																	W
	Hunter Water Corporation	Tomago Sb.	Obsv. bore	NS				F																		
	CPI, Mackie Martin Assoc.	S.Sb., Fern Bay	27 Piezometers	NS																						W
	Env. & E. Sci. for CSR Ltd.	CSR site	Bores	Regular				NH																		W
Tomago Aluminium P.L.	(Wallaroo)*	Obsv. bore	Monthly				F																		W	
Proposed	Tomago Aluminium P.L.	(Wallaroo)*		Monthly																					W	
	RZM Ltd.	Tomago Sb.	NS	NS			F			CN																
	D.J. Douglas & Partners for RZM Ltd.	Dredged sands, Tomago Sb.	Spearpoints; 10/ha	Post-mining	Fe																					
	Hunter Water Corporation	Shoal Bay Outlet	Obsv. Wells	NS				Cl										EC								
	RZM Ltd	Tomago Sb.	Spear-points	Before/After	Fe				S			S			EC			Alk	Tb						Plate	
Recomm.	Hunter Water Corporation	Mined area	NS	Regular																						
	Hunter Water Corporation	Swan Bay	Bores	Regular	Fe			Cl	N		O							pH	Hd	Alk	Tb	C				
	CPI	S.Sb., Fem Bay	Piezometers	NS																						

CPI - Coffey Partners International Pty Ltd.
 EES - Environmental & Earth Sciences Pty. Ltd.
 HWC - formerly the Hunter District Water Board.
 RAAF - Royal Australian Air Force.
 NS - Not Specified

Sb. - Sandbeds
 G. Storage = Grahamstown Storage Reservoir.
 * Wallaroo Toxic Waste Site, adjacent to project area.
 ** Saline-intrusion warning system adjacent to salt-water boundaries.

Information based largely on literature references (Section 5.0).
 Compilation suspected to be incomplete.
 Current status of operations not confirmed.
 Extensive field surveying required to update and maintain data.

Table 6.3: GROUNDWATER MONITORING, NEWCASTLE BIGHT

- documentation of the existing records is of variable quality, and some information may have been lost;
- monitoring aims need to be re-defined and a monitoring network designed accordingly;
- sampling and analytical protocols and standards need review;
- a digital data archive for the whole study area should be established;
- government authorities need to be more active and cooperative in the area.

6.3 Impacts of groundwater pumpage on the aquifer system

There are many natural processes or events within the study area which contribute to the dynamic nature of the groundwater system. These include discharge, direct evaporation, vegetative transpiration, drought, storms, airborne sea spray, salt water intrusion, sea level/climatic change, sediment compaction/diagenesis, seismicity, and biosphere support. However, in this section the focus is on disruption to natural groundwater patterns caused by direct use as a result of land settlement.

Pumping groundwater from an aquifer will inevitably change the balance between recharge, discharge and storage. The management task is to ensure that the consequent changes are within expected and acceptable limits.

The philosophy behind the early HWB extraction facilities was that a small proportion of the recharge water would be withdrawn, from within the recharge zone along the crest of the Tomago dune system. This would have a minimum impact on groundwater dependent ecosystems because the groundwater levels would be affected only in areas of maximum natural fluctuation, and would not necessarily affect watertable gradients (and groundwater flow rates) in the discharge zones.

In general, this seems to have worked although there is apparently insufficient monitoring data to confirm it. The trend towards deeper bores has resulted in greater declines of water level around the pumping sites, but this does not seem to have affected any dependent ecosystems. It might, however, have had some influence on water quality (by contributing to increasing iron concentrations).

Excessive or poorly located pumping could cause water level falls and changes in hydraulic gradient leading to a change in the pattern of groundwater flow. These changes could impact on dependent systems such as wetlands and vegetation communities relying on particular water table conditions.

A particular aspect of the aquifers in the Newcastle Formation is the proximity to the sea and estuaries, and indeed the continuity of the aquifers from a terrestrial to a marine environment. Problems associated with this situation are common to coastal aquifers, but nevertheless require management procedures which are specific to the area because of the particular nature of its geology and geomorphology, and because of the water requirements of the local community.

The fresh water in the Newcastle Formation aquifers occurs as extended lenses 'floating' on saline water and are essentially surrounded by salt. There is salt in the marine clay that underlies and interfingers with the sand bodies, in the ocean and estuary water, and in the sand bodies where they extend seaward beyond the shore line. The marine and estuarine salts are held in balance by recharge from rainfall along the dune ridges, creating a positive water head and groundwater outflow towards the shores.

Overpumping, or misplaced extraction points are usually the means by which the protective head can be reduced; perhaps to the point where the saline water/fresh water interface will move in a landward direction.

However, it is possible that other more subtle processes of aquifer disturbance could also lead to saline pollution. As a potential groundwater impact, the consequences for the Tomago/Tomaree/Stockton sandbeds are so serious that the process justifies a detailed review.

In the earliest stages of town water development in the Tomago Sandbeds it was recognized that 'groundwater in the sands immediately fringing the ocean, and in the Tilligerry lowlands, is saline and of poor quality;' and that the main aquifer is 'particularly vulnerable to damage by salt-water intrusion (SWI)' (Corlette, 1944). Surrounding salt waters 'created a major problem' for safe groundwater extraction,' not only from direct intrusion, but also from a general fall in head' (Soil Mechanics Ltd and Ercon 1971).

The safe yield of the Tomago aquifer has been linked to the potential for salt water intrusion (eg, Soil Mechanics Ltd and Ercon 1971, Viswanathan and Evans 1983). A superior head has always been maintained for the watertable above sea level, including a considerable safety factor for all pumping and dredging operations. The concept of safe yield, however, needs careful use, so that it does not over-simplify the situation. The aim of future aquifer management in the study area should be to design a groundwater withdrawal schedule which will not cause a permanent shift in the position of the salt water/freshwater interface, an unacceptable decline of water outflow to coastal wetlands, or a permanent change in watertable elevations in the vicinity of the fresh water wetlands.

As at 1971 (Soil Mechanics Ltd. op. cit.) 'little evidence had been found' for saline water intrusion, and it was assumed that 'acceptable limits had not been reached.'

Viswanathan and Evans (1983) calculated a relationship between the water level in observation bore IP-109 (Figure 5.3) and the extent of salt water intrusion as a restraint on safe yield, but noted that 'uncertainties over aquifer properties' clouded the estimates. It was considered that 'a SWI of 270m was acceptable at Tomago', corresponding to a drawdown to 3m in IP 109, 'at which point all pumping should cease.' Use of a single observation bore as an index for the status of the whole system is not, however, an adequate management procedure.

Preliminary investigations of the Stockton aquifer have found the fresh-salt water 'interface toe' within 60 m of the High Water mark' (Merrick, 1979a), and that 'SWI is minimal below the HWM,' 'generally within 100m of the shore' (Viswanathan and Michel 1982; Australian Groundwater Consultants Pty Ltd 1981a).

Basic computer modelling of the Stockton sands found that, for three years at zero recharge, 65ML/day could be pumped for an SWI of 'about 300m from the shoreline.' However, considering that watertables would be naturally low in a drought, it was conservatively estimated that '20ML could be extracted each day for a year without risk of significant SWI' (Viswanathan and Michael, op cit). AGC (1982), however, conclude that 'because groundwater movement is extremely slow relative to a typical drought period,' 'it should be possible to pump 65ML/day in an emergency' without major saline advance.

At Salamander Bay, geophysical investigations by Merrick (1979a) found 'definite saline intrusion' up to 1 km inland from the coast (Fig. 7.1).

Salinities in a fully-screened observation bore '10m from the sea' at Shoal Bay (Fig 7.1) varied from 800 mg/L chloride at the top, to over 12,000 mg/L below 40m in 1980 (Michel and Viswanathan, 1980). This bore apparently intersected the saline/fresh water interface. Several such bores should be constructed and monitored so that the movement of the interface can be observed.

The potential for mineral dredging to aggravate saline intrusion because of the increased permeability of the depleted sands has been suggested. Lateral outflow from storage could be enhanced allowing watertables to fall, the mounds would flatten more quickly and there would be less hydrostatic head to restrain SWI (eg Soil Mechanics Ltd, 1971). However, in 1971 'no indications of SWI had been found,' and the implications were 'not considered to be serious at the range of post-mining permeabilities observed.' This is not regarded as a likely reason for movement of the salt water interface, which would still be maintained in a state of dynamic equilibrium by the flow of freshwater. Although the hydraulic gradient may be less, the flow rate would be maintained because of the higher permeability.

Australian Water and Coastal Services (1990) remarked on the 'importance of tide gates and embankments along the Tilligerry Lowlands for 'reducing salt water intrusions' into the interdunal areas.

Despite the numerous attempts to examine the position and movement of the salt water/fresh water interface, there has been no consistent approach and no long term data collection and analysis which would give confidence to predictions of what will happen under differing pumping regimes. This is clearly a matter which requires considerable further study, but is not necessarily one which need prevent the use of groundwater from the aquifers.

6.4 Impacts of groundwater pumpage on the local environment

The most apparent impact of groundwater pumpage is likely to be on the wetlands. The level of groundwater in dunal areas fluctuates naturally, and the vegetation of dunal wetlands, as well as other areas of the dunes, are adapted to this variability. It is the duration and degree of fluctuations that is the primary influence on the vegetation established in a wetland. Unfortunately there has been little research into the specific water regime tolerances of different wetland types, although some general observations have been made. For example, a prolonged rise in water level in Broad-leaved Paperbark swamp forests will induce stress in the trees, resulting in leaf drop. The trees will recover quickly in response to a subsequent

return to lower water levels, but if the wetland remained inundated for several years the trees would gradually die.

Groundwater has been abstracted from the Newcastle Bight area (primarily the Tomago Sandbeds) for the past fifty years. The effect of this abstraction on the groundwater regime is not well established. There is no evidence of large-scale dramatic changes in wetland vegetation as a result of the abstraction, and the lack of baseline studies makes subtle changes difficult to assess.

Over a fifty year period, it would be expected that the vegetation would have adjusted to any change in groundwater regime. Consequently, the existing vegetation of the area could potentially be affected by a cessation of abstraction, as well as by an increase in the volume extracted. In the absence of appropriate background research, it is difficult to predict the impacts on wetlands, if any, that may result from changes in groundwater regime.

A study currently being undertaken by Shortland Wetlands Centre on watertable levels in Broad-leaved Paperbark swamp forests will provide limited data on this wetland type, but there is no comparative research being undertaken on other wetland types in the Newcastle Bight area. Any further proposals to substantially increase groundwater abstractions, which in turn would extensively lower the watertable, should be preceded by appropriate baseline investigations of wetlands, and an ongoing monitoring program should be established to assess impacts.

An increase in groundwater abstraction might also reduce freshwater discharge to the estuaries of the Hunter River and Tilligerry Creek. An increase in salinity of water in estuaries can favour the growth of saltmarshes over mangroves, and could lead to change in distribution of these vegetation types. Again, there has been no baseline studies to assess whether any such change has occurred as a result of the past 50 years' abstraction, making it difficult to predict the likelihood of such an impact. It may be possible to assess recent historical changes in area of mangroves and saltmarsh from aerial photographs, although there may be other causal factors for any observed changes.

A substantial increase in pumping might increase groundwater salinity through reversal of existing groundwater flows, resulting in immigration of salt water from adjacent estuaries. An increase in salinity of the groundwater could have substantial affects on existing vegetation, depending on the duration, degree and extent of the increase. The Groundwater Management Plan should provide for the investigation of this potential impact and of possible management strategies.

7. IMPACT OF LAND USE ON THE AQUIFER SYSTEM

This section reviews the impacts of land settlement on groundwater in the main sandbed aquifers of the Newcastle Formation. These impacts may be either on groundwater quantity or on quality or both. The discussion on quality is in terms of groundwater *contamination*, which is defined as any unnatural state of water quality.

Contamination becomes *pollution* when the degradation in water quality has become unacceptable, limiting its potential uses. Deciding what forms and levels of contamination are regarded as pollution is a matter for the community. However, pollution can be avoided and communities need to balance the social and economic benefits of having access to groundwater against the environmental degradation that might result. Until these community values are established, it is not possible to judge what types or levels of contamination constitute pollution. Comments are therefore restricted to a documentation of contaminated groundwater in the study area, without value judgements as to whether it amounts to pollution.

A similar rationale applies to any discussion on the impacts of land use on the rate of recharge to or discharge from the aquifer. A reduction (or increase) is not objectionable in itself, but may become so if it breaches standards which have been set by the community.

When attempting to evaluate impacts on groundwater the following points need to be noted:

- aquifers are below the ground and hence hidden and largely inaccessible;
- sampling points are usually few, scattered, and expensive to construct, maintain and use;
- the symptoms of the impact may take a long time to become manifest, and may appear some distance from the source;
- contamination plumes are difficult to detect;
- chemicals may be absorbed and trapped by sediments, making remediation difficult; and
- effective clean-up can be expensive, and is not always successful.

If the quality of a groundwater resource is valued by the community, it follows that a firm precautionary approach is appropriate when considering developments which have any potential to contaminate or otherwise degrade those resources.

The impact of groundwater pumpage on groundwater in the study area was discussed in Chapter 6. This chapter concentrates on recharge aspects, and on increases in groundwater discharge due to causes other than pumping (such as surface drainage schemes which are a common cause of increased groundwater discharge in the study area).

The location of groundwater contamination occurrences and threats is shown in Figure 7.1. The following paragraphs discuss some of the observed or expected impacts.

7.1 Urban development

In an area such as this study area, where permeable sand extends downwards from the land surface and the water table is at a shallow depth, urban development can have a major impact on both the quality and quantity of water in the groundwater system.

7.1.1 *Effects on groundwater quantity*

Roofing, roads, car parks and other paved areas concentrate rainfall and the run-off is generally controlled by a drainage system. At the very least, this will change the location of groundwater recharge, and may eliminate it altogether depending on how the drainage system is designed and managed. If stormwater run-off is collected and taken to a suitable recharge area, the result might be an enhancement of the total recharge rate. However, if the drainage system channels run-off away from the aquifer, or to areas where groundwater is discharging to the surface, the total aquifer recharge will be reduced. An even worse situation can occur if unlined drains are used which are deep enough to intersect the watertable. In this case, the drains will remove water from the aquifer at a rate which exceeds the natural outflow.

7.1.2 *Effects on groundwater quality*

There are many activities in an urban area that impact on groundwater quality in an area such as this. Fertilising and chemical treatment of gardens and lawns, washing motor cars, pet droppings, leaking petroleum tanks, leachates from rubbish disposal sites, accidental spills of chemicals, and inappropriate or accidental waste disposal from domestic residences, can all adversely affect groundwater quality.

The extent to which these effects have impacted on the groundwater resources of the study area is not known, but there is no doubt that they have occurred in and around all the urban areas.

7.2 Sewerage and septic tanks

In those parts of the study area area where reticulated sewage disposal has not been available the septic tank has been the most common type of on-site sewage treatment method for domestic wastes. On occupied allotments of less than about 0.4 hectares the septic tank usually treats toilet wastes only. The tank effluent flows into absorption trenches or sandfilters, while the sullage from the kitchen, bath and laundry passes through a grease trap and into stormwater drains. On the larger lots either all wastewater is treated in septic tanks and discharged to absorption trenches, or the sullage water passes through a separate grease trap. The effluent is required to be contained within the boundaries of the property, and this is expected to be achieved by ground absorption. Discharge rates from septic tanks are generally 150 to 200 litres/person/day. Typical compositions of sandfilter effluents and sullage are given in Table 7.1.

There is apparently little data available on the impact on groundwater of the sewerage system and septic tanks in the area. There seems little doubt, however, that there has been some impact and it might be quite significant and widespread. A survey of septic systems in the Lake Jindabyne area of NSW (O'Neill et. al. 1993) found that:

- one third of tanks are undersized; and improper construction is common;
- only 66% are working effectively; with 14% of tanks needing urgent desludging;
- many are unsuitably located in waterlogged land;
- most absorption trenches have been installed with little regard to long-term operation or environmental impacts; 44% have failed or need repair;
- 15% of residents unknowingly use unsuitable products; and
- transient tourists cause more problems than local residents.

There is no comparable data for the present study area, but it would not be surprising if the situation here is similar. The geological conditions are quite different, but most of the problems noted at Jindabyne result from inappropriate actions on the part of users rather than the physical environment. The proportion not working effectively may be less than at Jyndabyne because of the permeable sand in much of the area, but this might merely mean that more nutrient-laden water is soaking into the sand. If the situation is in any way comparable to that at Jindabyne, there must be a substantial contribution of nutrients to groundwater from septic tanks.

TABLE 7.1: Typical composition of domestic waste effluent
(after USEPA, unreferenced data)

Component	Concentrations (mg/L)	
	Effluent from septic tank and sandfilters	Sullage water
Suspended solids	16	
Biochemical Oxygen Demand (5 day)	14	290
Nitrogen NH ₃	130	165
Phosphorus (mostly as PO ₄)	15	25

Septic tank approvals have fallen from 236 in 1991 to 181 in 1992 since the Fringe Areas Sewerage Project scheme started in the Port Stephens Shire. There is no information as to how many of these units are now located on sandbed lands.

It is quite possible, even probable, that there has been leakage of nutrient-bearing effluent from some of the sewage treatment plants (discussed above, Chapter 5.2.2). These effects would be localised, but may result in a relatively high level of nutrients in the groundwater within these localities. It is also probable that there have been leaks in the sewage system, and this would result in widely dispersed small contamination occurrences.

Without a purpose designed survey, it is not possible to state whether there is the possibility of a serious problem. It should be stressed, too, that nitrate might not by itself be a suitable indicator. High nitrate levels can occur in the shallow groundwater in the dune system as the result of natural causes (G Winning, pers. com. 1994). Accordingly, it is recommended that a study of the impact of sewerage systems and septic tanks be undertaken as part of a Groundwater Management Plan.

7.3 Drainage systems

The extensive network of shallow artificial drainage channels and embankments in the study area was described in section 2.3. There is apparently very little information on the impact of the drains on the groundwater system, but there must be at least some impact. The Moors Drain (Fig. 5.3), for example, which commences near the eastern boundary of the RAAF land at Williamstown and extends eastwards to Tilligerry, was examined in August 1994 and found to have a substantial flow of groundwater. While the most apparent impact of this drain is to ensure that land at Williamstown does not become waterlogged, it seems clear that groundwater which could have been used beneficially is being discharged to the estuary.

A thorough re-assessment of the purpose, operation, effectiveness and impact of the drainage system in the study area must be an early component of the development of a Groundwater Management Plan for this area. Resolution of the conflicting needs of water management with the imperative for conserving water, and of land management with its drainage objectives, is required at an early date. If water must be removed, and there are no doubt localities where this is the case, open and unlined drains are not the only way to accomplish it. Appropriately located groundwater withdrawal works could serve the dual purpose of enhancing the groundwater reserves available for use and of removing it from areas where it is regarded as a nuisance, though there would be some costs involved.

With proper study and communication between land users, there should be no conflict with the recommendations to the Second Public Meeting by the 'NSW Steering Committee on Future Requirements of Drainage Facilities in the General Longlight-Williamstown Area (McGlynn 1992, esp p4; AWACS, 1990, 1991).

7.3.1 Acid-sulphate soils

Drainage works in low-lying lands bordering estuaries can cause serious problems if soils of the acid-sulphate type are found in the area. By lowering the watertable, drainage works expose these soils to oxidation and produce strongly acidic run-off waters, with deleterious consequences for aquatic organisms. Acid-sulphate soils are suspected to occur in the Tomago-Tomaree-Stockton area, as they are associated with areas of estuarine influence and marine incursions.

If present in the study area, they may occur along the Tilligery Valley (Fig. 2.1). While this has implications for run-off surface waters, it is not expected to have consequences for aquifer management, as the Tilligery Valley is a lowland aquifer discharge area.

7.4 Waste disposal

This section reviews the impacts on groundwater quality of deliberate waste disposal into the main sandbed aquifers of the study area. Use as a receptor for wastes has been a significant role for the aquifer systems in the Newcastle Bight area. The subject has not been formally studied, and no comprehensive reports have been found on the issue in the Bight area.

Disposal practices considered in this section include not only the well known direct disposal of wastes to land such as tips, dumps and landfills, but also less well known indirect disposal activities such as the disposal of effluent from septic tanks and industrial emission fallout as discussed in section 7.5.2.

Waste generation is a by-product of our consumer society. Domestic, industrial, commercial and recreation activities all generate large quantities of wastes. The volume of solid, liquid, and gaseous waste has been growing at an exponential rate over recent years, in conjunction with population increase and industrial expansion. Problems associated with waste disposal have received consideration in public inquiries and have resulted in the creation of legislation for environmental protection.

In the study area, waste disposal is an issue of growing magnitude for both public and private sectors. Although Newcastle and environs accounts for a large part of the total waste produced, country towns and rural industries are also faced with growing levels of waste material and disposal problems. The bulk of solid waste disposal has been by landfill in disused sand pits, on land reserved for municipal dumps, and on land with low economic productivity such as wetlands, swamps and flood-prone land. Many waste-disposal sites have been established in scattered locations on public land throughout the area. A system of licensing for these sites has been operating for many years, but illegal disposal of waste still occurs. Littering and the indiscriminate dumping of domestic rubbish, including old motor vehicles, is widespread throughout the area.

Sewage treatment systems associated with the towns and cities of the area account for the bulk of liquid waste from domestic and industrial sources. Seepage from septic tanks in unsewered residential areas also contribute to groundwater and surface water pollution.

The disposal of untreated waste has created a number of adverse effects. In addition to general health hazards, uncontrolled waste disposal has had serious effects on surface and groundwater quality in the vicinity of the disposal sites. On a local scale, waste disposal has destroyed a number of wildlife habitats and reduced the amenity of recreation areas. Most disposal sites are regarded as unsightly, often smell unpleasant, and are responsible for generating undesirable road traffic.

The migration of liquid wastes into aquifers in the Newcastle Bight area has generally been incidental to the main operation of the disposal of wastes to the land. Likely impacts must be

inferred from knowledge of the aquifer system in general and from observed impacts in other locations.

7.4.1 Government and municipal waste disposal sites

This category of potential groundwater contamination relates to the common type of municipal garbage dump where disposal is deliberate and into well-defined pits. The excavations may be constructed for the purpose, but in the study area they may include abandoned sand pits, dredge ponds, or road fill sites. Some of the pits have been cut down through the water tables of the main sandbed aquifers, so that initial waste disposal has been directly into the local groundwater.

There has been no comprehensive audit of municipal waste disposal in the study area. From information available to this study the major sites are known to include Lemon Tree, Nelson Bay, Raymond Terrace, Salamander, and others (Fig. 7.1). No details of the sites or of their impact on the groundwater system are available. Ultimately, an audit of groundwater impacts is needed.

7.4.2 Defence Department waste dumps;

RAAF Williamtown:

The site is old and now abandoned, and no details are available. Unless the pit is fully lined and top-sealed, leachate contamination of the underlying Tomago aquifer is likely to be occurring. Any threat is enhanced by the diverse industrial character of the base, and pre-World War II age of the tip. An audit of groundwater impacts of this site is needed.

Gan Gan Army Camp:

Unaudited, but there are possibly minor impacts from rubbish disposal.

Fern Bay; Armour Proofing Range (1941-1957):

Buried rubbish at this site includes asbestos, and large quantities of unexploded munitions. Lingering local contamination of the aquifer from associated metals and chemicals is possible. Mercuric compounds were possibly used in the manufacture of detonators and rounds said to be buried at the site.

Stockton Beach Artillery Proof Range:

Groundwater impacts of this site have not been evaluated. Buried rubbish apparently includes unexploded ordnance, red phosphorus smoke generators (Newcastle Herald, 25 Nov. 1993), and possibly mercuric compounds.

7.4.3 Industrial tip sites

CSR Ltd., Masonite factory near Raymond Terrace:

This dump site is old and abandoned. Waste was tipped into exposed groundwater in a disused sand pit and apparently consisted of masonite, timber scrap and boiler ash, with small amounts

of demolition rubble, spent oils, several drums of arsenic, and old electrical transformers containing polychlorinated biphenyls (PCB's).

A recent report states that ammonium, iron, manganese, sulphate, chloride, and arsenic 'have all exceeded NSW guidelines for safe drinking water in one or more bores at the tip'. However, the report also states that 'all elevated values (except arsenic?) are due to natural causes', although by reference to local and global guidelines 'the site can be described as contaminated' (Environmental and Earth Sciences 1992).

This document highlights the problem of the legacy of past practice, when the implications of disposal practices were poorly understood and community values may have been different.

7.4.4 Other waste disposal tips

Scattered small rubbish tips on rural properties, including hobby farms, have the potential for cumulative impacts on aquifers in sandbed areas through unregulated disposal of farm chemicals, waste oil, garbage, and carcasses etc.

There are scattered small rubbish tips at numerous recreational areas, but details are not available. An audit of groundwater impacts at such sites is required.

7.5 Manufacturing industry

This section deals with cases in which there is direct or indirect accession of contaminants to the groundwater store, as an incidental aspect of the manufacturing process, either deliberate or otherwise.

There has been no comprehensive audit of industrial contamination in the study area. From information available to this study the *major* sites appear to include those discussed below and shown in Figure 7.1.

7.5.1 Direct disposal

CSR Ltd., Masonite factory near Raymond Terrace:

Wood panels are produced by heating hardwood pulp under pressure, breaking down lignins to form a cement of natural phenolics, resins, and gums. The significant volumes of effluent water produced by the process are disposed of by irrigation onto adjacent fields (Figure 7.1).

The CSR scheme of irrigation disposal has been referred to as a 'waste absorption area' (eg NSW Roads and Traffic Authority 1991). In 1975 the company was licensed by the SPCC to 'spray irrigate effluent at 1.8ML/day at not more than 0.1 ML/hour and limited to:

- BOD: less than 4000 mg/L;
- pH: between 6.5 to 8.5; and
- Temp: maximum 35°C.

In 1988 the SPCC required BOD, TDS, and pH to also be monitored at a grid of spearpoints, then in 1990 BOD limits were altered to 5000-7000mg/L. Where these limits could not be met, the effluent was either diluted until it complied, or it was dosed with chemicals such as sodium hydroxide or lime.

Actual discharge information is sparse, but it appears that between 1975 to 1988 about 1.6-3.8 ML per week were irrigated, and approximately 1.5 ML/day since 1989. An effluent mound approximately 1000m across, which has formed beneath the absorption areas (Fig. 7.1), is probably being drawn into CSR's own extraction bores.

CSR is presently investigating the use of local wetlands to absorb process waste water as an alternative to irrigation (P. Brown, CSR; 1993 pers. comm.).

No other major schemes are known within the sandbed areas of the study area.

7.5.2 *Indirect degradation**

Tomago Aluminium smelter (TAL):

Established in 1983, the smelter was producing 240,000t/yr of metal by 1991, with expansion planned to 420,000 t/yr. Current plant output is 390,000 t/yr of aluminium per year.

An extensive environmental monitoring programme has collected a massive amount of data, 'the bulk of which confirms that the plant has operated well within the requirements of the NSW Clean Air and Water Acts' (CMPS, 1990).

Atmospheric emissions from the complex have been recognised as the main source of potential groundwater contamination in the surrounding Tomago aquifer. In 1993 the smelter was emitting 0.49kg of fluoride for each tonne of aluminium produced. However, total emissions which 50% by weight of gases, (mostly hydrogen fluoride, ozone, and sulphur dioxide) and 50% particulate solids, especially cryolite (Na_3AlF_6), calcium fluoride ('fluorite'; CaF_2), aluminium fluoride (AlF_3), and fluoridated alumina (N. Roser TAL, pers. comm. 1994). Total emissions of 0.64 to 0.76kg/t were predicted in the original Environmental Impact Statement for the plant.

Monitoring indicates that surface fluoride deposition is limited to a stable 4 km radius around the smelter, confirming the adequacy of the 1200 ha buffer zone (CMPS, 1990). At Mosquito Swamp (Fig. 2.6) 1 km from the smelter, fluoride has increased to about 1 or 2 mg/L, compared to very low natural background levels of less than 0.3 mg/L. Fluoridated drinking water or tea commonly contains about 1 mg/L fluoride.

Monitoring of groundwater fluoride in the Tomago aquifer around the plant has also been extensive but 'no significant increases in fluoride have been found in areas away from the smelter potline'.(CMPS 1990) The 'absence of measurable fluoride after 8 years is attributed to fluoride-fixation properties of the aquifers' (Coffey Partners International Pty Ltd 1990).

* see Fig. 7.1

Closer to the potline (Fig. 7.1), it was found that '15 of 20 bores had fluoride in groundwater of less than 0.3 mg/L in 1989' (Coffey Partners International op. cit.). However, the data also show that 5 bores had more than this amount, with a maximum of 16.4 mg/L fluoride, and a mean for the 40 results of 0.93 mg/L.

Coffey Partners acknowledge 'significant fluoride increases and spectacular fluctuations in some bores' but suggest that these are restricted to areas around the potlines where they are possibly due to site irrigation from stormwater-retention ponds. Rapid channelized infiltration is indicated, with fluoride fixation in the soils being 'less effective than predicted' and 'contrary to experimental results' (Coffey Partners International op. cit.).

Significant fluoride in groundwater at Bore 262 is attributed to a leaking retention basin, holding stormwater which may contain over 30mg/L fluoride (Coffey Partners International op. cit.).

There is no indication that emissions of oxides of nitrogen/carbon/sulphur, ozone, and hydrocarbons have caused any groundwater impacts at the TAL site (CMPS, 1990).

Plant chemicals include corrosion inhibitors, biocides, detergents, and caustic soda, as well as pitch, chlorine, and LPG. Although 'only environmentally compatible chemicals are used' (CMPS, 1990), it is not known if any of these, or their derivatives are a threat to groundwater.

Spent cathodes stockpiled under secure storage at the Tomago smelter site, which amounted to 8,000 tonnes by 1990, contain more than 10mg/L of leachable cyanide, and more than 150mg/L of leachable fluoride. With expansion, the annual amount will increase to 10,000 tonnes. Research is expected to find a method for treating this waste in the next few years.

Cathodes containing less than the above amounts of leachable contaminants are buried at the Wallaroo Waste Disposal Facility 22km north of Tomago, adjacent to the Grahamstown Storage Catchment area (Figure 5.2). Fluoride concentrations are 'typically about 60 mg/L leachable', or 'below superphosphate fertilizer'. Groundwater is monitored but 'no changes to backgrounds have been observed' (CMPS 1990).

Hunter Water Corporation water treatment plants and sewage treatment works:

Both town-water and waste-water treatment plants may be point sources of groundwater contamination in the sandbed aquifers of the Tomago/Tomaree/Stockton area. General contamination sources may include chemical and fuel spills, sewage leaks, workshop waste, and garbage.

Chemicals used for water treatment include alum, chlorine, lime, and fluoride. Possible impacts on groundwater have not been assessed, although a fluoride spill occurred at the Tomago water treatment plant in 1988. Sludge ponds containing alum are known to leak into the aquifer at the site (Fig. 7.1).

RAAF Williamtown air base, and domestic air terminal:

The RAAF supports 970 permanent residents plus 1500 day visitors. Although the air base is not a factory, its potential to contaminate groundwater has much in common with a large industrial and urban centre.

Potential sources of groundwater contamination include leaks or spills of fuel, oil, chemicals, and sewage as well as garbage leachate. Specific items of possible concern include fuel/lubricant hydrocarbons, aircraft washing waste, detergents, paint residues, paint strippers, dry cleaning fluid, pool chemicals, food waste, medicines, micro-organisms, photographic chemicals, fire-fighting foam, and run-off.

Minor spills of Avtur and Avgas up to 20 L have occurred and not all evaporate.

Stormwater infiltration into the porous sands is the principal means of transferring these surface contaminants to the aquifer. All run-off from buildings, maintenance areas and paving is collected by drains. However, by 1982 these had deteriorated and hazardous waste waters were leaking into the sandbeds (Gutteridge Haskins and Davey 1982).

New equipment and cautionary measures are said to minimise amounts of fuel that are flushed to the stormwater drains, but significant hydrocarbon contamination of the Tomago aquifer generally is likely beneath the base.

Tomago light-industrial corridor:

Groundwater contamination in the corridor has not been evaluated, but impacts are expected to be as diverse as the industries in the area. Mechanisms will be site specific, but mostly relate to surface contamination such as chemical/fuel/oil/waste spills, atmospheric emissions, leaking pipes/ponds/storages, stockpile leachates, and general waste disposal (industrial liquids, hydrocarbons, acids, wash-down, slag, contaminated plant, and process scrap, etc).

7.6 Agriculture, horticulture and apiculture

The impact of drainage systems in the area, many of which were originally for agricultural purposes, was discussed above in section 7.3. The present section deals with impacts on groundwater quality.

The impacts of agriculture on groundwater in the sandbed aquifers of the study area have been evaluated in the field, although not investigated in detail. From experience with groundwater elsewhere in the State that has been polluted by agricultural chemicals, the following impacts might be expected from a range of activities:

- **Cropping, horticulture, plant nurseries, market gardens:** Nutrients from fertilizers and pesticide residues may pass to the watertable and the effect may be enhanced by cultivation and clearing;
- **Stock (especially free-range pigs, beef/dairy, cattle, horses, poultry):** Nitrate and bacterial contamination of aquifers may occur, and is potentially serious;

- **Intensive husbandry (especially pigs, poultry, effluent ponds, sheds, manure stockpiles):** Serious point-source nitrate and bacterial contamination of aquifers can occur, especially in sandbed areas if no precautions have been taken;
- **Rural-residential land occupation:** Serious groundwater contamination from septic tanks is likely, and cumulative impacts are possible. Sporadic pollution from spilt fuels, lubricants, agricultural chemicals, waste disposal etc, can be locally serious, especially in sand bed areas;
- **Bee keeping (apiculture):** Chemical spills (Ethylene dibromide etc) may occur;
- **Viticulture (e.g. Bobs Farm area):** Spills of agricultural chemicals, fuel, and fertilizer residues may occur, and there may be disposal of by-products in the sandbeds;
- **Hobby farms (especially in the Raymond Terrace to Williamtown area):** Unskilled use of agricultural chemicals may lead to waste disposal in the sandbeds.

7.7 Extractive industry

The most obvious, and probably the most significant, impact on the aquifer system of the study area is that caused by heavy mineral mining. The areas affected are indicated in Figure 5.4. Mining commenced in 1972, and in its early stages the depth to which sand was extracted was limited to about 8 m by the equipment being used. Floating suction dredges were used to remove sand to that depth and after removal of the heavy mineral fraction the sand was replaced. The process decreased the cementation of the sand, and increased the effective porosity of the replaced material compared with the undisturbed sand (DJ Douglas 1993b).

Because of this effect, and the increased infiltration of rainfall during the early years after site rehabilitation due to sparser vegetation cover, it is now generally accepted that mining has not resulted in any decrease of the water storing or transmitting capacity of the aquifer (D J Douglas, op.cit.).

More recently, with changed mining methods using bucket wheel dredges, the depth of mining has been increased to some 20 m, and some of the earlier areas are being re-mined. It is apparently assumed that the impact on the hydraulic characteristics of the aquifer will be similar at the greater depth.

Of much greater concern is the impact of mining on groundwater quality. The main impact, and perhaps the only one, is the apparent increase in the concentration of iron in groundwater in the mined areas. HWC has had to abandon its No. 6 Pumping Station because the iron content is too high. Increases in concentration to levels in excess of 100 mg/L have been reported. There is not universal agreement on the reason for the increase in iron concentration, however, and it has been suggested that the greater drawdown of waterlevel resulting from the deeper HWC bores constructed in recent years is a contributing factor. Exposure of the aquifer fabric to oxygenated conditions may have caused oxidation of iron minerals in the sediments and led to increased solubility. The issue has not yet been resolved. (DJ Douglas 1990).

There is no doubt that mining has an impact on the aquifer. Apart from other considerations, there is the physical presence of the mining pits and associated ponds, dredges, topsoil removal and storage and infrastructure, with a high potential for introduction of contaminants direct to the watertable. A large volume of the aquifer is unavailable for use while mining is in progress. Long term changes to the hydraulic characteristics of the aquifer might be small or negligible, but there is sufficient evidence to suggest that there might be a long term impact on water quality. This impact could render part of the aquifer unusable as a source for public water supply because of the added cost of treatment to remove the iron before the water can be reticulated.

This is clearly a major conflict between different potential uses of the aquifer, and its resolution will be fundamental to any Groundwater Management Plan. Further studies are underway (D J Douglas, 1993) and they may make the position clearer. However, the aquifer system is a complex natural system, however, and there may never be enough information to enable all parties to agree on what is occurring. Resolution may eventually be necessary on the basis of some assumed outcomes.

7.8 Contaminated sites register

Although the general impacts of land settlement on groundwater in the sandbed aquifers of the region have been evaluated in the field, they have not been investigated in detail. A register of contaminated groundwater sites has not been established.

Figure 7.1 incorporates current knowledge of known contamination of the Newcastle Formation aquifers, as well as possible occurrences which may be inferred from hydrogeological experience with groundwater elsewhere.

7.9 Summary of contamination impacts on aquifers in the study area

The type of groundwater contamination in an area reflects local land use, and general land settlement impacts on groundwater are most intense in the western end of the study area adjacent to the industrial areas of Newcastle, Stockton, and Raymond Terrace. Urbanisation is also most intensive in the west where the population is mostly permanent. Groundwater contamination in these areas is diverse in character and includes a combination of chemical waste, fuels, lubricants, water treatment compounds, atmospheric emissions, sewage effluent, urban stormwater, accidental spills, and garbage leachate.

In the east, in the area of the Tomaree Sand Member, there is little industry and activities focus on serving the influx of retirees and summer tourists. Groundwater contamination in these areas is mostly septic tank seepage, contaminated urban run-off, fertilizer nutrient, and pesticide residues.

The Stockton Sand Member area is mostly undeveloped and is therefore largely uncontaminated. Septic tank seepage and urban run-off are probable contamination sources around Stockton village, at the western extremity of the dune system. Pollution of the aquifer from past military activities has not been evaluated.

General agricultural contamination is expected across all sand bodies, between the industrial and urban centres and outside the water and nature reserves.

8. OPTIONS FOR FUTURE MANAGEMENT OF THE AQUIFERS

The term 'management' is used in this chapter to mean balancing the uses to which the aquifer is put, in such a way that community expectations and values are met to the greatest possible extent while maintaining environmental and resource values. This implies that any or all of the possible functions of an aquifer system as outlined in Appendix 2 may be used. An outline of the way these functions might be used is presented in this chapter, together with some of the more important likely outcomes of that use. This chapter concludes with a breakdown of the study area into a number of smaller areas based on recharge areas and vulnerability to contamination/pollution.

An alternative water supply based on surface water storage, capable of providing a yield of the same order of magnitude as the Tomago Sand Member is likely to cost between \$50 and \$100 million. It therefore seems likely that use of the aquifer as a source of water for public water supply will be the most highly valued use, and the implications of such a choice in terms of the constraints on land use which would follow are discussed in chapter 9.

8.1 The aquifer as a source of water

The Newcastle Formation aquifers contain a large volume of low salinity groundwater, which is readily accessible, generally of a quality suitable for public water supply, capable of delivering a satisfactory pumping rate from bores, and with an indicated rate of average annual recharge which is large enough to contribute to regional water requirements. The recharge is direct, from local rainfall, and although subject to seasonal and longer term variations is buffered by the very large storage.

Given the predicted water needs of the community supplied by HWC, there seems little doubt that public water supply is the highest value use to which the aquifer system can be put. The consequent impact on the groundwater system itself, and on its dependent environments, will place a constraint on the rate of withdrawal of water. At the same time a decision to use or preserve the aquifer system for this purpose will place constraints on land use in the study area, and some potential high value land uses may have to be forgone for this reason.

In section 6.1 above, it was suggested that there would be a substantial increase of total annual water use (from both surface and groundwater sources) by HWC from current levels of about 90 GL/year, perhaps to around 125 GL/year by 2015. Current groundwater withdrawals are around 12 GL/year, and have in the past been at much higher levels. During the maximum usage period of the 1950s and 1960s, the annual withdrawal was between 15 and 25 GL/year. The sustainability of withdrawal at this higher rate cannot be assessed because of lack of monitoring data from that period. Neither water level declines nor vegetational response to those withdrawals appear to have been adequately measured. There might be increases in groundwater use by other users, but they will presumably be relatively small in comparison.

Long term sustainability of the aquifer system would certainly not be possible if withdrawals were to exceed the long term average recharge rate. Hence this figure can be used as an index of the upper limit of safe withdrawal. The real figure will be less than this, but how much less will depend on how much impact on the groundwater and dependent environments is assessed as being acceptable and also on the accuracy with which the aquifer system is understood. With a low degree of confidence, based on insufficient data and analysis, the withdrawal rate would have to be set at a very conservative amount.

The total average annual recharge to the three aquifers (Tomago Sand Member aquifer, Stockton Sand Member aquifer, and Tomaree Sand Member aquifer) was estimated in Chapter 3 above at about 65 GL/year. Because of the many assumptions on which the estimate was based, and the need to reduce the estimate to allow for edge effects around the aquifer margins and to allow for a fringe along the shoreline, the value of average annual recharge adopted for planning purposes should be much smaller than this. A value of 25 GL/year might be a reasonable figure. A higher rate might be realistic if it can be shown that the impact of pumpage at 25 GL/year during some parts of the 1950s and 1960s can be shown to have been acceptable. This rate of pumpage could be achieved by doubling the present pumpage from the Tomago Sand Member aquifer, maintaining the current level of pumpage from the Tomaree Sand Member aquifer, and pumping about 8 GL/year from the Stockton Sand Member aquifer.

A major factor in the ability of the aquifer system to maintain pumpage at this level is the large storage available, which acts as a buffer. Pumpage during dry years might, and probably would, exceed the recharge for that year, resulting in a decline of storage. This is not necessarily a bad thing in itself, nor is it necessarily bad for dependent ecosystems, but the aquifer would have to be managed in such a way that unacceptable declines were avoided. For example, two or more dry years in succession might result in storage (ie. water level) falls beyond acceptable limits, and pumpage might have to be curtailed. In the longer term, however, the large storage and relatively small annual withdrawal would result in overall maintenance of the storage.

Another way of using the groundwater would be to retain it as a "dry year only" source. Under these circumstances, it would be tempting to assume that withdrawals could be at a greater rate than the allowed average annual recharge rate. This is not necessarily a valid assumption, because the annual recharge is not cumulative. The aquifers are essentially in a state of dynamic equilibrium, and water moves continuously from recharge areas to discharge areas. Additional water added to the storage will increase the hydraulic gradient, and consequently the rate of flow, towards the discharge areas. Last year's water may no longer be in storage for this year's drought requirements. Use of the aquifer system as a dry year supplementary supply might be a good way of incorporating the sand aquifers into a regional water supply scheme, but would require very careful monitoring and built-in safeguards to prevent over-pumping. In particular, the possibility of successive dry years, and the consequent operational need for maximum use of water from the aquifer system, would be a situation requiring specific attention in a Groundwater Management Plan.

It might be possible to increase the annual recharge to the sand aquifer system, by manipulation of other sources of water. Artificial recharge is a procedure which is highly suited to aquifers of this nature. It might be feasible to harvest surplus water from surface streams in the area, and add it to the groundwater storage by infiltration through shallow

ponds in the higher parts of the aquifer system. This process can also be used as a means of improving some aspects of water quality (turbidity for example). Stormwater run-off from urban areas is another possible source of water for recharge, subject to specific quality constraints.

It is also possible to use water from sewerage treatment plants for artificial recharge of an aquifer, provided that sufficient treatment is provided and that the infiltration ponds are properly designed and operated (see AWRC 1982 for example). This would offer considerable scope for increasing groundwater withdrawals from the sand aquifers. Note, however, that this does not mean simply the disposal of secondary treated effluent from treatment works to disposal basins in the sand dunes. The degree of treatment required prior to infiltration would depend on other uses to which the aquifer system is to be put. If the infiltrated water is to be removed later by pumping from bores and used for municipal supply, the pre-treatment would need to be of a high order. A lesser degree of treatment would be needed if, for example, the water was to be used to create a freshwater barrier between the saline water along the coast and the pumping zone where water levels are subject to periodic declines. If infiltration ponds are designed and operated correctly (correct operation includes alternating wet and dry periods) it is possible to remove much of the nutrient from the water during the recharge process.

A further management factor for the sandbed aquifers is the need to coordinate drainage, aimed at alleviating waterlogging, with the need to optimise recharge to the aquifer. There may well be a need to remove water from some areas where the watertable is very shallow and the land surface is subject to waterlogging, but shallow drains which merely transport the unwanted water to the sea are not necessarily the best way to do it. Some coordination of groundwater withdrawal works and the need for prevention of flooding or waterlogging is warranted.

Any use of an aquifer system is likely to have an impact either directly on watertable level, and/or indirect impacts, such as the impact of falling watertable level on a dependent vegetation association. The impacts might be readily discernible, such as the case of a failure of supply from a bore because of local or regional over-pumping. But they can also be less obvious and, perhaps more harmful and long lasting, for example when groundwater is contaminated. Lack of sufficient knowledge about the groundwater system, or failure to anticipate likely consequences of aquifer usage, can cause environmental modification that at best will reduce the efficiency of the groundwater pumpage, and at worst can destroy the groundwater system as a source of useful water and perhaps also adjoining water bodies and dependent ecosystems.

Use of the aquifer system as a source of water should not be seen as a procedure which takes place in isolation. Management of the aquifer system should be seen as part of the management of the water system as a whole in the first place, and secondly as part of the management of the catchment. It should be conducted by an authority with control mechanisms appropriate to this purpose, based on comprehensive knowledge and understanding of the systems involved, and with systematic monitoring and recording of all aspects of the process.

8.2 The aquifer as a receptor for waste

The physical attributes of the aquifer sands of the Newcastle Formation are such that they are capable of being used as a receptor for all manner of wastes. They are permeable and porous and have a high capacity to transmit and store water and other liquids. Soluble solids could be readily removed from repositories within the sand, either by infiltrating water or by moving groundwater.

The sandbeds do not, however, have attributes which would make them suitable for waste disposal concurrently with their use as a source for public water supplies. The capacity to modify contaminants by chemical action, adsorption, precipitation, ion exchange or other means is in general very low (a possible exception being the humic cemented sands of the "Woolloomooloo Rock" in the Tomago Sand Member). The only attenuating process that is available then is dilution, and this is unlikely to be sufficient by itself. Further, the aquifers are open systems with unrestricted flow of water, with or without dissolved contaminants, to the discharge zones where they will enter the wetlands, estuaries, or the sea.

In fact it is difficult to conceive of a less suitable situation for waste disposal. The nearest example is the Botany Sandbeds at Sydney, where long term neglect, lack of knowledge, and general absence of any concerted effort to conserve a major groundwater resource, has resulted in widespread contamination and the loss of a valuable source of potable water.

Nevertheless, waste disposal is an unavoidable land use. The decisions to be made relate to whether the methods of disposal have a beneficial, neutral, or detrimental effect on the land. The likely impact on groundwater is often increased because of unwitting acts brought about by lack of knowledge or forethought. Measures to stop, or at least minimise, the impact of waste disposal on groundwater include reducing the initial generation of the waste at their sources; reducing the quantity of original waste by incineration, composting or ocean dumping; preventing leachate formation by encapsulating wastes in impermeable material; protecting disposal sites from rainwater infiltration; and intercepting and treating leachate before it enters groundwater flow systems. All these procedures are expensive, and require careful design of facilities and procedures, close monitoring, strict control procedures and vigilance on the part of the control authority, to have any chance of success. There is a multitude of possibilities for things to go wrong and, in a case such as the present one where the aquifer is so vulnerable to the impact of contamination from the land surface, waste disposal is a high risk activity.

8.2.1 *Industrial wastes*

Demand:

Apart from the establishment of individual major industries most of the industrial development is expected to occur in the Newcastle city area. Any increase in the generation of industrial waste is therefore expected to occur in that area.

The demand for using aquifer space for disposal of industrial wastes in the Newcastle Bight area has decreased significantly over the last decade largely due to the imposition of stricter controls on waste types accepted at landfills, more environmentally sound landfill operations, improved resource recovery technologies and increased costs of landfilling.

Landfill Disposal:

The Victorian Environmental Protection Authority has indicated appropriate methods of treatment and disposal for a variety of wastes (EPA 1986). A summary of these methods is given in Figure 8.1. The siting requirements for different landfill disposal facilities are given in Table 8.1. Note in Table 8.1 the requirement that there be no important aquifer at the site. Chemical fixation is an acceptable process for conditioning wastes for landfill disposal. Land farming and effluent irrigation is acceptable for some biodegradable wastes where toxic residues do not accumulate on the site, damage the land or run-off, provided it is well planned and operated.

Prescribed hazardous industrial wastes are currently disposed to a number of specially engineered landfills near the study area. The main example is the Walleroo Waste Disposal Facility 22 km north of Tomago. The lifetime of any operation will depend on the volume and types of wastes that it accepts in the future.

TABLE 8.1: Site requirements for industrial landfills
(after EPA, 1986)

Landfill type	Physical requirements	Land-use zone	Adjacent land-use zone	Buffer zone.
General landfill	Flat land, not flood prone, seismically stable, unimportant aquifer, impermeable natural or artificial barriers.	Special use zone. Reuse for: commercial, industrial, recreational, conservation.	Non resident, not intensive agriculture.	Yes
Secure landfill	Flat land, not flood prone, unimportant aquifer, impermeable barrier, seismically stable.	Special reuse zone. Re-used for: landscape, habitat, buffer zone.	Non residential, low intensity use, not for intensive agriculture.	Yes

There are no environmentally acceptable disposal facilities currently available for a small proportion of industrial wastes, referred to as intractable wastes. The intractable waste stream is unlikely to grow because of the increasing economic incentive for recovery of solvents, the reduction in chlorinated hydrocarbon wastes, and the availability of alternative treatments for mercury wastes.

Any secure landfill for intractable wastes must be located in areas where the underlying rocks have a low permeability, as an added precaution against groundwater pollution. There are no such sites within the area of the Newcastle Formation, but they can be found in some of the surrounding areas. Groundwater around such sites should be monitored under strict supervision, if they are within the area from which surface run-off or sub-surface flow could enter the Newcastle Formation sand aquifers.

Industry also produces semi-hazardous wastes which, with care, can be disposed of into landfill sites that are also used for inert wastes, such as building materials, and for municipal wastes. Such co-disposal of domestic and industrial wastes may, in fact, be used to optimise the effects of the attenuating processes that occur on the solid surfaces of the accompanying

wastes, as discussed by DOE (1978). Extreme care would be needed with such facilities in the Newcastle Formation sandbeds.

Borehole Disposal:

Disposal of wastes via boreholes is conducted in some countries under particular circumstances, but is discouraged in New South Wales. It would be totally unacceptable in or near the Newcastle Formation.

8.2.2 Municipal wastes

There is no essential difference, in terms of impact on an aquifer system, between industrial waste as described in the previous section, and urban waste. There is likely to be a difference in the chemical character of the leachate, and there is less likely to be toxic material present, but urban waste is equally capable of generating leachate which would have a quite unacceptable impact on groundwater quality if it entered an aquifer.

The same restrictions should therefore apply. Urban waste disposal by land-fill should not occur at any site from which run-off or infiltrating water could enter any part of the Newcastle Formation aquifer system which is being, or is to be used, as a source of water for domestic or town water supply purposes. This should eliminate all of the sandbeds areas, and adjacent areas of rock outcrop from which run-off or leachate could enter the sandbeds. A possible exception might be those parts of the sand aquifer system where contamination has already occurred, such as the area around Fullerton Cove. Even here, however, the situation is not clear cut, because of the contaminant transport function of the aquifer and the possibility of transport of contaminants to and beyond the shoreline.

8.2.3 Sewerage and septic tanks

Disposal of sewage by either reticulated sewerage systems of some sort or by the use of on-site methods such as septic tanks is an unavoidable adjunct to human development of any land area.

In the study area, the use of septic tanks is apparently declining, but seems unlikely to cease entirely. It is not clear whether the impact of existing levels of use are unacceptable, and some investigations are required to determine this. The main problem is that these facilities are widely dispersed, so if they are impacting on groundwater quality the effect will be widespread. They also provide a ready conduit to the watertable for a range of chemicals (pesticides, household solvents, oil etc.) which are often discharged via the sewer. If it is found that the use of septic tanks is having an unacceptable impact within the framework of the overall management of the aquifer system, then alternative methods should be investigated and introduced.

Sewage disposal from larger individual sources such as factories and tourist resorts not connected to sewerage schemes, and from the municipal sewerage schemes, present a different problem because of the concentration of impact in a small area. Use of the aquifer system as a repository for waste water is, in practice, feasible because of the very characteristics which

make it an aquifer. Used in this way, with little or no prior treatment of the water, the aquifer is being used purely as a means of transporting an unwanted water product from the location where it has accumulated to another, unspecified location where, it is assumed, it will not cause any trouble. Such use of the aquifer would preclude its use as a useful source for public water supplies, and may have other impacts on the local environment.

In addition to the actual sewage disposal arrangements, use of the aquifer as a place to bury sewerage pipes is also a factor. Such pipes are prone to leakage, and their location should be decided with this in mind so that leaks will have no impact on the aquifer.

8.2.4 Other discharge to land

There are numerous causes of incidental and accidental contaminant discharge to land areas in any area where human activity is taking place. The severity and implications vary with the type of activity and with the type of aquifer. In the study area, where the aquifer is so vulnerable to contamination from the surface, even small occurrences will have an impact. Hence, within any area nominated as being a source of water for public water supply purposes, the potential for incidental and accidental discharge to land must be minimised.

Urban, commercial, industrial and mining development all have some potential for generating discharges to land. In suburban areas potential sources of contamination include road run-off, fertiliser, other agricultural chemicals and hydrocarbons from domestic residences, septic tank effluent in some areas, leaking sewerage lines, and stormwater run-off. Similar but more concentrated problems will occur in commercial centres. Industrial enterprises are likely to be adjacent to or within urbanised areas and will generate specific waste products which may knowingly or unknowingly be discharged to the land surface. Service industries such as transport and fuel supply (which involve the transport of products which would be harmful if spilled) have potential for direct and indirect impacts.

The land in the study area is particularly vulnerable to problems of incidental and accidental discharge. The most relevant comparison in Australia is Perth, which is built on similar permeable coastal sand formations and where there are a multitude of problems relating to the conflict between the need for a variety of land uses and the need to maintain the city water supply drawn largely from the underlying sandbeds.

8.2.5 Outcome

The general situation with regard to waste disposal is that the whole study area is a highly vulnerable area. Because the permeable part of the aquifer extends to the land surface there is a direct path by which contaminants can travel from the surface to the watertable and join the groundwater store. The aquifer is therefore exceptionally vulnerable to damage from mismanagement of land surface activities and accidents. If the highest value use of the aquifer is decided to be the supply of water for public and domestic purposes, then the area within which the aquifer occurs and the surrounding area from which run-off might enter it are unsuitable for waste disposal. If other uses are deemed to be of more value for any or all of the sand deposits, waste disposal by landfill might be a compatible land use. Under these circumstances, however, the contaminant transport capacity of the aquifer system becomes

critical. Contaminants escaping from waste disposal operations could be expected to appear in groundwater discharge areas, and under some circumstances may be concentrated in those areas (eg coastal wetlands).

The clearest conclusion from any consideration of the use of the Newcastle Formation aquifer system for waste disposal is that this direction is fraught with risks if the use of the aquifer system as a source of public water supply for Newcastle and surrounding areas is regarded as the highest value use.

8.3 Using the aquifer for wastewater renovation

Very little attention seems to have been given to this use of the aquifer system, although it offers the potential for substantial benefits. The concept could be used as part of an overall water management strategy for the study area, in which reclaimed wastewater, stormwater run-off and water currently transported out of the area by drains are all used to increase the recharge to the aquifer and thus extend the potential for it to support long term withdrawals. Proper investigation of the capacity of the aquifer system to deal with water of the relevant quality, of its hydraulic characteristics, and of the impact of the additional water on local water levels, would be essential.

The main obvious factor here is the need for a regional water authority with the power and will to control all the necessary aspects of the water system and manage them in a way which will optimise the mix of consumptive use of water and acceptable impact on the environment.

Adoption of this approach is inconsistent with current practice in the study area, where the main use of the aquifer in the realm of waste water management seems to be as a repository of minimum short term cost.

8.4 The aquifer as a target for extractive industries

There are two distinct aspects to this type of use. Firstly, the sand of the Newcastle Formation is a valuable resource for the building and foundry industries, and when used for this purpose the entire bulk of the aquifer material is removed. There may be places where this can be done with little impact on the capacity of the aquifer system to supply water. Such places should be located and nominated as such, at an early stage of any Groundwater Management Plan implementation. Once established, such areas should not be extended.

The second aspect which is relevant for the Newcastle Formation aquifers is the removal of the heavy mineral fraction (rutile, zircon). While the total bulk of the minerals removed is only a small proportion of the sand body, a large proportion of the sand body is disturbed during the extraction. There are continuing debates about the success with which the land surface and attendant vegetation are rejuvenated, and about the impact on the aquifer in relation to its water systems. The main contentious issue appears to be the claimed increase in the concentration of iron dissolved in the water after mining. The economic value of the mineral fraction of the sand beds is high, and it seems probable that mining will continue. Some resolution of the conflicting needs of the mining use and of the water source use will be necessary as a basic feature of a Groundwater Management Plan.

8.5 Levels of recharge and vulnerability

The study area is not pristine land, and has been used for a variety of purposes for many years. Some of it is relatively undeveloped, but some is highly developed and shows the symptoms of being used to support an industrialised community. Proposals for future land use aimed at optimisation of the water resources of the area must, therefore, take account of the reality of this situation and cannot be based on the assumption that the groundwater can continue to absorb human impacts indefinitely. It is quite unlikely that any of the existing land uses will be discontinued. The area can therefore be expected to continue to support urban, rural and industrial development with their associated infrastructures and also some extractive industries. The task for a water resources manager in the area will be to influence or control these uses in such a way that groundwater continues to be a useful resource for the region and that the impact of that use on the environment is kept within acceptable bounds.

Current understanding of resource management highlights the need to achieve sustainable practices in all sectors of society. Consequently, there are many difficult decisions to be made in negotiating satisfactory arrangements that take into account the economic, environmental and social needs of the present population, while ensuring the preservation of resources and lifestyle choices for future generations.

Neither the distribution of existing land uses around the study area nor the groundwater system are homogeneous across the whole study area - in fact they both vary widely. It is not feasible, therefore, to adopt groundwater protection procedures that are uniform over the whole area. The differences have been used to divide the study area into a number of smaller areas which, based on current scientific and technical knowledge, reflect the level groundwater recharge and groundwater vulnerability to pollution. For each of these areas a consistent set of guidelines for land use could be devised. The location of the suggested smaller areas is shown in Figure 8.2. The specific characteristics of each of these areas are described below.

Area A1: Tomago-Stockton Groundwater, High Vulnerability (Groundwater Recharge):

The essential characteristics of this area are high vulnerability to pollution, and the potential for high value beneficial use of the groundwater. There are two parts to Area A1, occupying respectively the bulk of the Tomago Sand Member exposure area and the bulk of the Stockton Sand Member exposure area. They constitute the main recharge areas for the major aquifers, and incorporate the special areas and water reserves currently managed by HWC. They require the maximum degree of protection, as contaminants entering the aquifer through these areas could spread widely through the water body, and recharge rates could be seriously impaired if the areas are not properly managed. Ideally there should be no human activity in these recharge areas apart from the minimum necessary for proper management of the aquifer system and groundwater withdrawals (including all necessary monitoring), and passive recreation. There should also be controls on these activities. Aquifer management procedures should be conducted with minimum disturbance to the land, vegetation and native fauna. Passive recreation should be consistent with groundwater protection.

If the integrity of the groundwater resource in this area, and indeed in the Newcastle Bight area, is to be maintained, there should be minimal change to the existing protection regime that was established by the former HWB for the special areas.

Area A1 should be prominently sign-posted at all entry points, with text explaining the area's high vulnerability to pollution.

**Area A2 : Tomaree Groundwater,
High Vulnerability (Multiple Use - Groundwater recharge / Housing / Retail / Light Commercial):**

This area is the Tomaree Peninsula. High-level protection should be seriously considered for the whole of the Tomaree Province, including the areas of bedrock outcrop in the higher hills, because of the complex detail of the sandbed distribution, and the road areas, because of run-off into the sandbeds. Further sub-division of the area to allow for different land uses within it is understood to be necessary, but more detailed study than is possible within the context of this report is required. Such study should allow for urban, retail, commercial, resort, and rural uses, but should examine ways to give higher protection to areas in the vicinity of present and possible future groundwater withdrawal facilities. Guidance could be given by the DWR as groundwater manager, or its delegate, to the council on any proposed re-zoning decisions in this area.

Industrial use of land in this area is not compatible with the continued beneficial use of the aquifer in Area A2.

**Area B1 : Tomago-Tomaree-Stockton Groundwater,
High-Medium Vulnerability (Multiple Use - Housing / Retail / Light Commercial):**

This area occurs mainly as fringes of the main Tomago and Stockton Sand Member outcrop areas, extending to the surface limits of the sandbeds where it occurs. The fringe around the Tomago Area A1 takes in those parts of the sandbed below the 1.5 metre (AHD) groundwater contour line (Fig. 3.2). The fringe around the Stockton Area A1 occurs mainly as a 200 metre wide band, but widens in the east to take in the land between Areas Stockton A1 and Tomaree A2 (Fig. 8.2).

Within this area the groundwater system is likely to be discharging rather than recharging. Consequently, impacts of land use in this area are not of such direct importance to the maintenance of the groundwater system as they are in Areas A1 and A2. Contaminants arising from land use in this area may, however, be readily transported via surface run-off waters to wetlands and estuarine areas, and thus some guidelines for development and use may be necessary.

There is a degree of existing development within this area, mainly housing and farming. Continuation of these activities is unlikely to significantly impact on the integrity of the groundwater resource. However, extensive paved areas, septic tanks, garden fertilisers, and domestic animals have the potential to adversely affect the beneficial use of the groundwater resource. Storm water run-off needs to be properly managed, with further studies required to assess the best management strategies. Light commercial/retail developments (such as a local

shop) might be consistent with the requirements of the groundwater in this area, if subject to the same conditions as indicated above for domestic housing.

Disposal of sewage effluent by discharge direct to uncontrolled open ponds or pits is not compatible with groundwater protection in Area B1. Disposal of sewage effluent should be preceded by adequate treatment, and infiltration ponds should be designed and operated in a way that is compatible with best practice for use of reclaimed water for aquifer recharge.

There is some use of the aquifer as a source of industrial sand, at least in the Fern Bay area (Area C3) and possibly also in others. This type of activity seems likely to continue to be required in the vicinity of Newcastle, and subject to strict control, is consistent with the level of protection required in Area B1. Industrial use of land in this area is not compatible with the continued beneficial use of the aquifer.

**Area C : Tomago-Stockton Groundwater,
Medium Vulnerability (Multiple Use - Scenic Protection / Housing / Retail / Light Commercial / Suitable Industrial):**

This area includes the south-western end of the Stockton Peninsular and generally extends to Cox's Lane, some 5 km from Fern Bay (Fig. 8.2). This area is already subject to stress from industrial uses and some housing, and there are proposals for an expanded urban area. There has also been localised contamination of the aquifer which may or may not be reversible. Given the need for continued urban and light industrial use in the region, this area therefore seems the most suitable for such activities.

The groundwater quality is already at risk from present developments. With further industrial use of the groundwater there is a possibility of contaminated groundwater discharging into the Hunter River or estuary. Considerable attention should therefore be given to control and monitoring of land and aquifer use in this area to try to avoid irreversible damage occurring to the groundwater, the estuary and the Hunter River.

**Area D : Tomago-Stockton Groundwater,
Lower Vulnerability (Urban / Retail / Light Commercial / Suitable Industrial):**

This area takes in the western end of the Tomago Sand Member, and extends to the western boundary of Area A1, 200 metres east of Masonite Road (Fig. 8.2). There is presently some heavy industry operating within this area and there may be future urban development here, both of which can pose threats to underground and surface water quality. Contaminants arising from these types of land use may be readily transported through groundwater and via surface run-off waters to wetlands and estuarine areas, and thus some guidelines for development and use are necessary.

Impacts of past industrial land use in this area have led to the impairment of groundwater quality. Accordingly, industry within this area should operate within guidelines aimed at minimising future impacts on groundwater. The lower vulnerability of this area is compatible with the need for land near Newcastle to be available for industrial use. It must be emphasised, however, that industrial land use should not be encouraged on the sandbed areas, especially where alternative sites can be found on lands outside sandbed areas.

**Area E1 : Tomago-Stockton Groundwater,
High Vulnerability (Water Storage):**

The sandbeds in this area are overlain by the Grahamstown Reservoir. The guidelines and management practices which currently protect this potable water supply are likely to protect the groundwater resource. The links between the storage facility and groundwater need to be considered when assessing all new major development proposals (such as augmentation), for this storage.

**Area E2 : Tomago-Stockton Groundwater,
High Recharge and Vulnerability (Multiple Use - Housing / Retail / Light Commercial):**

The area along the northern fringe of the Tomago Sand Member, and in particular the area to the north underlain by consolidated rock formations in land rising to the catchment boundary, presents a particular problem. Run-off water from this area enters the Tomago sandbed as recharge along its northern fringe. Some consideration should therefore be given to special protection for this area, to ensure the quality of the run-off water entering the aquifers is acceptable.

9. FUTURE ISSUES

The three aquifers can be used in a range of ways. Some of these uses are incompatible with protection of groundwater, and some will impact on each other. It will be the role of the proposed Groundwater Management Plan to guide the community to a resolution on these issues so that the optimum benefit can be derived from the aquifer system.

The various likely or possible uses are listed in Table 9.1 below. For each use, one or more primary impacts are noted, together with secondary or indirect impacts, the implications for the community of those impacts, and the issues that arise from them. The relative importance of the issues dealing with them, are then discussed.

TABLE 9.1 Aquifer use (including land surface): impacts, implications and issues

AQUIFER USE	PRIMARY IMPACT	SECONDARY IMPACT	IMPLICATIONS
Groundwater pumpage	Lowered water table in recharge areas	Possible impact on wetlands and associated vegetation if not properly managed	Need for data, good design and operation of works, and careful monitoring of aquifer system
		Possible increase in dissolved iron content of water by oxidation of aquifer exposed to air	Increased cost of water treatment before use
	Reduced groundwater flow to discharge areas	Possible lowering of watertable gradient and reduction of groundwater flow towards shore and wetlands; possible landward movement of salt water interface	Need for data, good design and operation of works, and careful monitoring of aquifer system
Heavy mineral mining	Temporary sterilisation of part of the aquifer system	Need for greater rate of withdrawal from rest of aquifer system	Possibility of greater impacts than would otherwise occur
	Possible impact on characteristics of replaced aquifer	Change to pattern of groundwater system	Change to impact of groundwater pumpage on local environment
	Impact on iron content of water	May make the water too expensive or impossible to treat for reticulation	Length of time for recovery may be so long that the impact is effectively permanent
Industrial sand mining	Potential source of contaminants to groundwater	Removal of part of the aquifer system	May render parts of the aquifer unusable for water supply, and result in long-term reduction in aquifer size
Sewage disposal	Potential major source of contamination	Possible degradation of large part of the aquifer system	Need for further investigation of better ways of disposal
Drainage	Potential loss of water from aquifer storage	Potential environmental impacts associated with depletion of groundwater	Impact on waterlogged land can be duplicated by beneficial groundwater pumpage
Transport	Potential for groundwater contamination	Need to consider location of roads & facilities Need to monitor and control activities at airports	Need for more care to avoid/clean up spills etc and monitor sites
Housing	Potential for groundwater contamination and reduction of recharge	Need to consider location of housing developments and design	
Construction	Potential for groundwater contamination at construction sites	Unpredicted sterilisation of part of aquifer	Need for control and monitoring of construction industry

Table 9.1 (cont)

AQUIFER USE	PRIMARY IMPACT	SECONDARY IMPACT	IMPLICATIONS
Recreational vehicles	Potential for groundwater contamination from fuel and oil spills	Potential for damage to sensitive landforms and vegetation	Need to consider controlling access to sensitive areas
Industrial users - groundwater use	Potential impact on groundwater flow pattern	New flow pattern might have unwanted consequences.	Need for investigation, assessment, licensing and monitoring to ensure compliance with conditions
Industrial users - land use	Potential for groundwater contamination	Potential to sterilise part of aquifer by pollution, and for impact on adjoining water bodies	
Passive recreation	Minimal		

9.1 Groundwater pumpage

Groundwater pumpage can potentially have an impact on the environment, in particular the impact on the estuarine and dunal wetlands. There is no record of past pumping having caused such impacts, and no evidence that current levels of pumping are of concern, but the lack of environmental data makes subtle or gradual changes difficult to detect. Proper investigation of the aquifer system, and appropriate design and operation of the pumping system, should ensure that impacts of this nature are avoided in the long term. Short term impacts might be unavoidable, but appear unlikely to cause long lasting damage. Prolonged impacts, however, have the potential to cause definite changes to vegetation (section 2.5) and consequently to wildlife.

Baseline studies of water levels, water quality and dependent environments, followed by appropriate monitoring, is important for proper management of aquifers in the study area.

The issue of iron concentration in the groundwater, and its causes, is still a matter of contention. Linked to this issue is the potential for iron bacteria build up in water pipes and bores.

9.2 Aquifer protection

The various levels of aquifer protection suggested in section 8.5 are not compatible with some possible land and aquifer uses in these areas. This means that community decisions are needed, based on the way different parts of the natural resources of the area are valued by the community, regarding the suggested levels of aquifer protection.

The following paragraphs outline some of the issues which may arise within some or all of these areas.

9.3 Heavy mineral mining

There are two major issues relating to heavy mineral mining, one being short term and the other essentially permanent.

Physical alienation of part of the aquifer system, while sand is removed, processed and replaced causes temporary disturbance, and the aquifer system is large enough in relation to the disturbance and to current levels of pumpage to enable groundwater withdrawals to continue elsewhere, at a rate increased sufficiently to account for the shortfall. It is accepted, on the basis of current knowledge,

that the hydraulic characteristics of the replaced aquifer are not significantly different from those of the undisturbed aquifer.

The impact on dissolved iron concentration, however, is another matter. There seems little doubt that heavy mineral mining does increase the iron concentration to some extent. It might not be the only factor at work. The extent of the increase is still being debated, and the length of time which might elapse before pre-mining concentrations return is uncertain. There is some possibility that the time for return of low values will be long enough for the increase to be regarded as effectively permanent. It is at least possible that the increased iron content will render the water untreatable within reasonable cost limits. Consequently, the area being mined might have to be regarded as unproductive in terms of future public water supply. If this is the case, then the community will have to decide which is the activity of greater value.

9.4 Industrial sand mining

The scale of this type of mining is smaller than for heavy minerals, but when it does occur the whole of the aquifer fabric is removed, leaving a void. Although the quantity aspects of groundwater are not likely to be significantly affected by this type of activity, the excavation during mining and the terminal void provide easy access to the watertable for a variety of pollutants. Consequently, the location and operation of such works should be very carefully controlled and monitored. A limitation on depth to no closer than 2 to 3 metres from the water table would be desirable. Otherwise, they should be licensed under Part V of the Water Act 1912. These constraints will lead to a limitation on location and place constraints on owners/operators which will add to costs.

9.5 Sewage disposal

The aquifer system could potentially be used to dispose of sewage. However, this use is completely incompatible with its use as a source of drinking water.

The one organisation (HWC) has responsibility for both water supply and sewerage, although it's right to use the water is not subject to a licence. Sewage disposal is subject to licensing by the EPA.

There is a clear need for sewage disposal in the study area to be reviewed, to ensure that sewage disposal strategies are developed in the context of regional water management objectives.

9.6 Drainage

Drainage in the study area has largely been carried out for agricultural purposes, but has also occurred to alleviate waterlogging problems on other land, in particular the Williamstown Air Base. There is no real conflict with other uses of the aquifer system, except that groundwater storage can be affected. The ownership, operation and funding arrangements for drainage works in the area are unclear.

There may be better ways to prevent waterlogging, which would be more consistent with water management objectives. The whole aspect of drainage in the study area should, as for sewerage, be reviewed from a regional and integrated water management perspective.

9.7 Transport

Fixed facilities such as roads, workshops and airport facilities impact on the recharge path to the aquifer, and provide a source and concentration mechanisms for contaminants. Vehicular use of the roads and facilities provides a source of contaminants. Ideally, roads should not be located on the sensitive sandbed areas, or should be located and designed to minimise impacts.

9.8 Housing

If housing development extends over a substantial proportion of the aquifer system, as commonly seen in Australian cities, the impact on groundwater conditions will be severe. There will be disruption (at best) or diversion of recharge, and endless possibilities for contamination. While individual inputs may be small, the cumulative effects will ensure that the overall impact is large. The best way to limit the impacts would be for future housing development to occur in groundwater discharge areas rather than recharge areas.

9.9 Construction

Ensuring construction sites have no impact, or at least an acceptably small impact, on groundwater quality in the study area will be difficult. Some regulation of contractors may be appropriate, and in some areas there may be a need for site inspections and groundwater monitoring, with consequent costs.

9.10 Industrial users

The potential impacts of industrial use, especially on groundwater quality, are substantial. Industrial use, therefore, is not a particularly compatible use for an area occupied by a shallow sand aquifer such as this. On the other hand, this form of land use is already well established in the area and seems likely to increase. Given this situation, the best approach seems to be to preclude unsuitable industrial development on sandbed areas where possible, and where not, to contain such use to one part of the area.

This is the reasoning behind the suggestion in section 8.5 that sympathetic types of industry be located in Area D. Here, groundwater quality has already been affected, and less stringent conditions on industry are needed. Nevertheless, there will still be a need for control of activities, licencing under Part V of the *Water Act 1912*, and in some cases, for monitoring and reporting. All this will add to operating costs. Industrial enterprises could be encouraged to use groundwater for plant processes (rather than relying on reticulated water) to encourage groundwater protection.

9.11 Conclusions

The sand aquifers of the Newcastle Formation form an important regional freshwater resource which has the potential to supply a large proportion of the water requirements of the area. There are conflicting requirements, however, between maintaining the groundwater as a resource for human and environmental needs, and management of land use in the area. Some of the requirements are mutually exclusive, while others are more amenable to resolution. Overall management of the region must be based on decisions made about these issues. The mix of decisions which are made will lead

to more satisfactory regional development if the groundwater system is understood and the impacts of land use decisions are appreciated.

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FIGURES

1.1 - 8.2

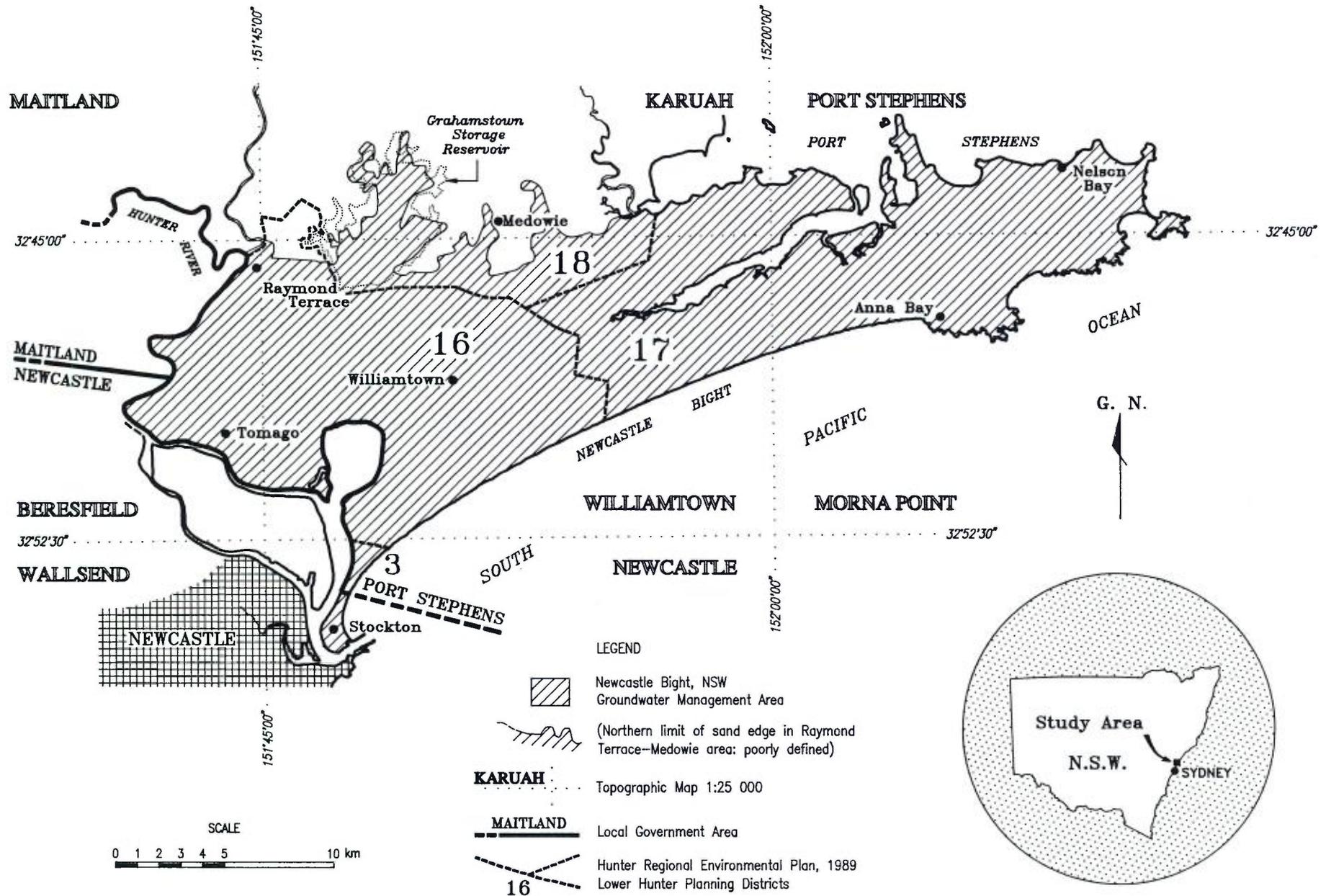
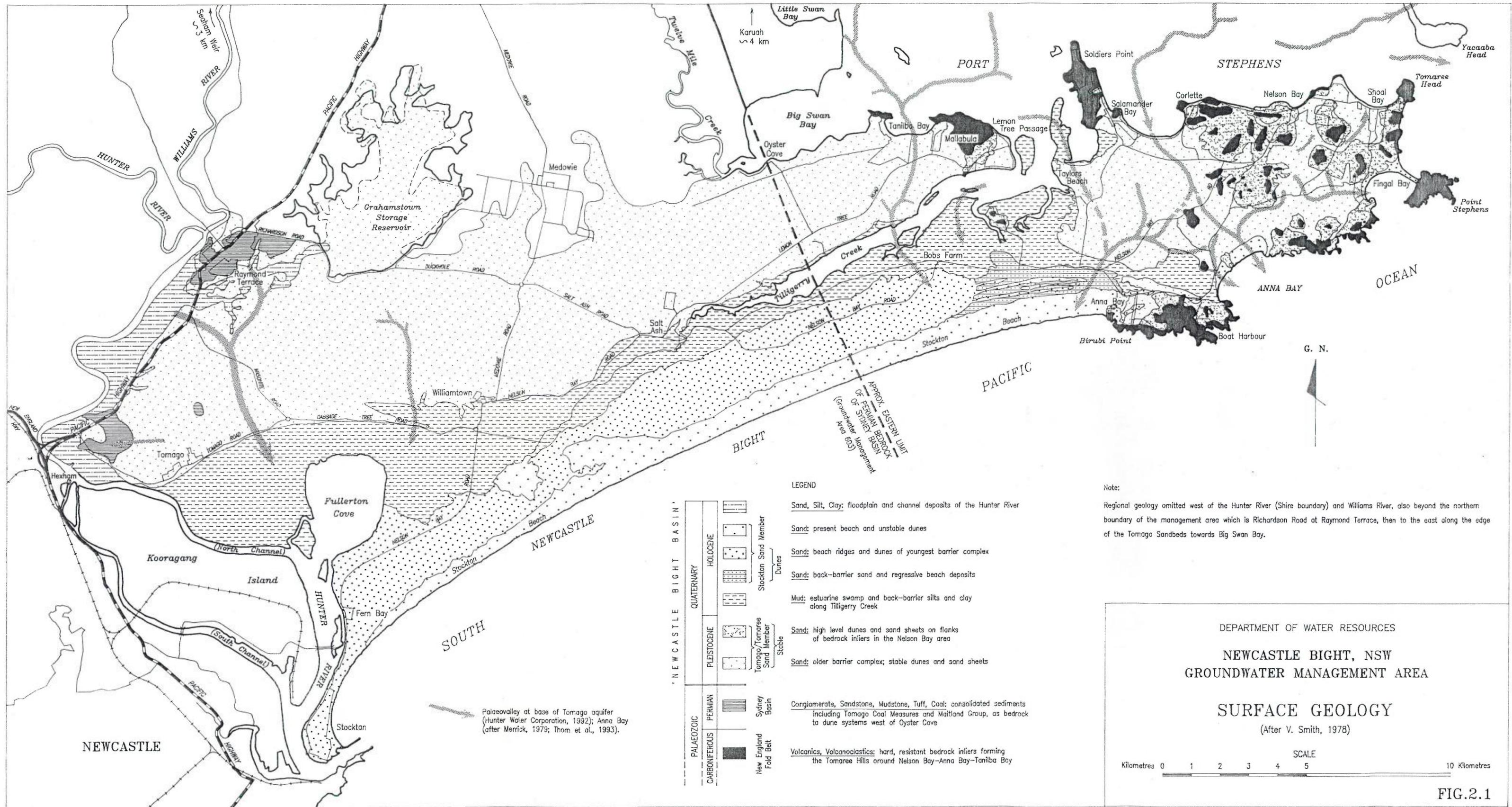


FIG.1.1 NEWCASTLE BIGHT DISTRICT, REGIONAL LOCATION MAP AND PROJECT AREA



Note:
 Regional geology omitted west of the Hunter River (Shire boundary) and Williams River, also beyond the northern boundary of the management area which is Richardson Road at Raymond Terrace, then to the east along the edge of the Tomago Sandbeds towards Big Swan Bay.

Palaeovalley at base of Tomago aquifer
 (Hunter Water Corporation, 1992); Anna Bay
 (after Merrick, 1979; Thom et al., 1993).

APPROX. EASTERN LIMIT
 OF PERMAN BEDROCK
 OF SYDNEY BASIN
 (Groundwater Management
 Area 69)

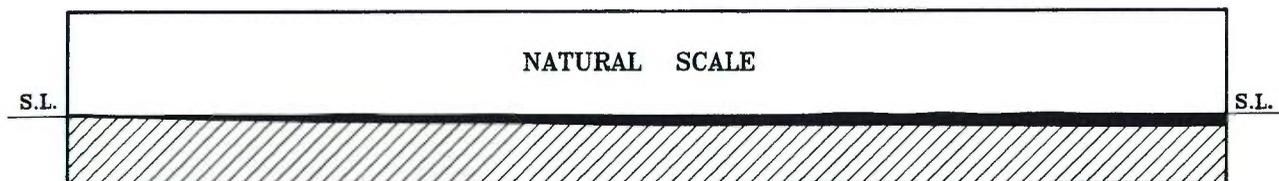
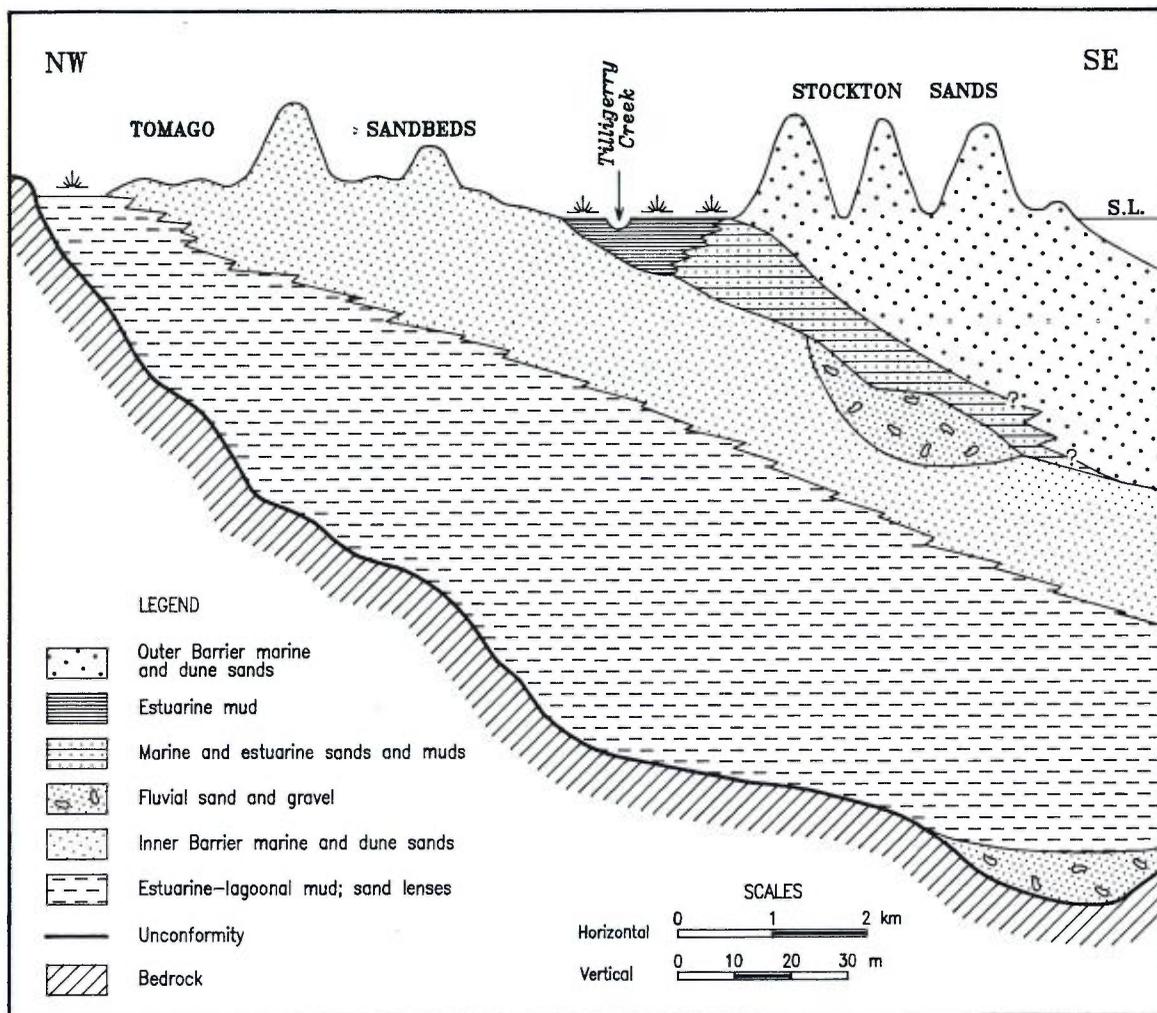
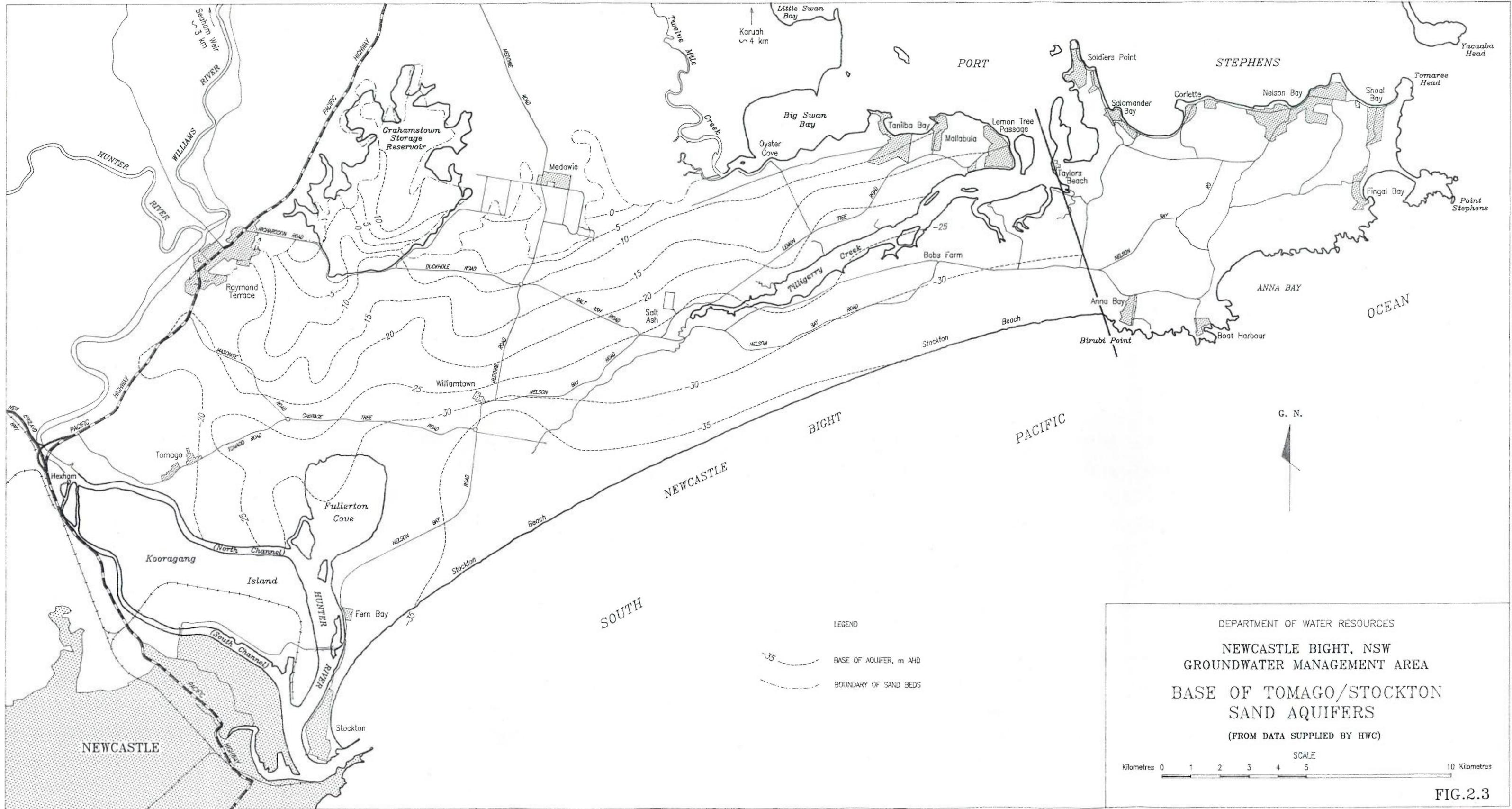


Figure 2.2: GEOLOGICAL CROSS SECTION THROUGH TOMAGO-STOCKTON SANDBEDS (schematic, after Thom et al., 1992)



DEPARTMENT OF WATER RESOURCES
 NEWCASTLE BIGHT, NSW
 GROUNDWATER MANAGEMENT AREA
 BASE OF TOMAGO/STOCKTON
 SAND AQUIFERS
 (FROM DATA SUPPLIED BY HWC)

SCALE
 Kilometres 0 1 2 3 4 5 10 Kilometres

FIG.2.3

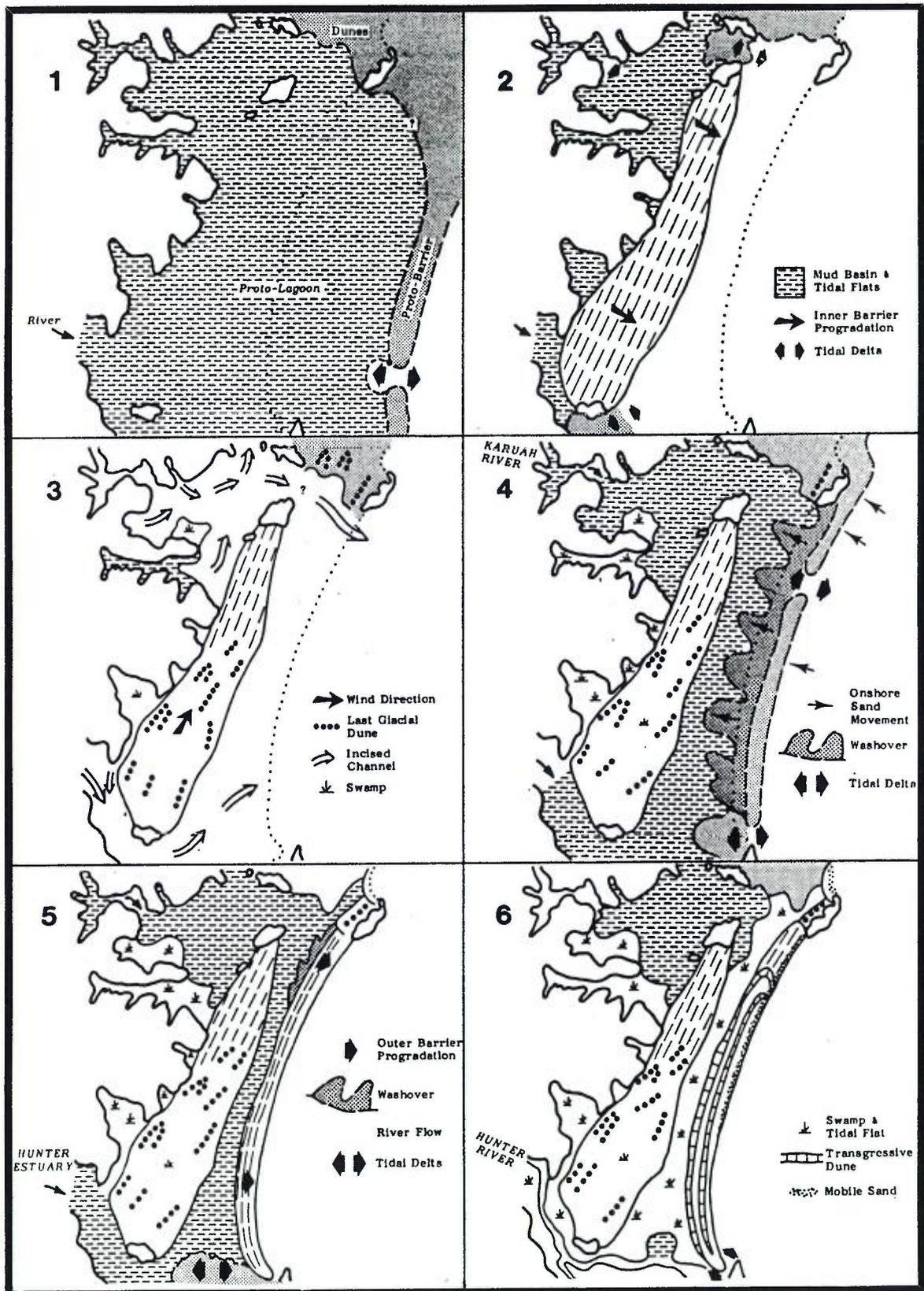
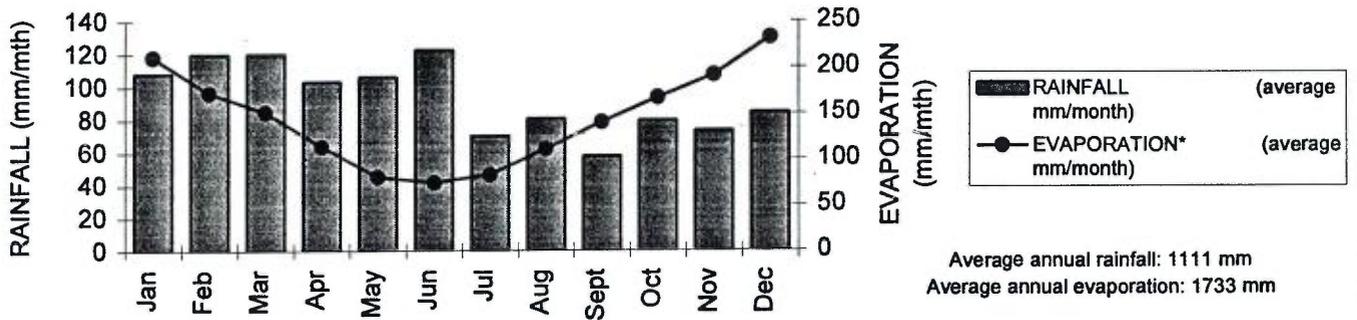


Figure 2.4 QUATERNARY EVOLUTION OF THE NEWCASTLE BIGHT BASIN
 (Figure 4-23 of Thom et al. 1992)

Rainfall (1942-1992) and Evaporation (1974-1992) at Williamstown



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
RAINFALL (average mm/month)	108.2	120.0	120.3	103.3	106.3	122.7	70.5	81.1	58.2	80.0	73.7	84.8	1129
EVAPORATION* (average mm/month)	211	172	152	114	81	75	84	112	141	167	192	233	1733
AV. DAILY MAX. TEMPERATURE (C)**	27.6	27.2	26.2	23.6	20.1	17.5	16.8	18.3	20.9	23.3	25.3	27.1	274
AV. DAILY MIN. TEMPERATURE (C)**	17.9	18.0	16.3	13.4	10.0	7.9	6.2	6.8	8.9	12.0	14.2	16.5	148

* Mean Daily Pan Evaporation (mm)

(data from Bureau of Meteorology)

** (1950-1992)

Figure 2.5 RAINFALL AND EVAPORATION AT WILLIAMTOWN

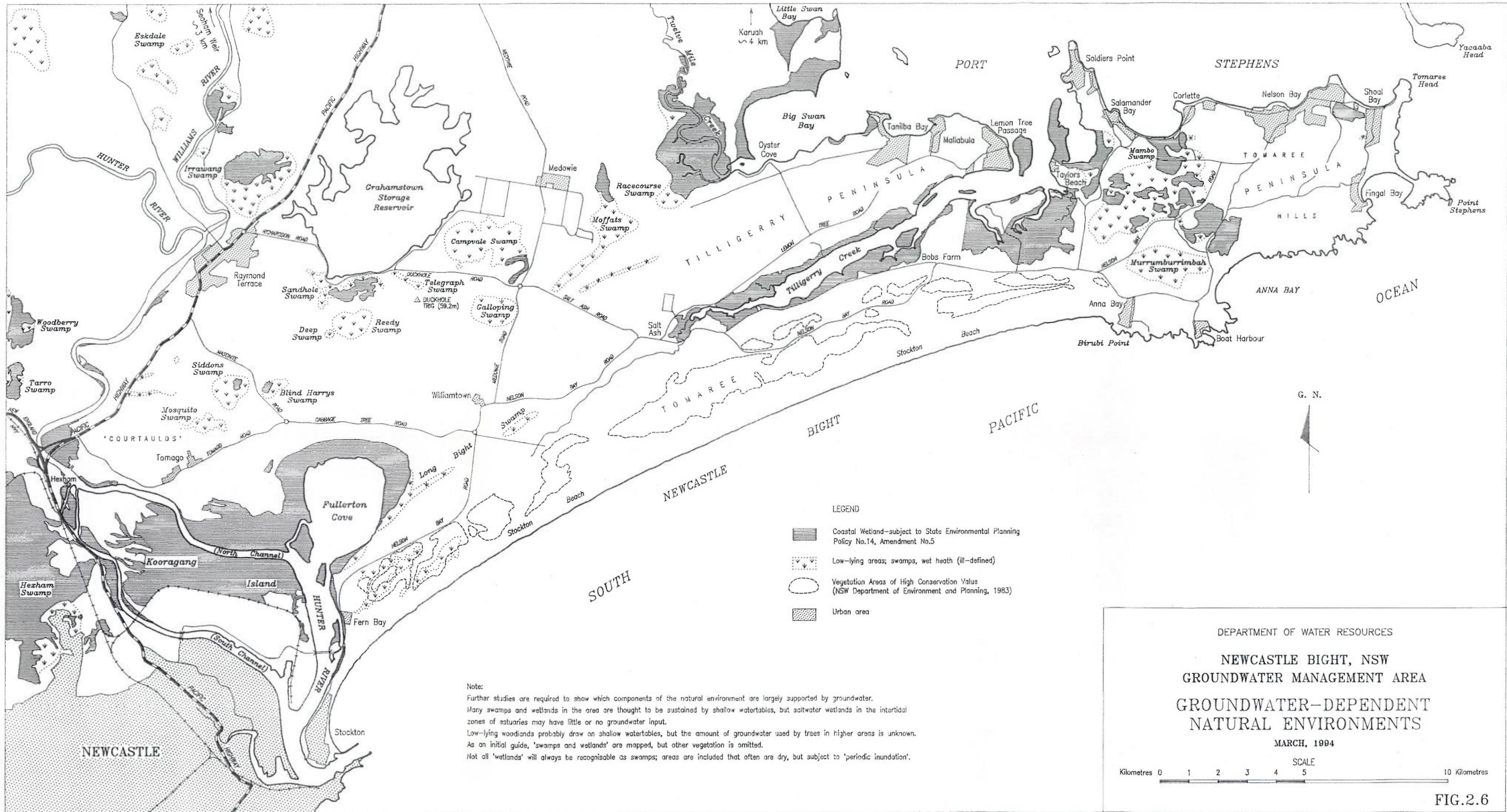


FIG.2.6

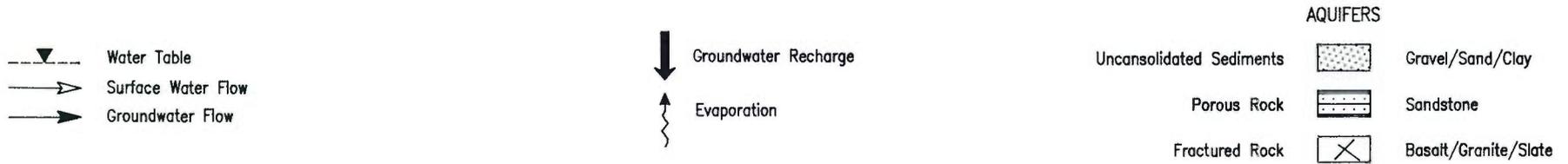
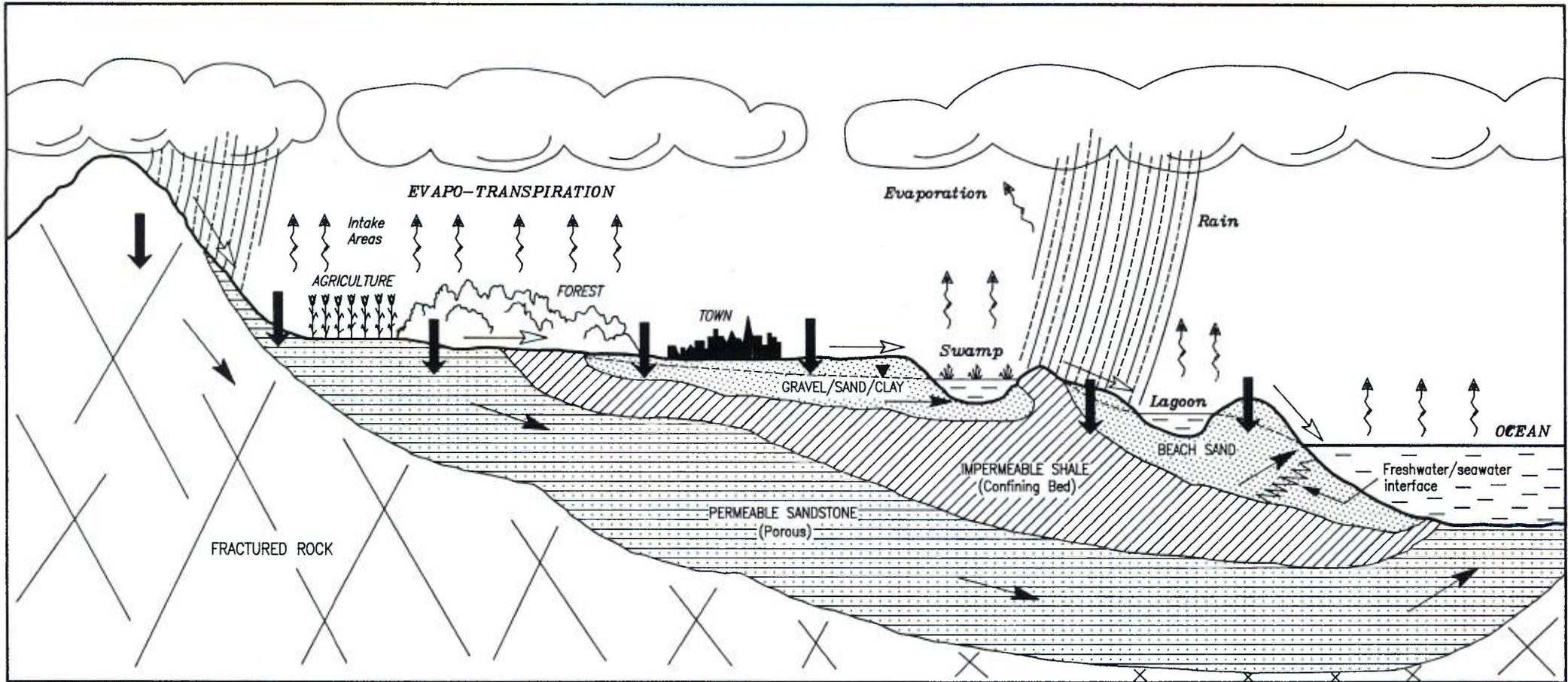


FIG 3.1 THE WATER CYCLE

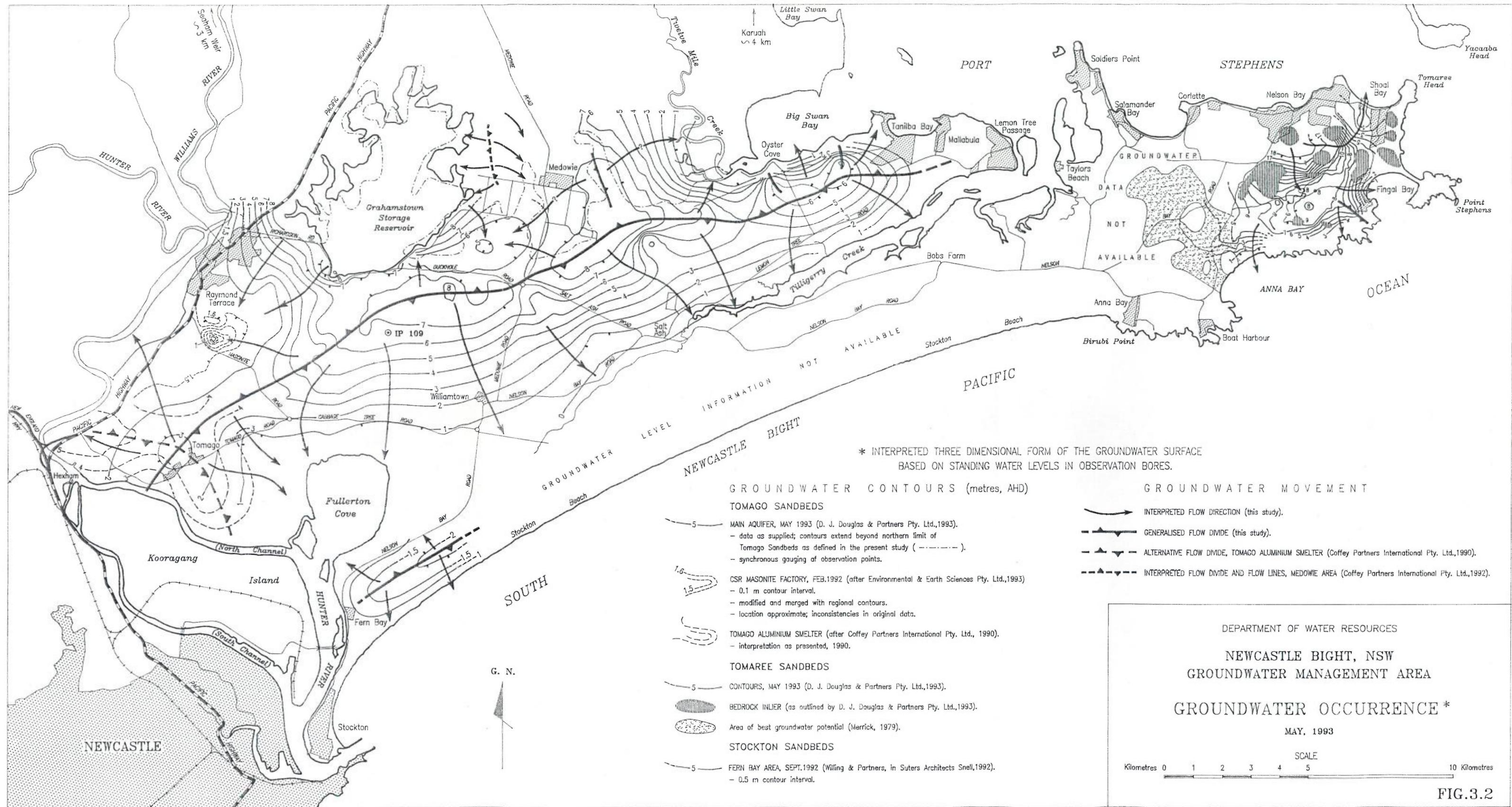
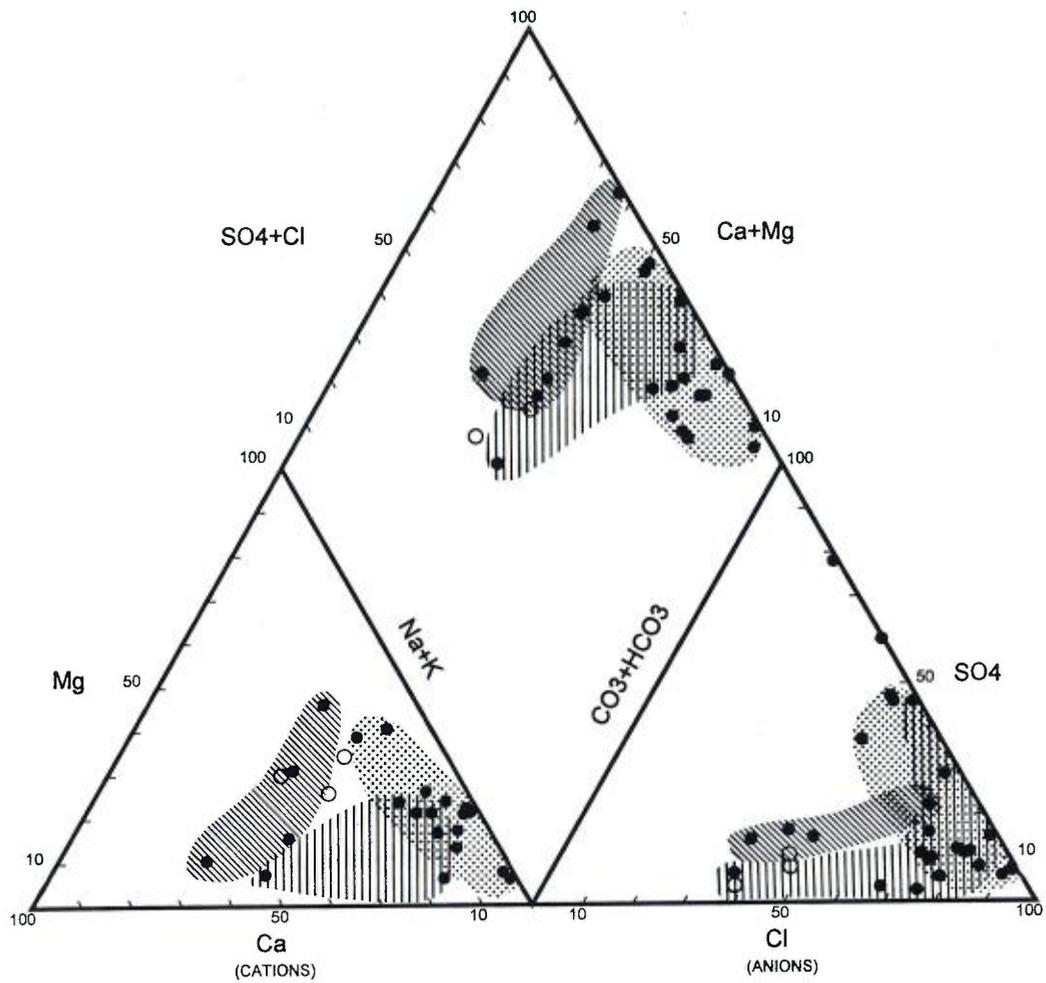


FIG.3.2



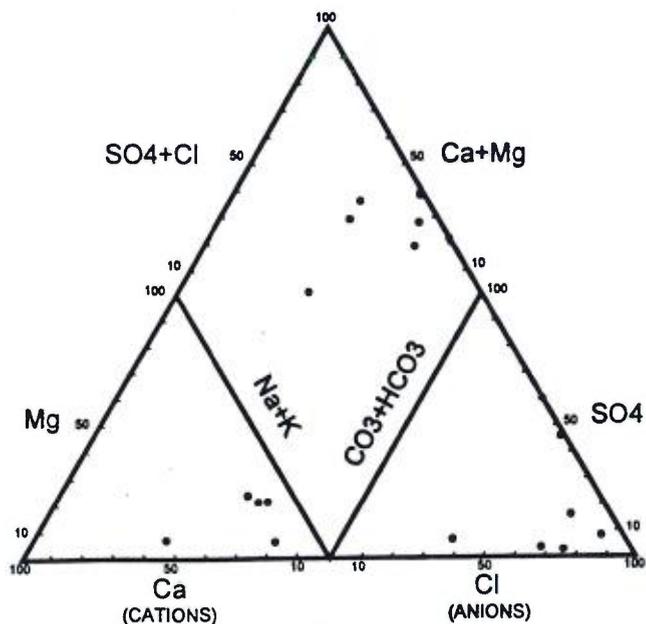
● Groundwater samples*:

- ▨ Province 1 - Tomago Sandbeds
- ▩ Province 2 - Stockton Sandbeds
- ▤ Province 3 - Tomaree Sandbeds

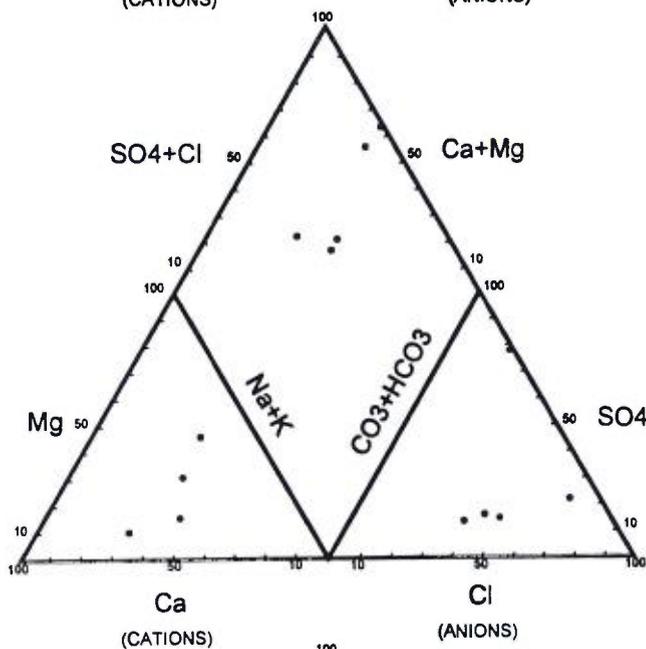
○ Surface water samples*

*Department of Water Resources, Oct. 1993

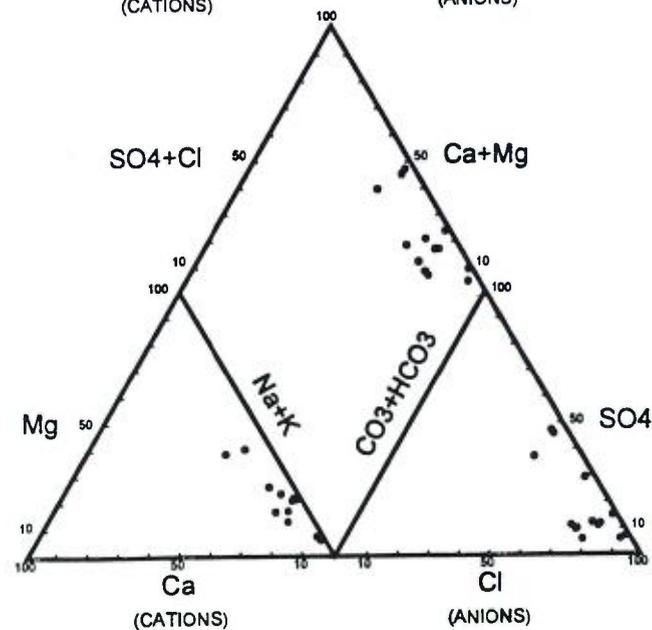
Figure 3.3 TOTAL GROUNDWATER CHEMISTRY, TOMAGO TOMAREE STOCKTON SANDS (Piper Diagram)



GROUNDWATER CHEMISTRY*, PROVINCE 1:
TOMAGO SANDBEDS



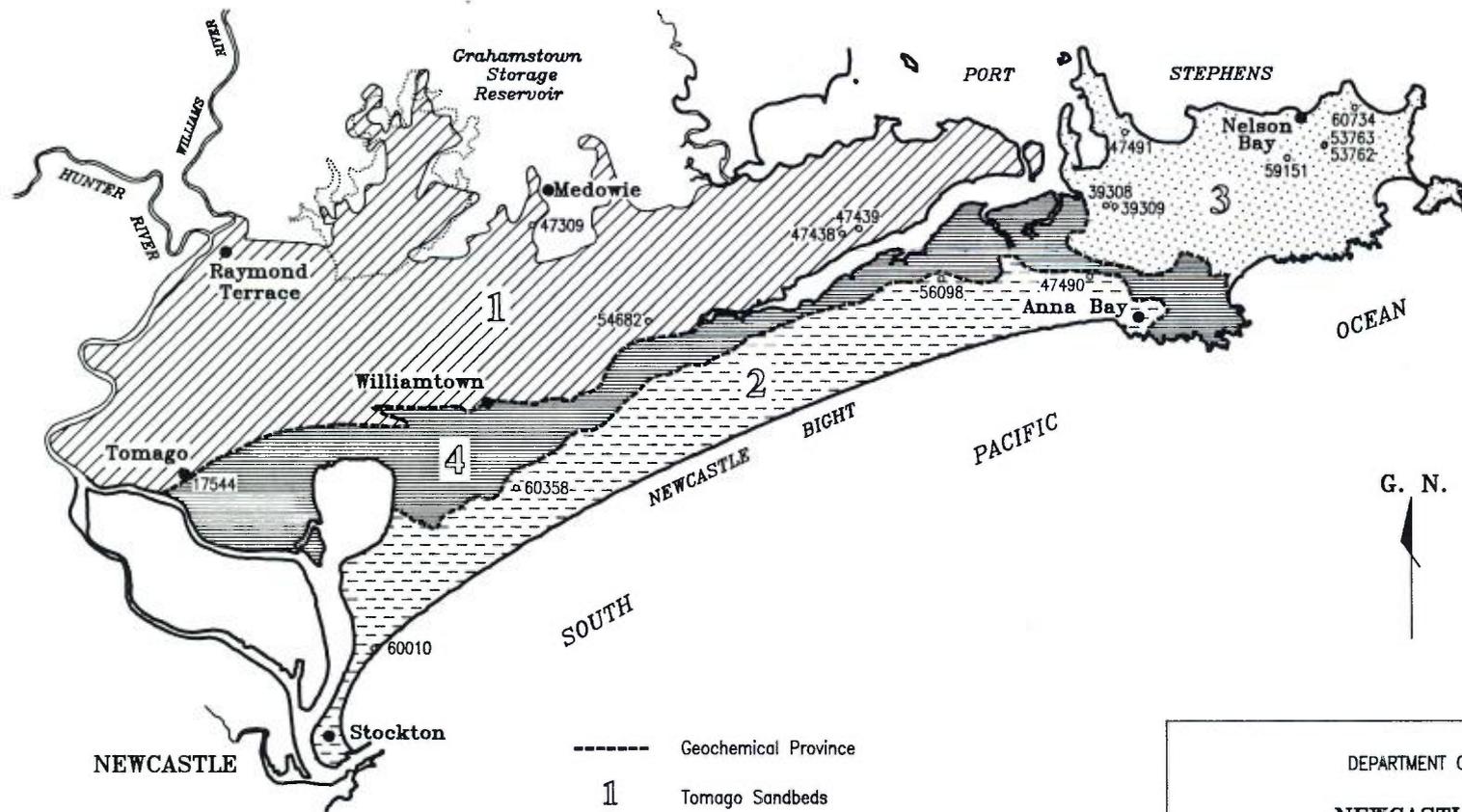
GROUNDWATER CHEMISTRY*, PROVINCE 2:
STOCKTON SANDBEDS



GROUNDWATER CHEMISTRY*, PROVINCE 3:
TOMAREE SANDBEDS

*Department of Water Resources, Oct. 1993

Figure 3.4 GROUNDWATER CHEMISTRY; PROVINCES 1-3 (Piper Diagram)



----- Geochemical Province

- 1 Tomago Sandbeds
- 2 Stockton Sandbeds
- 3 Tomaree Sandbeds
- 4 Fullerton Cove-Tilligerry Creek

◦ 60358 Registered bore with geochemical data held by Department of Water Resources, used for defining Groundwater Geochemical Provinces.

DEPARTMENT OF WATER RESOURCES
**NEWCASTLE BIGHT, NSW
 GROUNDWATER MANAGEMENT AREA**
**GROUNDWATER
 GEOCHEMICAL PROVINCES**

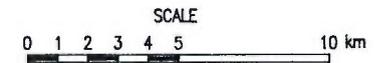
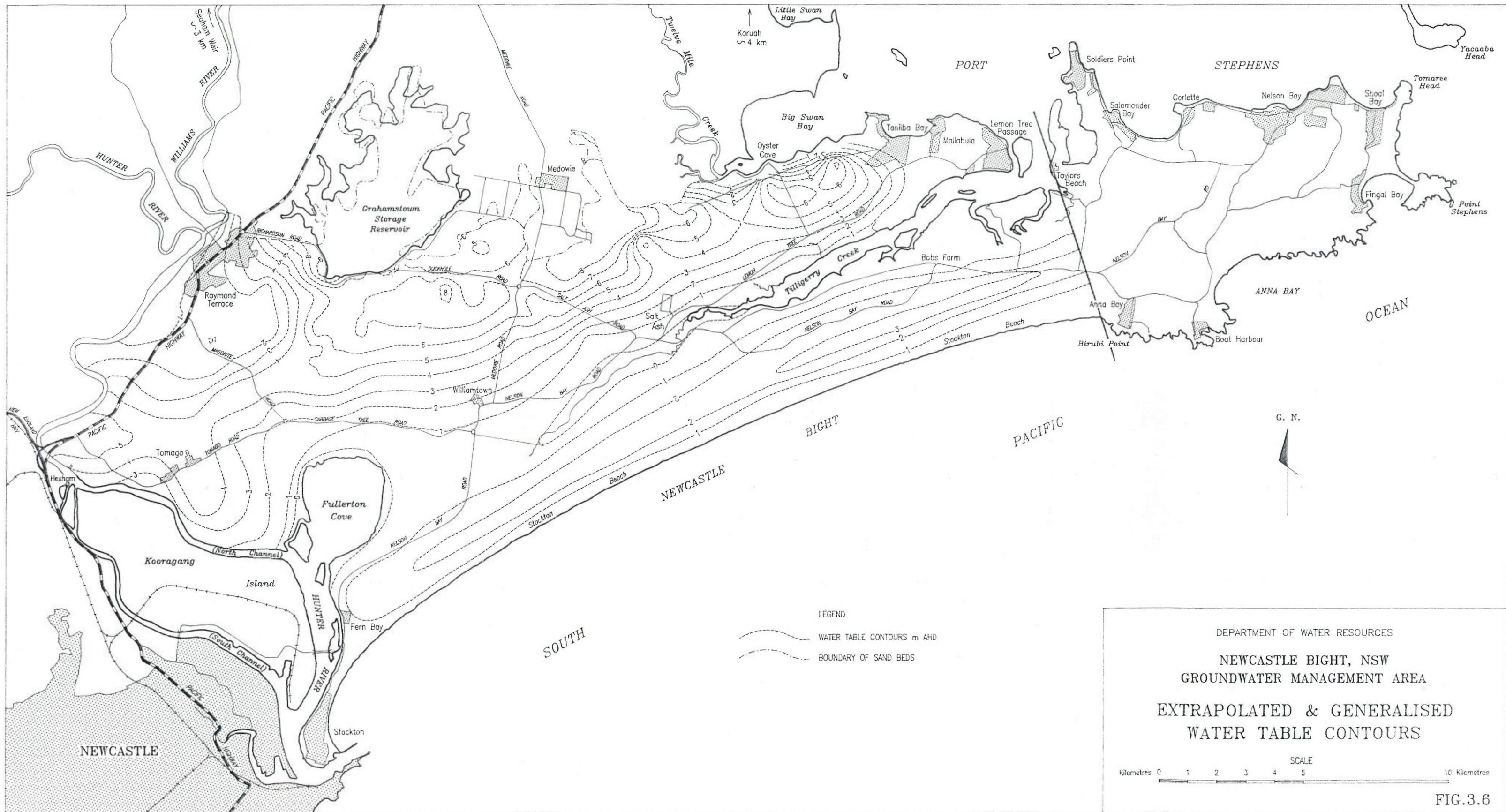


FIG.3.5

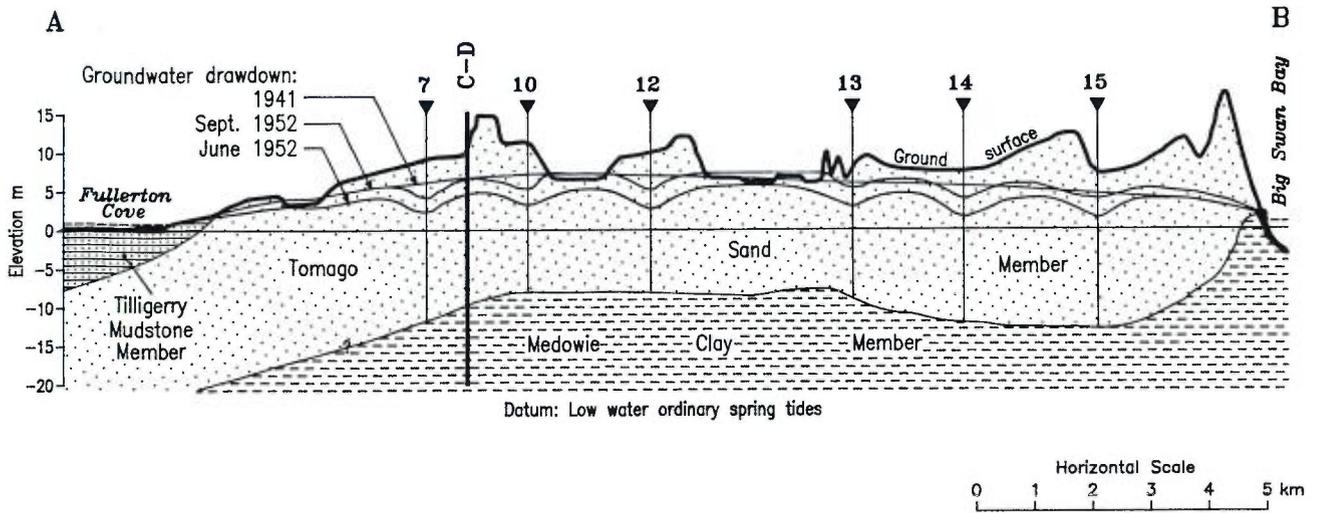


DEPARTMENT OF WATER RESOURCES
 NEWCASTLE BIGHT, NSW
 GROUNDWATER MANAGEMENT AREA
 EXTRAPOLATED & GENERALISED
 WATER TABLE CONTOURS

SCALE
 Kilometres 0 1 2 3 4 5 10 Kilometres

FIG.3.6

CROSS SECTION A-B



CROSS SECTION C-D

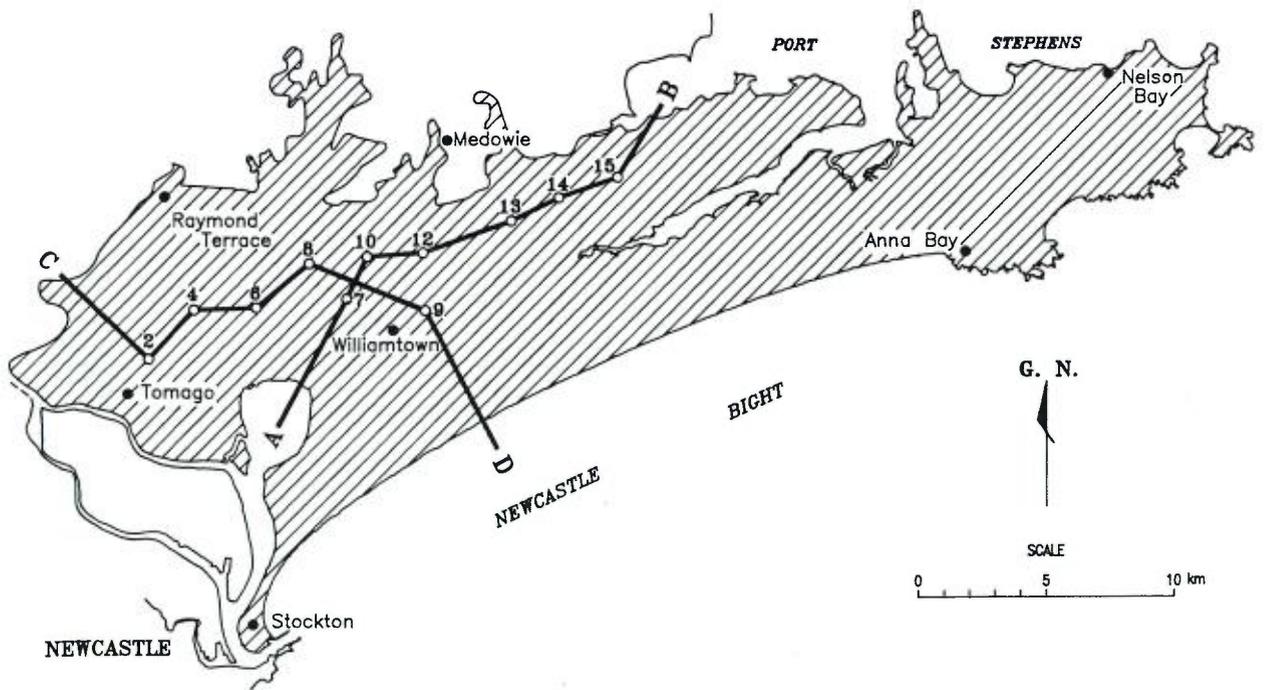
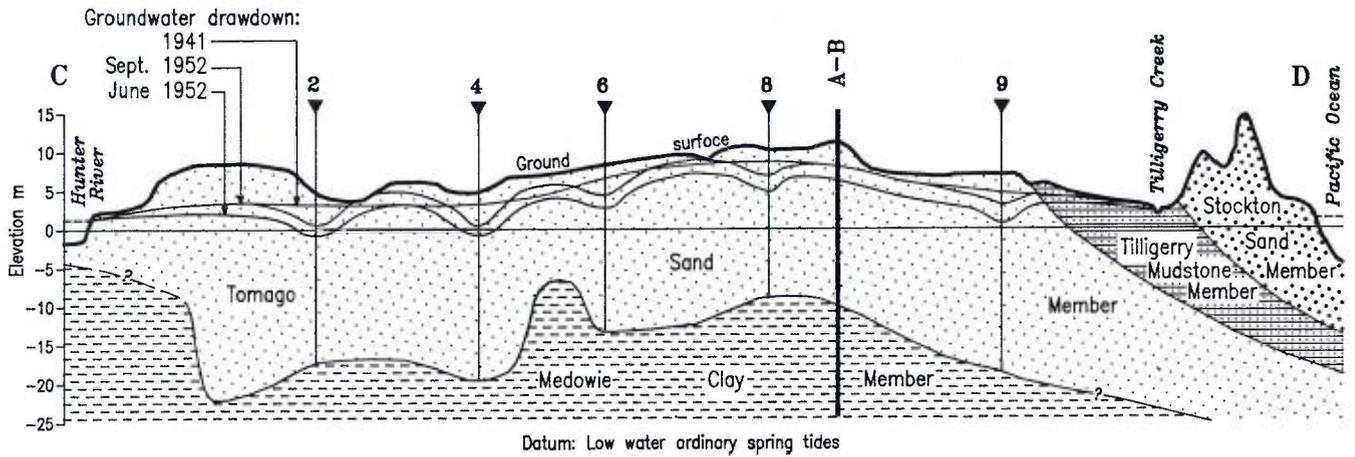


Figure 3.7: CROSS SECTIONS, NEWCASTLE FORMATION (limited data, after Hunter Water Corporation unpub.)

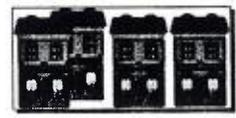
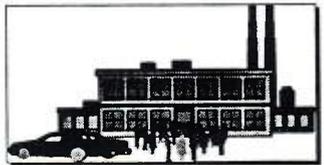
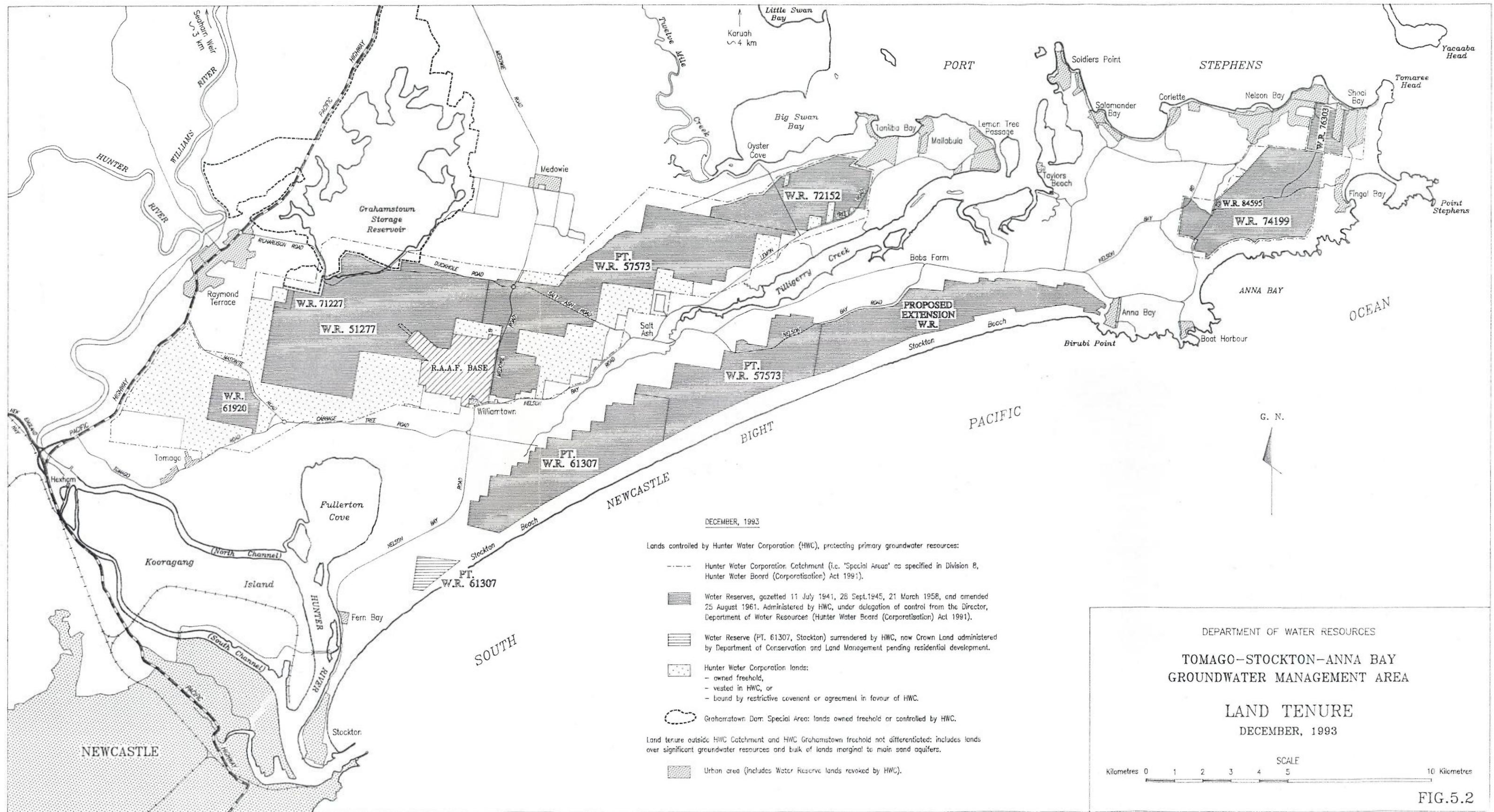
AGRICULTURE	INDUSTRIAL	MINING	DEFENCE	UTILITIES	URBAN	RECREATIONAL	RESERVE
Mixed farming	Aluminium smelting	Heavy-min. sands	RAAF Base	Water storage/extraction	Residential build-up;	Tourism	National Parks
Cattle grazing	Shipbuilding/repair	Industrial sands:	Air-weapons range	Water treatment plants	-city, towns, villages	Resort/hotel	Nature Reserves
Sheep grazing	Metal fabrication	-glass	Army camp	Water supply	Rural residential	Conservation	Water Reserves
Dairying	Speciality chemicals	-foundry	Parachute range	Effluent disposal	Recreational resident.	Sports	SEPP 14 Wetlands
Poultry, eggs	Electrical equipment	-construction	Exclusion zones	Septic disposal	Retirement	Golf clubs	Water Catchments
Piggeries	General processing	Dredging	Hazardous Land	Garbage disposal	Administration	Sightseeing	Botanical gardens
Horse studs	Timber processing	Rehabilitation	Noise Forecast Area	Power supply	Health	Camping	Crown Lands
Stockyards	Mineral processing	Aggregate		Fuel storage and supply	Education	Caravan parks	Aboriginal sites
Apiculture	Recycling yards	Coal (potential)		Road network; mixed	Commerce	4WD/buggies	National Trust
Viticulture	Rural industry			Road reserves	Saleyards	Bowling clubs	Floodplain
Aquaculture	Earthmoving			Airport	Warehouses	Motordrome	Scenic land
Oysters	Buffer zones			Marinas	Fuel sales	Walking	
Forestry				Sea ports		Beaches	
Horticulture				Transport terminals		Hunting	
Orchards				Communications		Scuba diving	
Plant nurseries				Hospitals		Gardens	
Vegetables				Drainage easements		Bird-watching	
Forage/hay						Racecourses	
Hobby Farms							
Non-arable/Steep land							

Figure 5.1 LAND-USE CATEGORIES, NEWCASTLE BIGHT

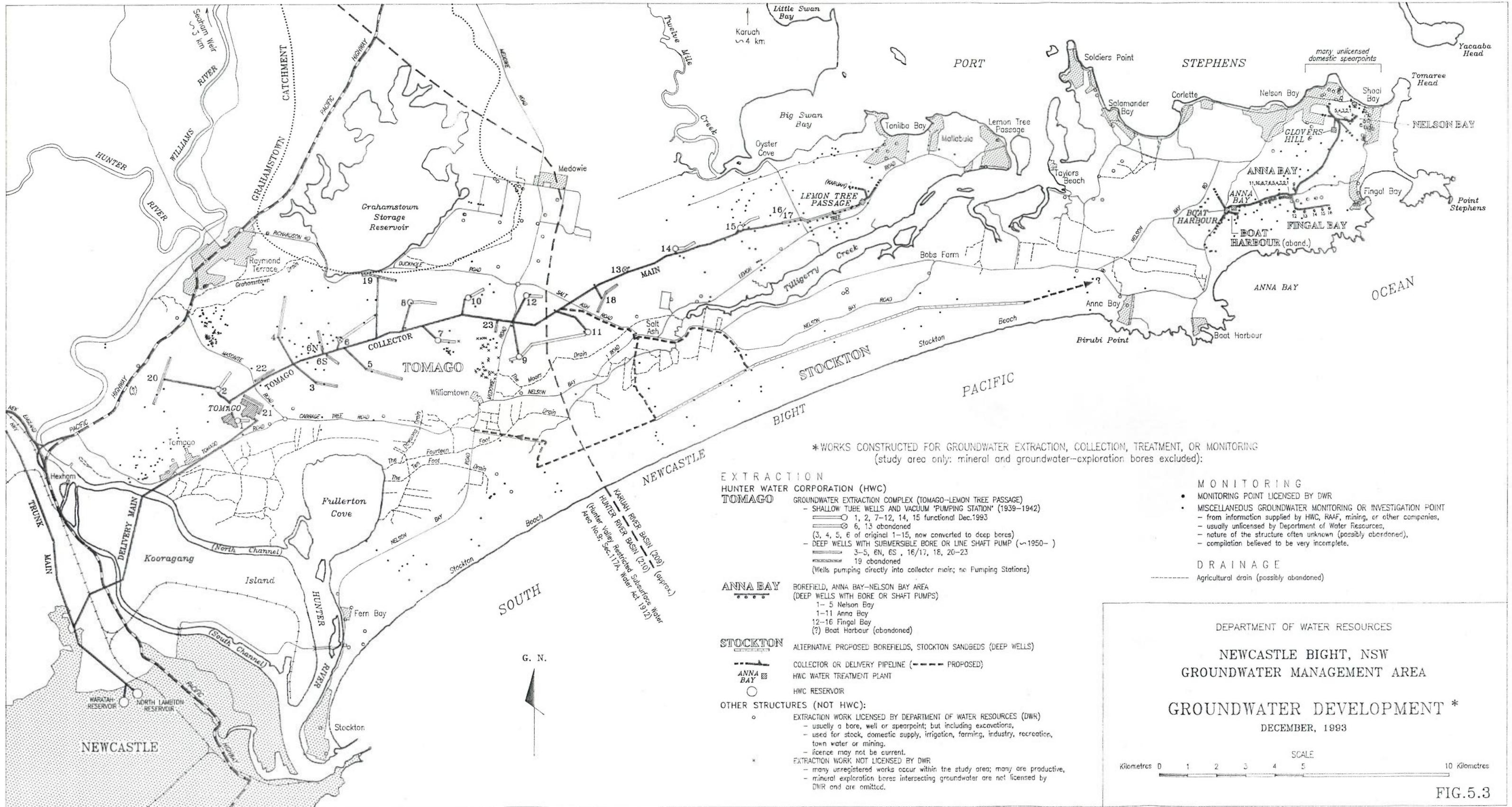


DEPARTMENT OF WATER RESOURCES
 TOMAGO-STOCKTON-ANNA BAY
 GROUNDWATER MANAGEMENT AREA

LAND TENURE
 DECEMBER, 1993



FIG.5.2



*WORKS CONSTRUCTED FOR GROUNDWATER EXTRACTION, COLLECTION, TREATMENT, OR MONITORING (study area only: mineral and groundwater-exploration bores excluded):

- EXTRACTION**
- HUNTER WATER CORPORATION (HWC)**
- TOMAGO**
- GROUNDWATER EXTRACTION COMPLEX (TOMAGO-LEMON TREE PASSAGE)
 - SHALLOW TUBE WELLS AND VACUUM 'PUMPING STATION' (1939-1942)
 - 1, 2, 7-12, 14, 15 functional Dec.1993
 - 6, 13 abandoned
 - (3, 4, 5, 6 of original 1-15, now converted to deep bores)
 - DEEP WELLS WITH SUBMERSIBLE BORE OR LINE SHAFT PUMP (~1950-)
 - 3-5, 6N, 6S, 16/17, 18, 20-23
 - 19 abandoned
 - (Wells pumping directly into collector main; no Pumping Stations)
- ANNA BAY**
- BOREFIELD, ANNA BAY-NELSON BAY AREA (DEEP WELLS WITH BORE OR SHAFT PUMPS)
 - 1- 5 Nelson Bay
 - 1-11 Anna Bay
 - 12-16 Fingal Bay
 - (?) Boat Harbour (abandoned)
- STOCKTON**
- ALTERNATIVE PROPOSED BOREFIELDS, STOCKTON SANDBEDS (DEEP WELLS)
- OTHER STRUCTURES (NOT HWC):**
- COLLECTOR OR DELIVERY PIPELINE (--- PROPOSED)
 - HWC WATER TREATMENT PLANT
 - HWC RESERVOIR
- OTHER STRUCTURES (NOT HWC):**
- EXTRACTION WORK LICENSED BY DEPARTMENT OF WATER RESOURCES (DWR)
 - usually a bore, well or spearpoint; but including excavations,
 - used for stock, domestic supply, irrigation, farming, industry, recreation, town water or mining.
 - licence may not be current.
 - * EXTRACTION WORK NOT LICENSED BY DWR
 - many unregistered works occur within the study area; many are productive,
 - mineral exploration bores intersecting groundwater are not licensed by DWR and are omitted.

- MONITORING**
- MONITORING POINT LICENSED BY DWR
 - MISCELLANEOUS GROUNDWATER MONITORING OR INVESTIGATION POINT
 - from information supplied by HWC, RAAF, mining, or other companies,
 - usually unlicensed by Department of Water Resources,
 - nature of the structure often unknown (possibly abandoned),
 - compilation believed to be very incomplete.

DRAINAGE

--- Agricultural drain (possibly abandoned)

DEPARTMENT OF WATER RESOURCES

NEWCASTLE BIGHT, NSW

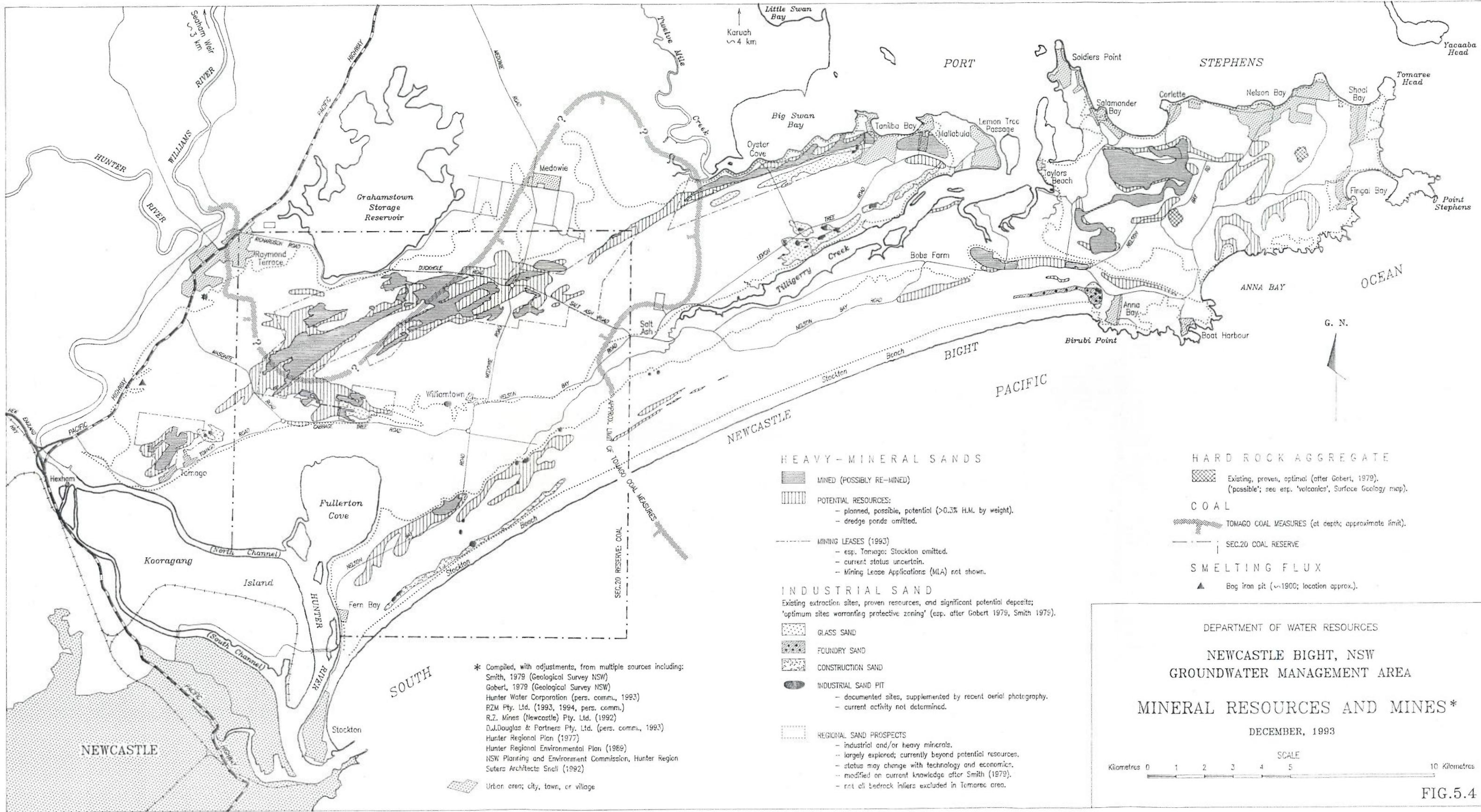
GROUNDWATER MANAGEMENT AREA

GROUNDWATER DEVELOPMENT *

DECEMBER, 1993



FIG.5.3



* Compiled, with adjustments, from multiple sources including:
 Smith, 1979 (Geological Survey NSW)
 Gober, 1979 (Geological Survey NSW)
 Hunter Water Corporation (pers. comm., 1993)
 RZM Pty. Ltd. (1993, 1994, pers. comm.)
 R.Z. Mines (Newcastle) Pty. Ltd. (1992)
 D.J. Douglas & Partners Pty. Ltd. (pers. comm., 1993)
 Hunter Regional Plan (1977)
 Hunter Regional Environmental Plan (1989)
 NSW Planning and Environment Commission, Hunter Region
 Suters Architects Snell (1992)

Urban area; city, town, or village

- HEAVY-MINERAL SANDS**
- MINED (POSSIBLY RE-MINED)
 - POTENTIAL RESOURCES:
 - planned, possible, potential (>0.3% H.M. by weight).
 - dredge ponds omitted.
 - MINING LEASES (1993)
 - esp. Tomago; Stockton omitted.
 - current status uncertain.
 - Mining Lease Applications (MLA) not shown.
- INDUSTRIAL SAND**
 Existing extraction sites, proven resources, and significant potential deposits; 'optimum sites warranting protective zoning' (esp. after Gober 1979, Smith 1979).
- GLASS SAND
 - FOUNDRY SAND
 - CONSTRUCTION SAND
 - INDUSTRIAL SAND PIT
 - documented sites, supplemented by recent aerial photography.
 - current activity not determined.
 - REGIONAL SAND PROSPECTS
 - industrial and/or heavy minerals.
 - largely explored; currently beyond potential resources.
 - status may change with technology and economics.
 - modified on current knowledge after Smith (1979).
 - not all bedrock inliers excluded in Tomaree area.

- HARD ROCK AGGREGATE**
- Existing, proven, optimal (after Gober, 1979). ('possible'; see esp. 'volcanics', Surface Geology map).
- COAL**
- TOMAGO COAL MEASURES (at depth; approximate limit).
 - SEC.20 COAL RESERVE
- SMELTING FLUX**
- Bag iron pit (~1900; location approx.).

DEPARTMENT OF WATER RESOURCES

**NEWCASTLE BIGHT, NSW
GROUNDWATER MANAGEMENT AREA**

MINERAL RESOURCES AND MINES*

DECEMBER, 1993

SCALE

Kilometres 0 1 2 3 4 5 10 Kilometres

FIG.5.4

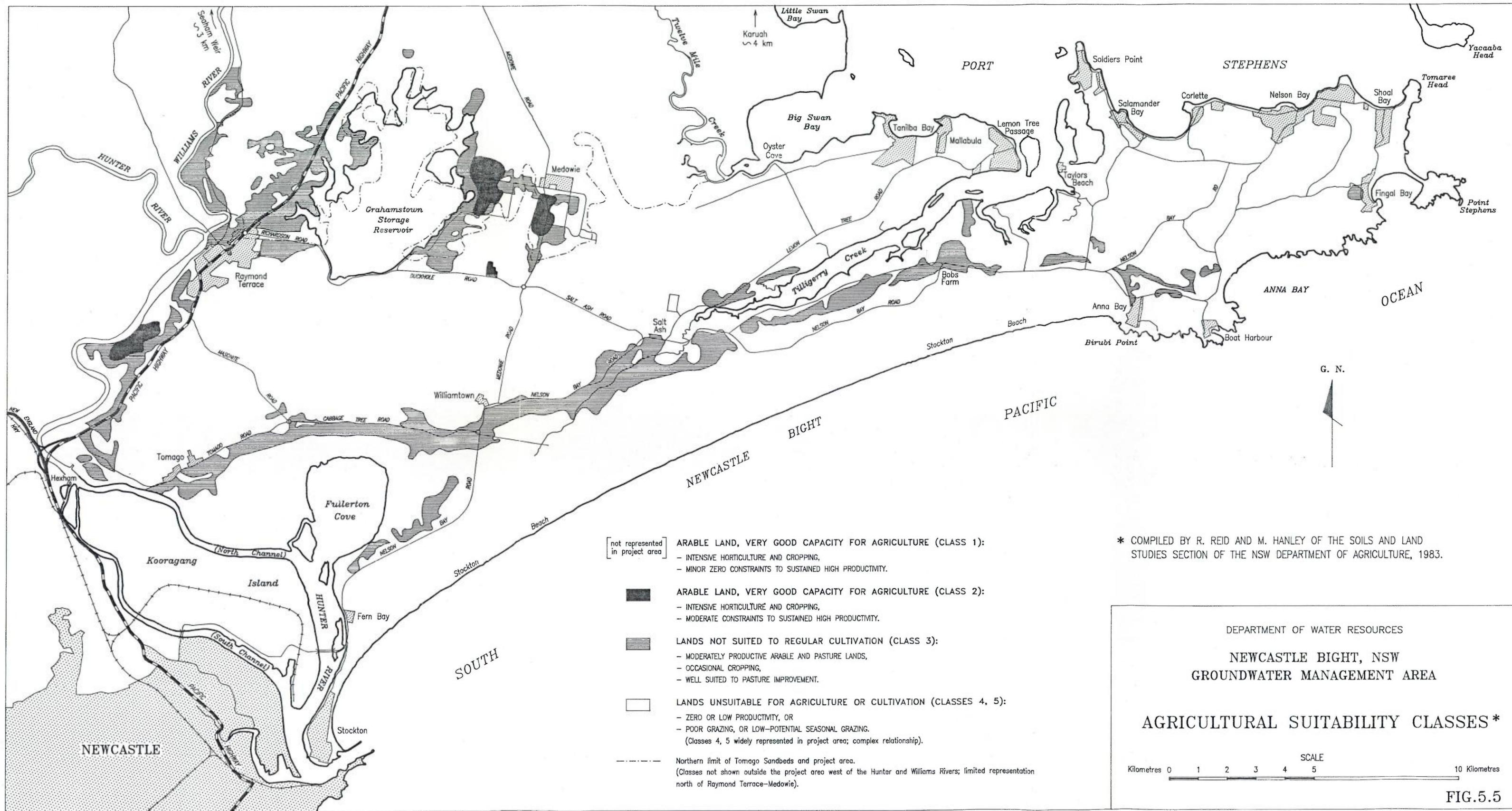
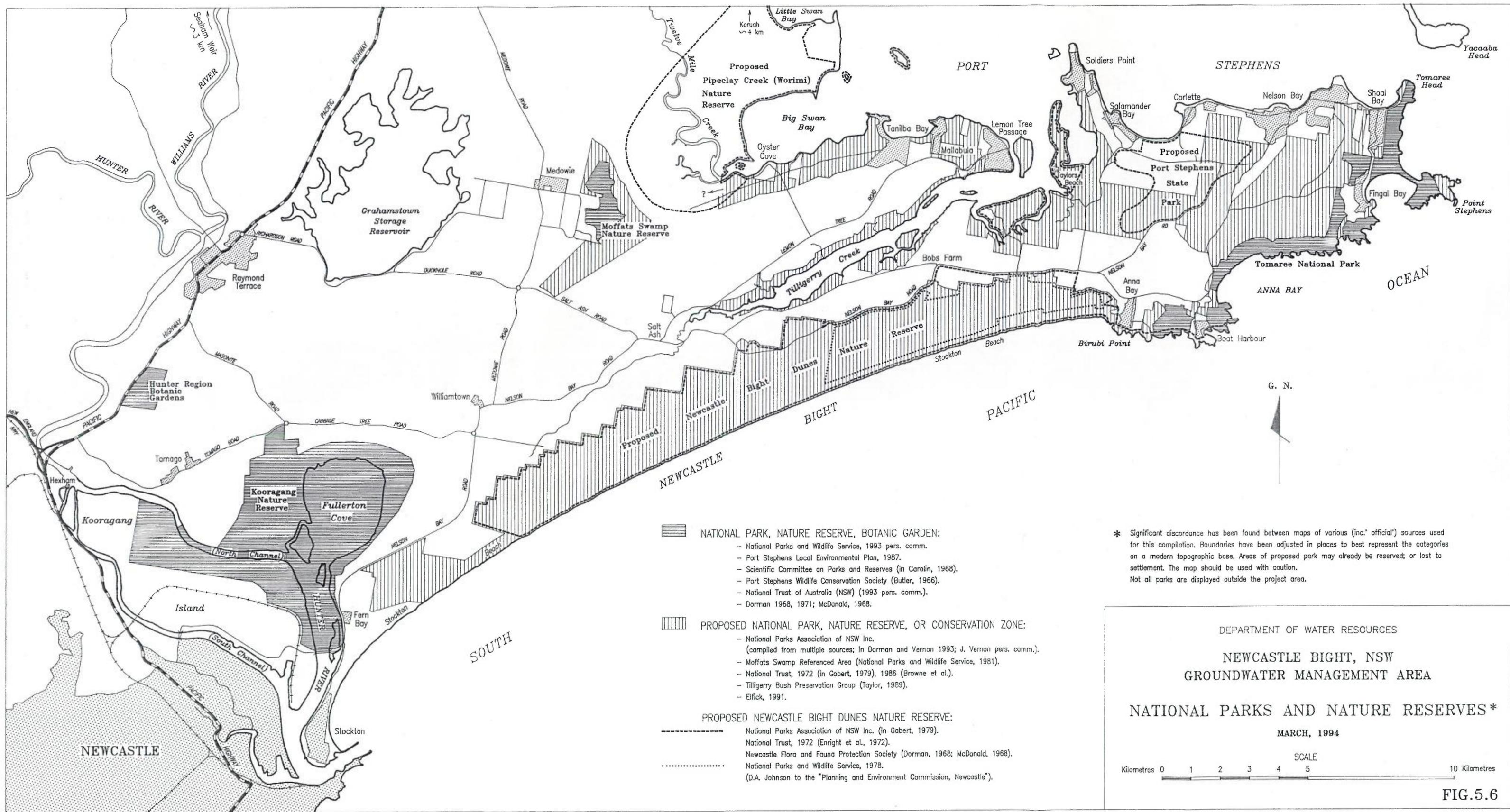


FIG. 5.5



 NATIONAL PARK, NATURE RESERVE, BOTANIC GARDEN:
 - National Parks and Wildlife Service, 1993 pers. comm.
 - Port Stephens Local Environmental Plan, 1987.
 - Scientific Committee on Parks and Reserves (in Carolin, 1968).
 - Port Stephens Wildlife Conservation Society (Butler, 1966).
 - National Trust of Australia (NSW) (1993 pers. comm.).
 - Dorman 1968, 1971; McDonald, 1968.

 PROPOSED NATIONAL PARK, NATURE RESERVE, OR CONSERVATION ZONE:
 - National Parks Association of NSW Inc. (compiled from multiple sources; in Darman and Vernon 1993; J. Vernon pers. comm.).
 - Moffats Swamp Referenced Area (National Parks and Wildlife Service, 1981).
 - National Trust, 1972 (in Gobert, 1979), 1986 (Browne et al.).
 - Tilligerry Bush Preservation Group (Taylor, 1989).
 - Elfick, 1991.

 PROPOSED NEWCASTLE BIGHT DUNES NATURE RESERVE:
 - National Parks Association of NSW Inc. (in Gobert, 1979).
 - National Trust, 1972 (Enright et al., 1972).
 - Newcastle Flora and Fauna Protection Society (Dorman, 1968; McDonald, 1968).
 National Parks and Wildlife Service, 1978. (D.A. Johnson to the "Planning and Environment Commission, Newcastle").

* Significant discordance has been found between maps of various (inc. official) sources used for this compilation. Boundaries have been adjusted in places to best represent the categories on a modern topographic base. Areas of proposed park may already be reserved; or lost to settlement. The map should be used with caution.
 Not all parks are displayed outside the project area.

DEPARTMENT OF WATER RESOURCES
NEWCASTLE BIGHT, NSW
 GROUNDWATER MANAGEMENT AREA
NATIONAL PARKS AND NATURE RESERVES*
 MARCH, 1994

SCALE

Kilometres 0 1 2 3 4 5 10 Kilometres

FIG.5.6

Figure 6.1 Groundwater Pumpage, Hunter Water Corporation (and predecessors)

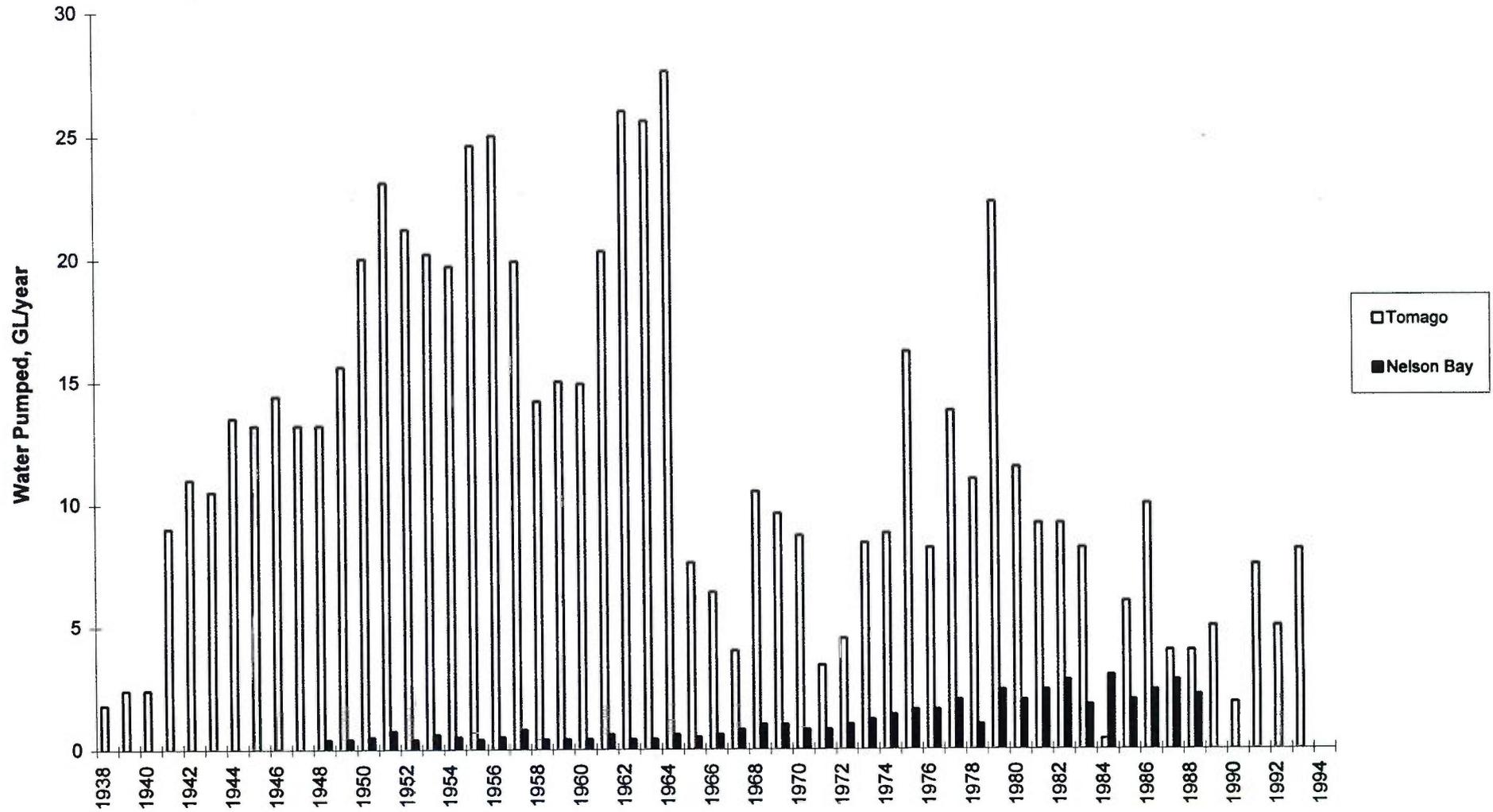
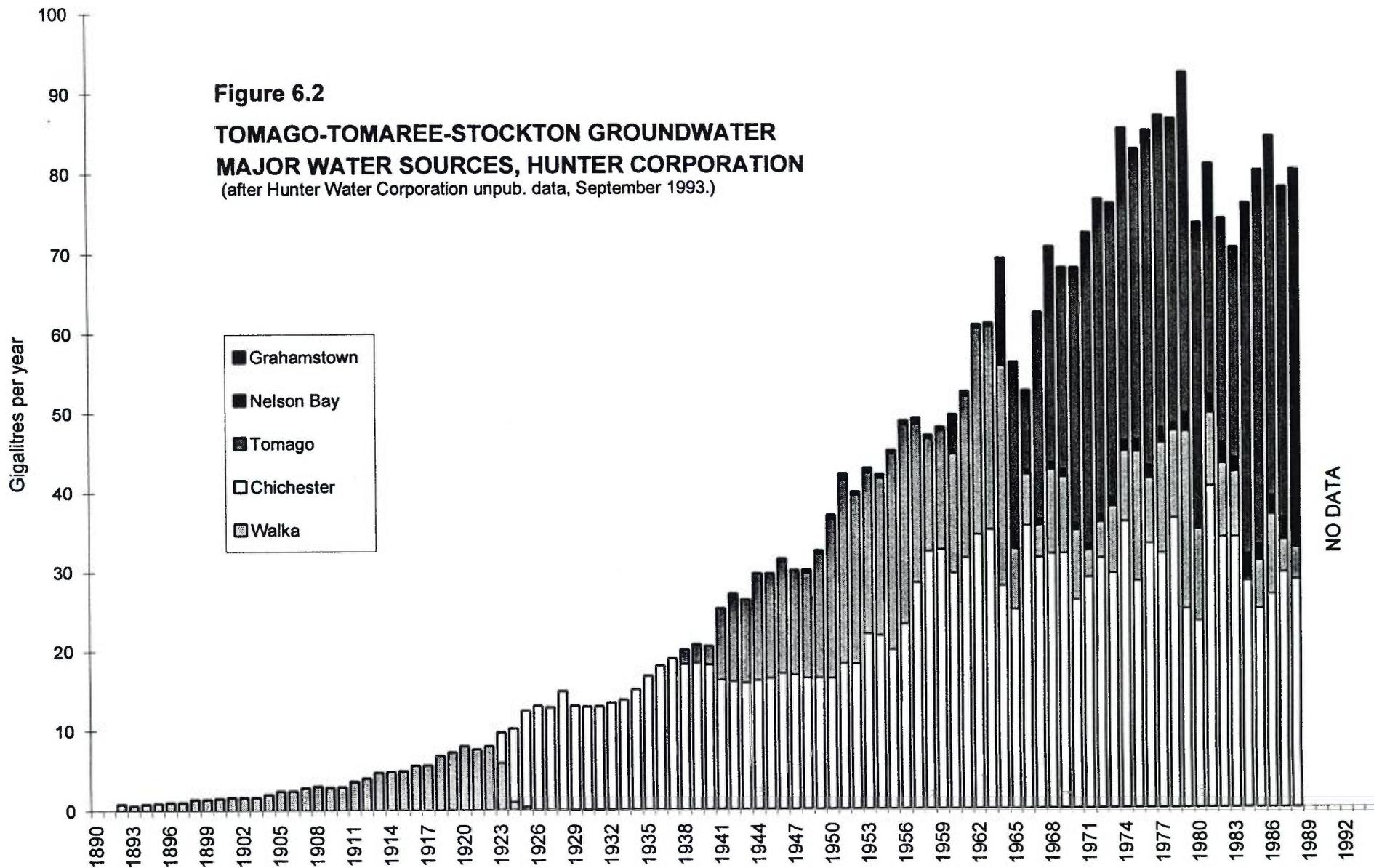
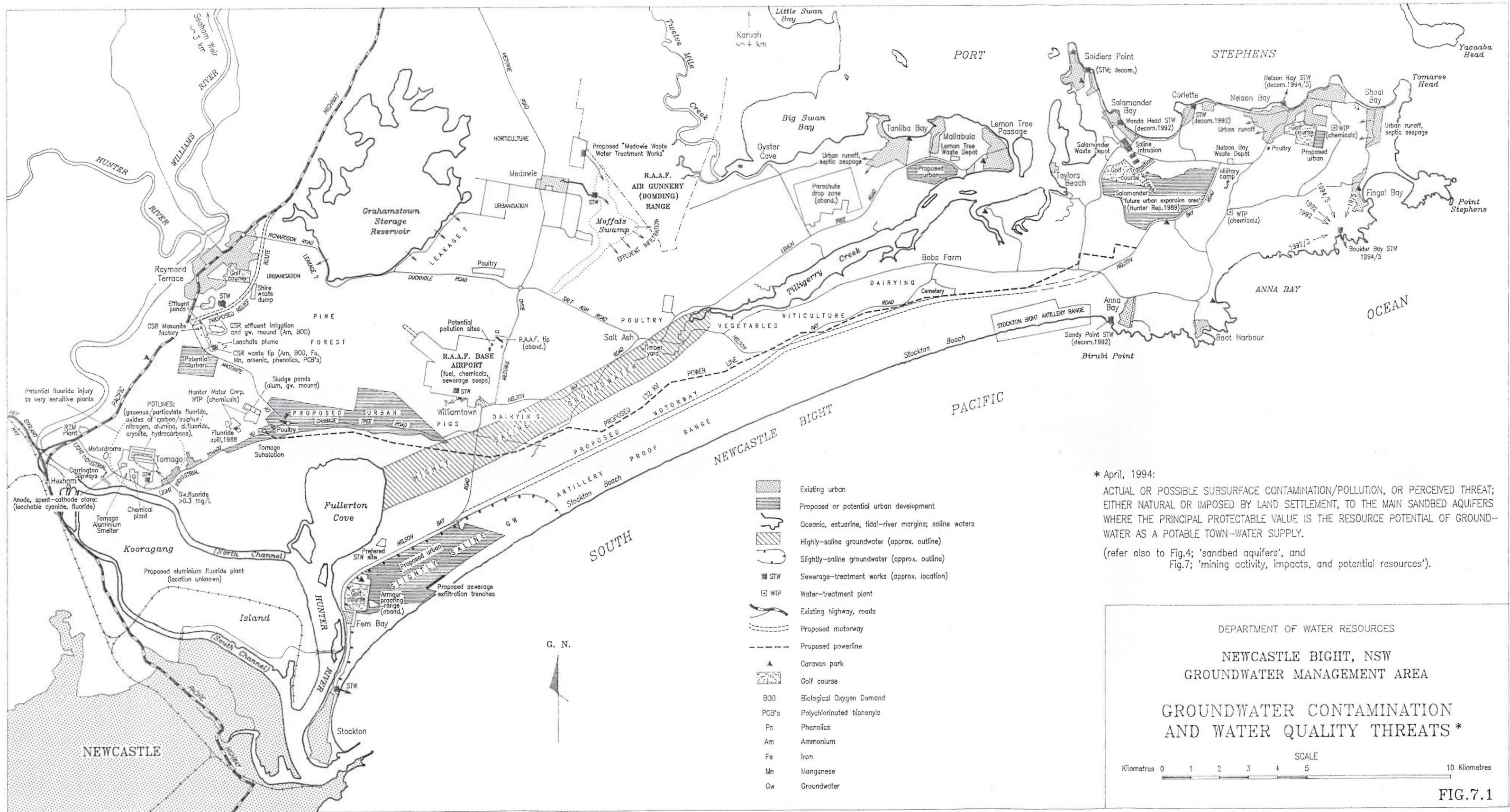


Figure 6.2

**TOMAGO-TOMAREE-STOCKTON GROUNDWATER
MAJOR WATER SOURCES, HUNTER CORPORATION**
(after Hunter Water Corporation unpub. data, September 1993.)



NO DATA



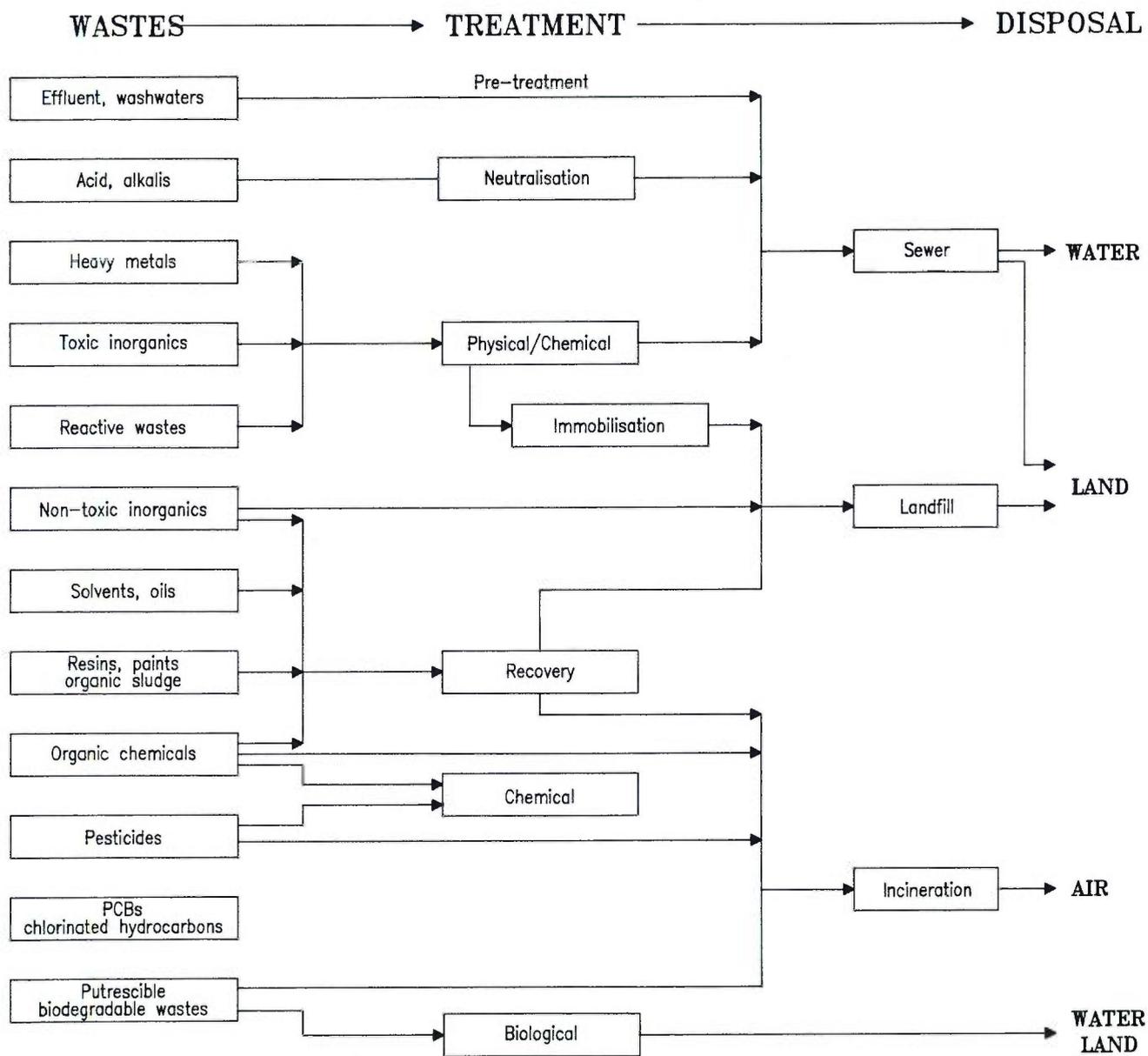
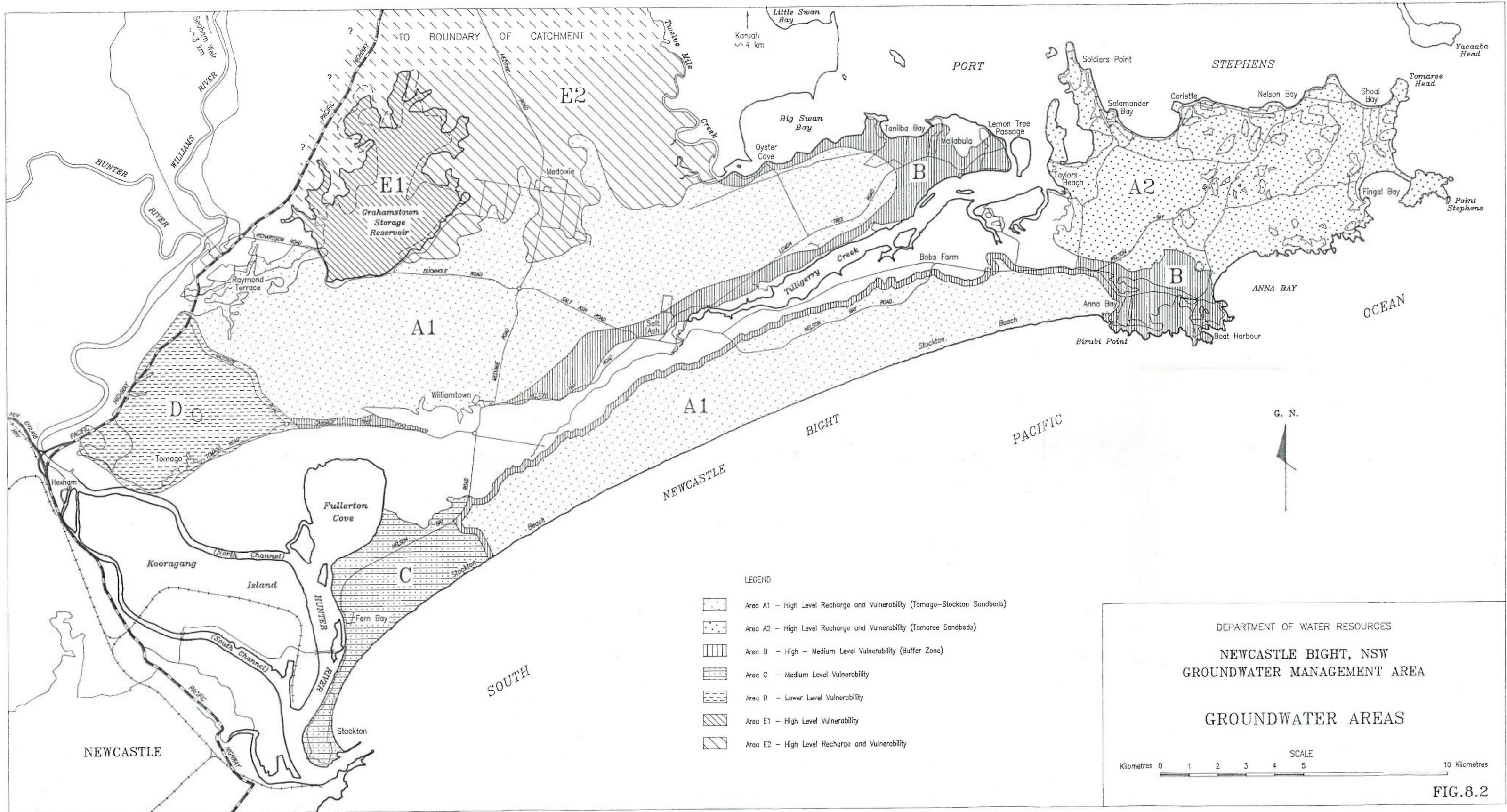


FIGURE 8.1 SUMMARY OF INDUSTRIAL WATER TREATMENT AND DISPOSAL METHODS (after EPA 1986)



DEPARTMENT OF WATER RESOURCES
 NEWCASTLE BIGHT, NSW
 GROUNDWATER MANAGEMENT AREA
 GROUNDWATER AREAS

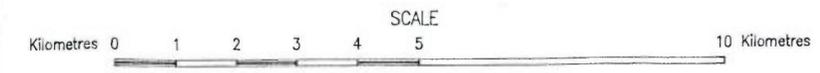


FIG.8.2

APPENDIX 1

SUMMARY OF COMMUNITY SUBMISSIONS

Collation and analysis of responses by the community to
'call for submissions'

February, 1994

In response to the Department's call to the community for submissions regarding the groundwater in the Tomago/Tomaree/Stockton area (in October/November, 1993), submissions were received from:

MR SID BARKER

BORAL RESOURCES (NSW) PTY LTD.

ROSALIE CAMPBELL

CSR WOOD PANELS (CSR LIMITED)

DEPARTMENT OF MINERAL RESOURCES

DEPARTMENT OF PLANNING

MR PHILIP DIEMAR

ECONETWORK PORT STEPHENS

ROY AND ANN GREEN

MRS B. HAZELL

MRS E.A. HULL

HUNTER RIVER BOTANIC GARDENS

HUNTER REGION FOUR WHEEL DRIVE COUNCIL

HUNTER WATER CORPORATION LIMITED

MR ANTON MAAS

MARSH ROAD PROGRESS ASSOCIATION INC.

NATIONAL PARKS ASSOCIATION OF NSW INC.

NATIONAL PARKS AND WILDLIFE SERVICE

NEWCASTLE AIRPORT

NSW AGRICULTURE

NSW FISHERIES

PUBLIC WORKS DEPARTMENT

ROADS AND TRAFFIC AUTHORITY

RZM PTY LTD.

SHORTLAND ELECTRICITY

STATE FORESTS OF NEW SOUTH WALES

TOMAGO ALUMINIUM CO PTY LTD.

BILL AND DESLEY TORNING

L.M. TRUEBRIDGE

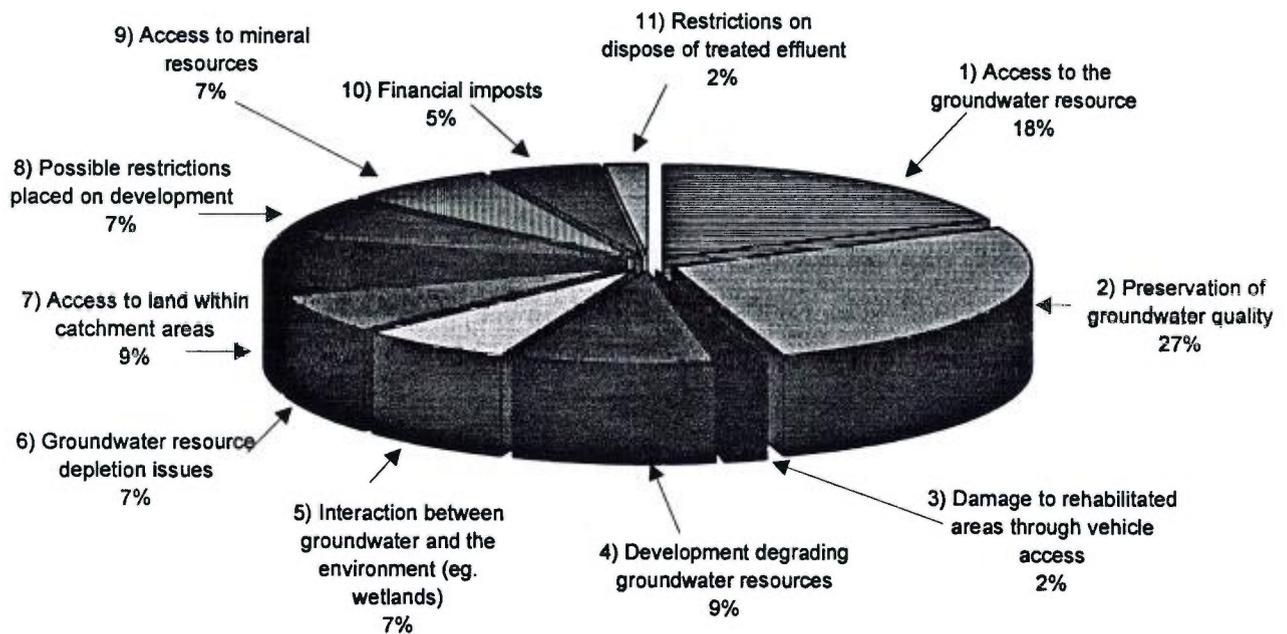
VAN WYK & SON FLOWER SUPPLY PTY LTD.

WALLAROO CONSERVATION GROUP

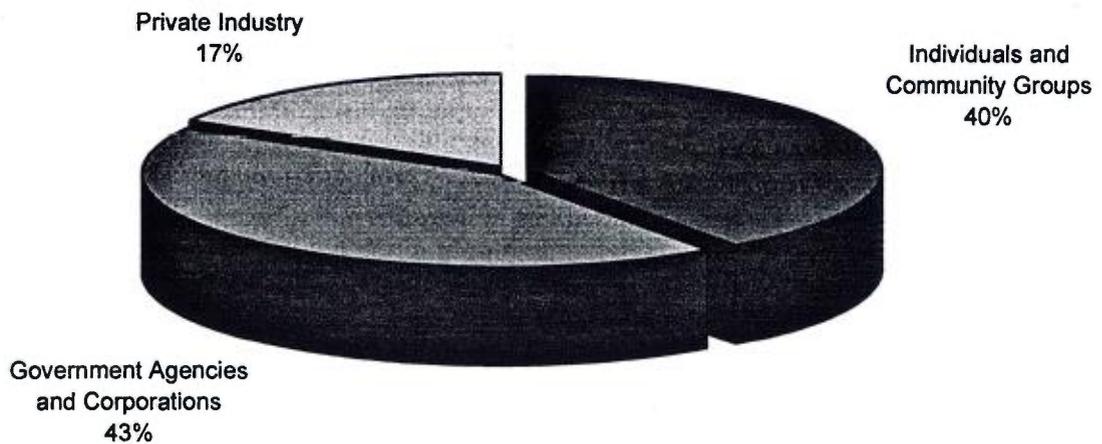
The issues raised in the submissions cover:

- the impact of sand mining on the aquifers
- water charges and costs associated with treating effluent and waste water
- use of groundwater for domestic purposes
- protection of wetland areas
- the impact of drainage structures on groundwater
- the use of groundwater for irrigation
- contamination of groundwater by leakage from septic tanks and sewerage systems
- the impact of dune disposal of sewage
- controlled access for four wheel drive vehicles to water reserves and the possible impacts of four wheel drive vehicles
- safe yields from the aquifers
- the possibility of poor quality landfill containing the groundwater
- the use of spearpoints
- the need to expand conservation areas
- the impact of urbanisation
- the impact of waste from industry.

TOMAGO/TOMAREE/STOCKTON GROUNDWATER - WRITTEN SUBMISSIONS RECEIVED IN RESPONSE TO PROPOSAL TO DEVELOP MANAGEMENT PLAN



Main Concerns Highlighted in Submissions Received



Origin of Submissions Received

APPENDIX 2

**ATTRIBUTES AND USES
OF AQUIFERS SYSTEMS**

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ATTRIBUTES AND USES OF AQUIFER SYSTEMS

Aquifer systems throughout the world are used intentionally and unintentionally in a number of ways. The main uses have been as a storage and distribution system for water, and as a receptor for solid and liquid wastes. Less commonly, aquifer systems have been used as: natural treatment media for the renovation of wastewater; sources or sinks for thermal energy; as a source of building material and industrial minerals; and for the storage of gas and fluids other than water. The attributes of an aquifer system which enable these uses, and the limits and impacts of those uses, are summarised in Table A2.1, and discussed in more detail in the following paragraphs.

1. ATTRIBUTES OF AN AQUIFER SYSTEM

An aquifer is a body of earth material which has the capacity to store and transmit water. There are degrees of such capacity, and the term aquitard has been applied to aquifers which have a very low capacity to transmit water. A third term, 'aquiclude', has been used to describe a body of earth material which has zero capacity to transmit water. Aquifers can be bounded above, below, or laterally by an aquitard or an aquiclude. The terms are subjective, however, and the same rock might be regarded as an aquitard under some circumstances (for example if very large quantities of groundwater are being sought) but as an aquifer if the requirement is for very small supplies. It is best not to use them in any specific way, and the term 'aquifer system' is used here to describe an aquifer which has variations of storage and transmitting capacity within it, and which is bounded by geological formations with a markedly different character and which have a notably lower capacity to store and transmit water.

1.1 Storage and transmission of water in aquifers

Note that the term 'aquifer', as defined, does not include the water which it might contain. That is, an aquifer may be empty of water and still referred to as an aquifer.

Some aquifers are overlain, or capped, and effectively separated from the land surface by another formation which has little or no capacity to transmit water. If an aquifer in this situation is full, ie. it is saturated right up to the contact with the overlying formation, it is said to be 'confined'. It can only store more water if the water pressure is sufficient to expand the actual rock fabric of the aquifer. This is, in fact, a very common occurrence, and when a bore (tubewell) penetrates such an aquifer the water level in the tubewell will rise above the top of the aquifer formation. In the special case where the water level rises to the land surface, there is a natural, or artesian, flow. When water is withdrawn from this type of aquifer, the aquifer stays saturated but the water pressure is reduced and the fabric of the aquifer contracts.

If there is no overlying formation bounding the aquifer, and the aquifer formation is continuous to ground level, water will fill the aquifer up from the bottom until all the water available is stored. The top surface of the saturated material is called the watertable, and the aquifer is said to be 'unconfined'.

TABLE A2.1: Attributes of Aquifers that Facilitate Potential Uses

Potential use		Necessary physical attributes
Water source function	Water supply	Spatially extensive; high aquifer transmissivity and storativity; impermeable surface cover; shallow water depth; high recharge from pristine areas; appropriate quality water.
	Water storage and distribution	High hydraulic conductivity and storativity; available and unused storage capacity; Unconfined aquifers, including the intake areas of confined aquifers, can be recharged using surface spreading techniques or via recharge bores.
Waste disposal, mining and attenuation function	'Dilute and disperse' disposal sites	High hydraulic conductivity, heterogeneous aquifer material; large storage for dilution; high dispersivity; steep hydraulic gradient; isolated from surface waters; thick unsaturated zone is advantageous; poor groundwater quality is desirable.
	'Release and confine' disposal sites	Low hydraulic conductivity; homogeneous aquifer material with high attenuation capacities; low hydraulic gradient; relatively deep water table; isolated from surface waters; poor groundwater quality is desirable.
	'Concentrated and contain' disposal sites*	Theoretically these can be engineered in any near surface geological formation. However, it is desirable that sites have physical characteristics as for the 'Release and confine' disposal sites above.
	Wastewater renovation	Unconfined porous media aquifer with thick unsaturated zone and adequate attenuating capacity with other characteristics for 'Water storage and distribution' above.
Energy source and storage functions	Heat source	High groundwater temperature; high aquifer transmissivity and storativity.
	Heat sink	Low groundwater temperature; high aquifer transmissivity and storativity.
	Hydraulic energy source	High pressure differentials; for most purpose it is necessary for the potentiometric surface to be above the ground surface.
	Gas and fluid storage	Confined aquifer with structural or stratigraphic trap, low groundwater flow velocities preferable.

The capacity to transmit water is called the hydraulic conductivity (loosely equivalent to permeability). If the hydraulic conductivity is high, then the aquifer will transmit water at a high rate. The **rate** at which water will be transmitted depends on the hydraulic gradient, which is essentially the difference in water pressure at the two points between which the flow rate is being measured. In an unconfined aquifer, the gradient of the watertable can be used. Watertable contours can be prepared by plotting the water level measured in a network of observation bores. For a confined aquifer, the same procedure is used, but the surface joining all the measured water levels is a pressure surface (above the top of the aquifer). This surface is called the potentiometric surface.

The capacity to store water is called the storativity. In an unconfined aquifer the storativity is approximately equivalent to the porosity (the percentage of the aquifer volume which is pore space). The precise value is the volume of water which would drain under the influence of gravity from a cubic meter of aquifer, expressed as a percentage or fraction (of one cubic metre). The value is commonly between 0.05 and 0.25 (5% and 25%). In a confined aquifer the storativity is related to the elastic contraction of the aquifer fabric as the water is removed, and values are commonly in the range 10^{-3} to 10^{-5} .

Water does not usually just enter an aquifer and stay in one place. It will enter the aquifer in some locations, and leave it at other places. The time between entering the aquifer (a process called recharge) and leaving it (discharge) may be as little as a few days or as long as millions of years. The difference depends on the nature of the aquifer, the climate, and the topography which determines the relative position of recharge and discharge areas.

Discharge occurs where the watertable intersects the land surface, or in places where the potentiometric surface is above the land surface **and** there is an upwards pathway through the confining layer (eg by faults or locally less impermeable zones). Thus by definition, groundwater discharge occurs at positions with a low elevation. Springs are perhaps the most well known type of natural groundwater discharge. Many wetlands are supported by groundwater discharge, and the base flow of many rivers is also maintained by groundwater flow in them. This enables rivers to keep flowing for a long while after rainfall has ceased.

Recharge of unconfined aquifers occurs under natural conditions, by direct infiltration of rainfall and local run-off or, where stream beds cross the outcrop area, by infiltration from the stream. Recharge of confined aquifers can only occur by lateral flow from areas where the aquifer is unconfined and able to accept infiltrating water. Thus any area where there is an unconfined aquifer at the land surface, and which is not a groundwater discharge area, can be a recharge area.

Under natural conditions aquifers are usually in a state of dynamic equilibrium, and the volume of water recharging the aquifer and the volume discharged are approximately equal.

The amount of water that recharges an unconfined aquifer is determined by three factors:

- the amount of precipitation left over after evapotranspiration and runoff;
- the vertical hydraulic conductivity of the near-surface unsaturated portion of the aquifer system in the recharge area of the aquifer; this determines the rate at which water is capable of moving downward to the aquifer; and

- the transmissivity of the aquifer and hydraulic gradient of the watertable, which together determine the rate at which water can move away from the recharge area.

The direction of groundwater flow is as one would expect, ie. generally from areas with high elevation to areas with low elevation. The main control is the location and elevation of the discharge areas. The precision with which the direction of flow can be assessed depends on how precisely the shape of the watertable (or potentiometric surface) is known, which in turn depends on how many observation bores there are available for measuring the water level.

The volume of water stored in an unconfined aquifer can be estimated by determining the volume between the aquifer base and the watertable, and applying the storativity factor. Clearly, the volume will change as the watertable changes because of fluctuating water levels. Water level fluctuations are a normal part of any groundwater system, and under natural conditions will respond mainly to recharge conditions. During wetter times, the recharge rate will increase, water levels will rise, there will be a consequential increase in the hydraulic gradient (slope of the watertable) and therefore an increase in the rate of movement of water through the aquifer. The result of this will be an increase in the rate of groundwater discharge.

If recharge and discharge areas are close, there will be a rapid response in the discharge rate. If they are well separated, there can be a substantial delay in the impact on discharge. The extreme values are days at one end, and thousands of years at the other. In both cases, however, the water levels near the discharge zone will show a very small change, while the water levels in the recharge zone will show a larger fluctuation. If the recharge and discharge areas are sufficiently far apart, the temporary period of higher water levels results in a period of increased volume of water in storage.

Another important aspect of the aquifer system is the relationship between recharge rate and total storage. If the total storage is very large compared to the recharge rate, then the stored volume will not be significantly changed by short term variations in recharge conditions. If the recharge rate is of the same order of magnitude as the storage, then changes to recharge conditions will have a major impact on the volume of water stored in the aquifer.

If water levels in the recharge area are shallow, that is very close to or at, the land surface, water which otherwise have entered the aquifer as recharge will not be able to do so and will instead become part of the surface water run-off. This is known as rejected recharge.

Water level trends indicate what is happening in the aquifer. A steady trend indicates equilibrium conditions during the period of measurement, while a falling trend will indicate that discharge is exceeding recharge and a rising trend will indicate an excess of recharge. Such trends must be viewed in the context of long term seasonal or climatic cycles in order to appreciate their full significance.

An aquifer was defined above as 'a body of earth material' with certain characteristics, but the discussion to date has been mainly about the capacity to store and transmit water. Water is stored and transmitted through a matrix, or fabric, of earth materials and it is the composition and texture of this fabric which give an aquifer its characteristics. This aspect of the attributes of an aquifer are discussed in the following section.

1.2 Aquifer materials

The minerals from which geological formations are composed are not, in themselves, permeable, and it is only by the way in which they are arranged together in the rock matrix that an aquifer has this characteristic. There are three main types of formation into which aquifers can be grouped, but as with any attempt to classify natural phenomena the divisions are not perfect and there are overlaps between them.

Most aquifers are composed of crystalline rocks (granite, basalt, gneiss, for example) formed of an interlocking network of mineral grains, and are essentially impermeable. They only exhibit porosity and permeability if they have been subjected to stresses, during or after their formation, which have resulted in a network of fractures through them (sometimes referred to as secondary porosity and permeability). If these fractures are sufficiently interconnected, the rock mass will be able to transmit water, and the capacity to do so will depend on the extent, intensity and openness of the fracture network. It is rare, but not unknown, for such rocks to yield large quantities of water, but they are useful aquifers as a source of stock water supplies. In many cases, they are regarded as the 'impermeable' basement to more productive aquifer systems.

Sedimentary rocks, as their name implies, are formed by the deposition of sand and silt, mud and sometimes gravel, in rivers, lakes, or the ocean, followed by burial at great depth and subsequent elevation by earth movements. Some sedimentary rocks (mainly some sandstones and limestones) retain some of the intergranular porosity of the initial deposit, although often much reduced as a result of the rock-forming processes. In these cases, the capacity to store and transmit water can be very high, especially if they also have some secondary permeability because of fracturing. Limestones are a special case in which the actual fabric of the rock can be dissolved to form large openings in the rock mass. Some sedimentary rocks (mudstone, for example) do not have primary permeability and will only be an aquifer if earth processes following their formation have imparted a degree of secondary permeability.

The third group of important aquifer materials is the young, unconsolidated deposits of sand, silt, clay and gravel. These have no intrinsic difference to similar deposits which have been converted to sedimentary rocks, but they have not yet been subject to the rock forming process and are generally characterised by lack of strength. Some of these materials have a high degree of porosity and permeability, particularly the coarser river sands and gravels, and the very even grained clean quartz sands of the coastal dune deposits.

The fabric of an aquifer, that is, the shape of the hard bits and the way they are arranged, determines the size, shape, and degree of interconnection of the pore spaces in which the water is stored and moves. It is the framework for the space in which the water is held, so its shape and character are important. These factors are, however, secondary in the sense that the **values** of hydraulic conductivity and storativity are the essence, and the characteristics of the aquifer fabric which lead to those values do not matter. This is correct in terms of the aquifer fabric as a mechanical support for the water-holding space, but there is another aspect to the aquifer fabric. The earth materials which form the aquifer are minerals, that is they are chemical compounds which are subject to chemical and physical interaction with water (or any other fluid which might be contained in the pore spaces). This aspect can have a major impact on the quality of water in an aquifer.

Some of the processes can have an impact on the permeability and porosity of the aquifer. In the case of a limestone for example, the porosity can be dramatically increased by solution, but the opposite effect might occur, leading to deterioration of an aquifer, in other cases.

An understanding of the physical and mineralogical character of the aquifer matrix is therefore an essential part of any comprehensive analysis of an aquifer system.

1.3 Water quality

The final aspect of aquifer attributes which should be discussed here is the quality of the groundwater in it. The quality of groundwater is determined by physical and chemical processes which act on it from the moment it is condensed in the atmosphere to the time it is finally discharged from the sub-surface flow system.

The main factors influencing the chemistry of groundwater are summarised in Figure A2.1. The flow diagram is presented as a model for hydrochemical interpretation. It shows that the chemical composition of natural groundwater is influenced by:

- the chemistry of water recharging the groundwater system (cyclic salts present in rainfall);
- the uptake of oxygen and the release of carbon dioxide as water percolates through the soil;
- chemical reactions between the water, soil and rocks aided by carbonic acid, liberating bicarbonate which may be added to the water;
- addition of other soluble compounds from the soil and other chemical and physiochemical reactions between water and rock in the aquifer.

Reactions in the groundwater environment include dissolution of minerals in the aquifer, ion exchange between water and minerals (mainly clays), reduction of sulphate in solution by biological agents in aerobic environment, fixation of nitrogen compounds and concentration of chemicals by evaporation and/or filtration through sediments acting as semi-permeable membranes.

The inclusion of contaminants can also affect the hydrochemical cycle. The main mechanisms by which groundwater can be contaminated are by leaching and/or filtration of contaminants from landfills and other sources, such as septic tank effluent, liquid waste disposal, use of fertilisers and pesticides, etc. A number of attenuation processes also operate, both in the unsaturated zone and in the saturated zone. Contaminants are not all attenuated to the same degree and the aquifer system has a finite capacity to assimilate them.

The geochemical cycle also includes the return of water to the atmosphere by evaporation and/or transpiration, leaving mineral matter behind, or the return of water to the oceans directly or as stream flow, carrying mineral matter with it.

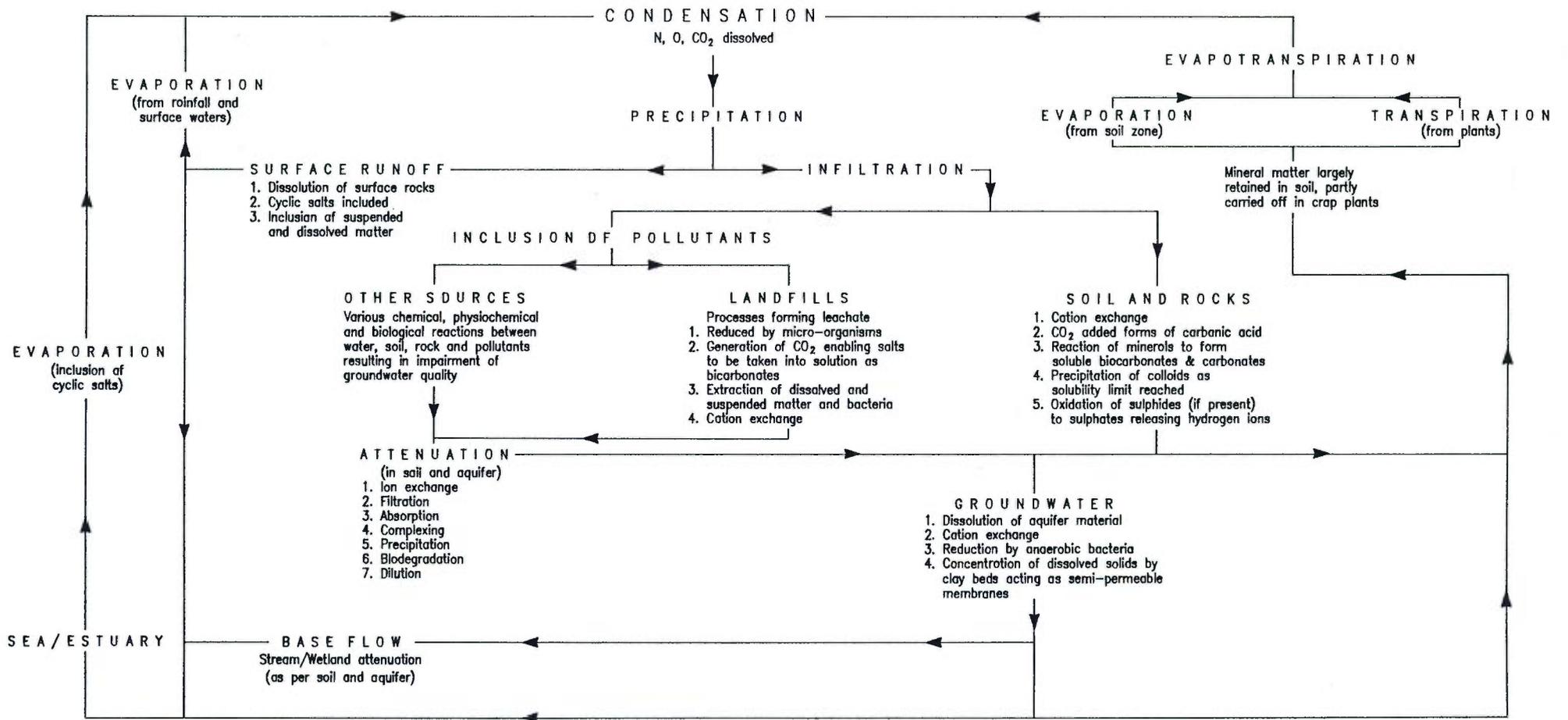


Figure A2.1: Postulated hydrochemical model for the Newcastle Bight Area

2. POTENTIAL USES OF AN AQUIFER

As outlined above, an aquifer has many attributes which may cause it to be useful in terms of human needs. Some of the potential uses are mutually exclusive, and choices must be made. Sometimes these choices are made in ignorance, or unintentionally. Better outcomes are likely if they are made intentionally and with understanding of the natural systems involved.

Potential uses of groundwater are summarised in Table A2.2.

Table A2.2: Possible uses of groundwater

Use	Aspect
Domestic	Drinking water, including mineral water Washing and bathing Toilet flushing Garden watering
Agricultural	Irrigation Stock watering Equipment washing
Industrial	Heat transfer Steam generation Processing Washing, dust suppression
Municipal	Watering of parks, gardens, sports grounds Cleaning
General	Emergency drought supplies Fire fighting

2.1 The aquifer as a water source

A major use of many aquifers is the maintenance of existing ecosystems; that is, the maintenance of groundwater discharge to rivers, wetlands, springs, and the sea. These uses should be considered in terms of the impact on them by the consumptive uses described in table A2.2.

2.1.1 Aquifer yield

The capacity of an aquifer system to provide a water supply is limited by its physical characteristics and by decisions made by its managers/users on what limits to place on the impacts of the pumpage.

When groundwater is pumped from an aquifer, the water is withdrawn from storage around the pumping bore. As the influence of the pumping (referred to as the cone of depression) grows, an increasing part of the aquifer will contribute water from storage. The amount of groundwater discharging naturally from the aquifer will remain at the pre-development rate until the pumping cone reaches the recharge or discharge area. If the cone of depression reaches a discharge area, the hydraulic gradient towards that discharge area becomes flatter. The rate of groundwater discharge will be reduced because of this.

If the pumping cone reaches the recharge area of an aquifer, it may increase the rate of recharge by inducing infiltration of water which was previously rejected. It is even possible for a section of the aquifer to change from a discharge area to a recharge area. For example, drawdown near a wetland may eliminate groundwater discharge to the wetland and induce infiltration from the wetland into the aquifer, reversing the direction of flow.

If pumping continues after either of these limits has been reached, the cone of depression will expand until groundwater discharge has been reduced, or until recharge has been increased, sufficiently to balance the volume of water removed by pumping. When this occurs a new condition of dynamic equilibrium is reached. At this stage the yield is regarded as sustainable and current groundwater allocation policies in New South Wales aim to not exceed such a yield. If the sum of the remaining discharge and the pumping withdrawals exceed the available recharge, the cone of depression will not stabilise. It will not be able to expand, so the aquifer system will adjust itself by increasing the depth of the cone of depression. In simple terms, water levels will continue to fall.

If the transmissivity of the aquifer is too small to allow it to conduct water to the pumping bores at the pumping rate, the water level in and around the pumped bores will decline whether or not the aquifer as a whole is adequately recharged.

Groundwater can be mined in much the same manner as other earth resources. This happens when groundwater is withdrawn at a rate greater than the rate at which it is being replenished, over a prolonged period. Groundwater mining can provide water for a finite time period, and can be useful for limited life projects. For example, metalliferous mines in areas where other water supplies are limited, and which can use poorer quality water for processing, can sometimes only proceed if supported by a groundwater mining venture. It should be understood when contemplating such a scheme that these ventures tap fossil groundwater which might never be replaced.

If the storage/recharge rate ratio is high, it is possible to allow controlled depletion of the store of groundwater, followed by recovery of water levels. Water is pumped from the aquifer at a rate which exceeds the recharge rate over shorter periods, but the procedure is sustainable over a long time frame, such as several decades. The groundwater reservoir would be operated over a range of water levels so that aquifer space is created for storage of water on a cyclic basis.

The feasibility of this approach depends on the availability of aquifer space to store recharge water, on sufficient water being in storage when pumping is needed, and on the availability of water to recharge the aquifer when required. The concept of cyclic storage is not applicable when the rate of recharge is limited by the capacity of the aquifer to transport and store groundwater rather than by the amount of water available for recharge.

The amount of water available from a region can be optimised by using groundwater and surface water conjunctively in a planned and coordinated manner to meet water requirements. The main advantage of conjunctive use schemes is that the overall system yield can be substantially increased. Surface water can be used to supply most of the annual water requirements, and groundwater is retained primarily for use in years of low rainfall. Such usage depletes groundwater storage when available natural recharge is lowest. The drawdown

in the water level creates storage space in the aquifer and replenishment is expected by natural recharge in years of more plentiful rainfall.

Artificial recharge is one further matter which requires mention in any discussion of aquifer yield. It is a procedure whereby water is brought from some external source to a recharge area and then introduced into the aquifer (usually via infiltration ponds or bays). It is feasible where there is a need to balance pumpage with additional recharge, where the geometry of the aquifer is suitable and there are places where infiltration from land surface to watertable can take place without obstruction, and where there is a suitable external source for the water. Such sources might be surplus flows in a river or stream for example, stormwater run-off, or reclaimed wastewater. In the latter cases, a degree of water purification should occur prior to infiltration through suitable design and operation of infiltration ponds. Artificial recharge is extensively used in Europe, Scandinavia and the USA as a water management tool. In some cases it is used purely for the purpose of water quality improvement, but there is usually a water conservation purpose as well.

2.1.2 Bore yields

Bore yield, ie the rate at which water can be pumped from a bore, depends on the hydraulic characteristics of an aquifer. They also depend on the way the bore is constructed, and in the case of a bore field, on the layout of the bores. There are numerous styles of bore construction, and they are not universally suitable in any one context. The efficiency of a bore will not have any impact on the aquifer, but will influence pumping costs. In an inefficient bore the pumping water level in the bore will be deeper than it would be for an efficient bore, at the same pumping rate. Consequently, the pumping costs will be higher. Outside the bore, the water levels in the aquifer will depend only on the rate of withdrawal and are not affected by the efficiency or otherwise of the bore.

Attention to bore design is an important part of groundwater management, and should be given due emphasis where appropriate.

2.1.3 Water quality

Generally speaking, because groundwater has travelled through a rock mass under natural conditions it contains no suspended material. The following comments apply mainly to those aspects of water quality which relate to dissolved material. The quality depends both on that material, and on the properties which the dissolved materials impart to the water.

Three main areas of groundwater use, and their associated quality requirements, are referenced, but it is stressed that although there are prescribed standards in some cases they are not necessarily applicable to each.

2.1.3.1 Domestic Water Supply

Drinking, cooking, washing, toilet flushing, and gardening are the main domestic water uses. Tables A2.3 and A2.4 provides a guide to quality limits.

Table A2.3: Criteria for human consumption

Substance	Maximum allowable concentration (mg/L)	
	1	2
Total soluble salts	1500	1000-1500
Iron	1	0.3
Manganese	0.1	0.1
Copper	1.5	1
Zinc	15	5
Arsenic	0.05	0.05
Lead	0.05	0.05
Calcium	200	-
Sulphate	400	400
Magnesium	150	-
Chloride	600	400
Magnesium and sodium sulphates	1000	-
Nitrate	45	10 (as N)
Fluoride	1.5	0.5-1.7
Cyanide	0.2	0.1
pH	6.0-9.2	6.5-8.5

* 1. World Health Organisation International Standard, 1984.

* 2. National health and Medical Research Council and Australian Water Resources Council, 1987. Guidelines for Drinking Water Quality in Australia (Australian Government Publishing Service: Canberra).

*(In Berkman, 1989)

There is no evidence of deleterious effects occurring in humans consuming water that exceeds 1000 mg/L total soluble salts. The guideline is based on taste considerations; above 1500 mg/L, taste generally renders water unacceptable for human consumption. Most urban consumers would reject drinking water with total salts above approximately 500 mg/L.

The suitability of water for human consumption is a specific function of the Health Department of NSW. Advice on such matters should be sought in the first instance by reference to the local government health officer.

2.1.3.2 Irrigation Water Supply

Water quality standards for irrigation use are based on the total salinity of the water and on the concentration of specific ions such as sodium, chloride, and boron which may be toxic to plants or have unfavourable effects on crops. The relative proportions of some of the constituents are also important. For example, a high ratio of sodium to the total concentration of calcium and magnesium can cause deflocculation of clay in the soil leading to damage to soil structure and decline in infiltration rates.

**Table A2.4: Water Quality Criteria for Major Uses
(modified after Leonard, 1992)**

Water Use												
Parameter	Drinking		Washing	Irrigation and garden watering (continuous)	Stock watering	Steam generation	Cooling (single cycle)		Processing			
	Desirable	Long term					Textile Industry	Pulp & paper	Chemical Industry	Petroleum Industry		
Total dissolved solids (mg/L)	1500	500	500 (200 with treatment)	See Table A2.5	See Table A2.7	35000	1000	35000	150	1080	2500	3500
Chloride (mg/L)	600	200	-	See Table A2.5	1000	1900	600	22000	-	200	500	1600
Bicarbonate (mg/L)	-	-	-	-	-	600	600	180	-	-	600	480
Sulphate (mg/L)	480	200	-	-	1000	1400	680	2700	-	-	850	900
Nitrate & nitrite as N (Mg/L)	200	200	-	-	1000 (700 cattle)	-	500	1200	-	-	250	220
Magnesium (mg/L)	150	50	-	-	250 (400 cattle)	-	-	-	-	-	100	85
Sodium (mg/L)	770		-	-	2000	-	-	-	-	-	-	-
Iron, total (mg/L)	1.0	0.1	1	1.0	-	80	14	1	0.3	2.6	10	15
Silicate (mg/L)	-	-	-	-	-	-	-	-	-	-	-	-
Hardness (as CaCO ₃)	600	100	Use softeners	-	-	5000	850	7000	120	475	1000	900
pH	6.5-9.2	-	-	4.5-9.0	-	-	5.0 to 8.9	5.0 to 8.4	6.0 to 8.0	4.6 to 9.4	5.5 to 9.0	6.0 to 9.0
Sodium absorption ratio	NA	NA	NA	See Table A2.6	NA	NA	NA	NA	NA	NA	NA	NA

Source: NH and MRC (1980) recommendations are given for drinking water quality for all parameters except sodium which is from Hart (1974):

Salinity Tolerance

The suitability of water for irrigation depends partly on salinity but also on a variety of other factors such as the type of crop, the leaching fraction applied, the frequency and method of application, climate, and soil type. Five classes can be described, and their suitability for use on various plants is given in Table A2.5.

**Table A2.5: Salinity Classes for Irrigation
(data after Hart, 1974)**

Class	Comment	Electrical conductivity ($\mu\text{S/cm}$)	TDS (mg/L)
1	Low-salinity water can be used with most crops, most soils, and with all methods of water application with little likelihood that a salinity problem will develop. Some leaching is required, but this occurs under normal irrigation practices, except in soils of extremely low permeability.	0-280	0-175
2	Medium-salinity water can be used if moderate leaching occurs. Plants with medium salt tolerance can be grown, usually without special measures for salinity control. Sprinkler irrigation with the more-saline waters in this group may cause leaf scorch on salt-sensitive crops, especially at high temperature in the daytime and with low application rates.	280-800	175-500
3	High-salinity water cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required, and the salt tolerance of the plants to be irrigated must be considered.	800-2,300	500-1,500
4	Very high-salinity water is not suitable for irrigation water under ordinary conditions. For use, soils must be permeable, drainage adequate, water must be applied in excess to provide considerable leaching, and salt-tolerant crops should be selected.	2,300-5,500	1,500-3,500
5	Extremely high-salinity water may be used only on permeable, well-drained soils under good management, especially in relation to leaching and for salt-tolerant crops, or for occasional emergency use.	>5,500	>3,500

Sodium Hazard

If sodium exceeds the total of calcium and magnesium the water may be a hazard to healthy crop growth due to excessive uptake of sodium by the plant or the restriction of uptake of calcium and magnesium.

Irrigation water, even when relatively low in total soluble salts, may be detrimental to the maintenance of good soil structure, due to a poor balance between sodium and calcium and magnesium. It may be necessary to apply soil dressing of the deficient elements. The maximum tolerable Sodium Absorption Ratio (SAR) for various crops under normal soil conditions are provided in Table A2.6.

Table A2.6: Tolerance of crops to sodium absorption ratio of irrigation water (after Chatfield, 1967)

Maximum tolerated	Crop type
8.5	Deciduous fruits, nuts, citrus, avocado
18	Beans
46	Clover, oaks, tall fescue,
102	Wheat, lucerne, barley, tomatoes,

Bicarbonate Hazard

The nature of soils is such that sodium associated with carbonate and bicarbonate may build up in them after irrigation with certain kinds of water. The method of calculating the Bicarbonate Hazard (RSC) is outlined in VIRASC (1980). If the calculated RSC is between 1.25 and 2.5, the water is marginal, but use of soil amendments may make it possible to use the water successfully. If the value is greater than 2.5, however, the water is probably not suitable for irrigation.

2.1.3.3 Stock Watering

Livestock can tolerate water with a higher salt content than is suitable for irrigation or most domestic uses. Animal species differ in their tolerance to salts. Among commonly domesticated livestock, sheep can best tolerate saline waters, and poultry are the least tolerant.

Criteria used in New South Wales for stock watering are provided in Table A2.7. The limits given must only be considered as a guide and not fixed. Tests with the stock should always be carried out in cases of borderline waters.

Table A2.7: Criteria for Livestock Drinking Water Supplies

Stock	Desirable max. level for healthy growth (i)		Max. level at which good condition can be expected (ii)		Max. level which may be safe for limited periods (ii)	
	($\mu\text{S/cm}$)	(mg/L)	($\mu\text{S/cm}$)	(mg/L)	($\mu\text{S/cm}$)	(mg/L)
Sheep, dry feed	10 000	6 000	22 000	13 000	23 300	14 000
Beef cattle	6 7000	4 000	8 300	5 000	16 700	10 000
Dairy cattle	5 000	3 000	6 700	4 000	10 000	6 000
Horses	6 700	4 000	10 000	6 000	11 700	7 000
Pigs	3 300	2 000	5 000	3 000	6 700	4 000
Poultry	3 300	2 000	5 000	3 000	6 700	4 000

- NOTES:
- (i) The suggested limits apply when salinity is mainly due to sodium chloride. If purgative salts such as magnesium sulphate or sodium sulphate are presented in appreciable quantities, concentrations given should be reduced.
 - (ii) Level depends on type of feed.

2.1.3.4 Other On-farm Water Requirements

Quality requirements vary depending on the particular use of the water but because a single source must often be used for all purposes it is suggested that quality should be similar to those for domestic use. Water to be used for washing and sanitising equipment such as milking machines and dairy utensils needs to have low salinity and hardness.

The principal hardness-causing substances in water are calcium magnesium salts. Hard water reacts with soap to form a greasy scum and soap will not lather until all the calcium and magnesium has been used up. Hence more soap is needed. Calcium salts can also form an encrustation of calcium carbonate which eventually blocks irrigation equipment and hot water systems. Deposits on heating elements will cause the elements to overheat and burn out. The utility of water with given levels of hardness is indicated in Table A2.8.

Table A2.8: Limits for Water Hardness

<i>Hardness</i> (mg/L)	<i>Purpose</i>
150	Dairy equipment and hot water systems.
200	General domestic use; washing, cooking, personal hygiene.
300	Dips and chemical sprays.
over 300	Septic tanks and hosing down

The most effective way to treat hard water for domestic use is to install an ion exchange resin softener. When the water is passed through the softener, the calcium and magnesium are replaced by sodium from the exchange resin. This results in an increase in sodium salts in the supply, which is undesirable but may be preferable to hardness in some cases. The reaction is reversible and the exhausted exchange resin can be regenerated by flushing with a solution of sodium chloride (common salt).

Highly mineralised water is not recommended for mixing with pesticides. Suggested limits of TDS and total hardness are 3000 mg/L and 300 mg/L respectively. Some manufacturers indicate any precautions, or additional treatments necessary, on the pesticide container.

Problems with sheep and cattle dips are less likely and water of quite high salinity may be used satisfactorily. A recommended maximum TDS is 15000 mg/L.

2.1.3.5 Industrial Water Supply

Water is generally used in industry for one of three basic purposes:

- heat transfer,
- power generation, and
- processing.

The quality requirements vary widely and depend on the actual use to which it is put. Even within the one industry there may be several unit processes that require different quality water. The quality of the water used may affect the product by staining, corrosion, chemical reaction or contamination; the equipment by corrosion, scale deposits or erosion; and the plant efficiency by sludge and scale formation, foaming or organic growths. For instance, make-up water for high pressure boilers must meet exacting criteria whereas inferior water can be satisfactorily employed for cooling of condensers. Within each industry, criteria cannot readily be established, only recommended limiting values or ranges stated.

In general, different industries have specific requirements related to the water quality and the direct effect of various constituents on particular industrial processes. The guidelines for industrial consumption (steam generation, cooling, and processing) are designed to protect plant equipment and to ensure reasonable plant efficiency. The data for process water reflects the quality of raw water that has been successfully used by the various industries, and are therefore minimum requirements. Poorer quality water is acceptable, however, for such operations as dust suppression.

The generalised water requirement for some industries are discussed below.

2.1.3.6 Power Generation

Steam generation requires water that is of sufficient quality to prevent the formation of scale or other deposits, corrosion, and foaming or priming. The silica content should be low to prevent formation of deposits on turbine blades and in boilers. However, most boiler water is conditioned before use by chemical treatment and sometimes by ion exchange and distillation. High pressure boilers require better quality water than lower pressure boilers. Cooling water should be non-corrosive and should have sufficiently low concentrations of calcium carbonate, sulphate, and phosphate to be non-scaling.

2.1.3.7 Chemical Industry

Chemical industries vary widely as to their water quality requirements. Often the requirements are similar to those for drinking water.

2.1.3.8 Food Processing

Food processing is a complex operation and each food has its own requirements. General limits are based on drinking water limits plus special consideration for constituents which cause stains or odours. Calcium and magnesium limits are rather low because many vegetables tend to harden if boiled in water high in these ions. Water moderately high in these ions, however, is better for baking than is very soft water.

2.1.3.9 Other Industrial Uses

The use of saline water for making concrete results in only a small reductions in strengths. However, corrosion of inadequately protected steel reinforcement must be guarded against. The corrosion problem must also be considered in the selection of pumping and pipeline equipment to be used with saline water.

2.2 The aquifer as a resource for extractive industries

The matrix of an aquifer system can have an intrinsic value for extractive industries. Clay, sand, and gravel of an appropriate grade can be used as a raw material source for industries such as chemical, refractive and building. In addition, minerals can be contained in the aquifer system.

Extraction need not necessarily, but may indeed, have an adverse impact on either the aquifer or the groundwater associated with it. In some instances the community has taken the view that the extractive industry has a higher value than the groundwater contained in it, and the aquifer system is either removed or becomes partly or largely dysfunctional. It is important that it is recognised that the community has a right and a role in deciding whether the aquifer will be used in this manner.

Extraction need not necessarily destroy the aquifer system. If minerals or gems are involved, and the aquifer is formed of unconsolidated deposits, the matrix material can be removed, processed and replaced. If done with sufficient planning and care, this can be accomplished in such a way that little or no long term damage is caused to the groundwater.

Extraction of large volumes of material for the building, refractive, and chemical industries generally results in a void being created and must be carefully managed to avoid contamination of the groundwater. This is particularly the case on the fringes of urban areas where waste disposal may be uncontrolled and illegal dumping is likely to occur.

2.3 The aquifer as a receiver of waste

The treatment and ultimate disposal of wastes, especially hazardous wastes, is a pressing problem facing most communities. Several options are available for the 'disposal' of wastes and some are summarised in Table A2.9. Many of them are too low in value to recycle, too

difficult to degrade, and too concentrated with heavy metals and other non-flammable materials to incinerate. Many of the disposal methods are, in fact, only volume-reduction techniques which leave a residue of hazardous material that ultimately still requires disposal. The disposal option of last resort for most of these substances is burial in the ground, where aquifers constitute waste disposal sites as shown in Figure A2.2.

**Table A2.9: Groundwater Disposal of Wastes
(modified after USEPA, 1977)**

Category	Option
1. In-ground disposal	<p>1.1 Solid wastes open dumps landfills dilute and disperse sites release and confine sites concentrate and contain sites</p> <p>2.2 Liquid wastes disposal bores shallow drainage deep injection discharge to sewers absorption in landfills use of treated effluent as recharge water</p>
2. On-land disposal	<p>2.1 Solid wastes composting and use as fertiliser</p> <p>2.2 Liquid wastes use of treated effluent as irrigation water</p>
3. Above-ground storage and treatment	<p>Holding and evaporation ponds Permanent storage in containers</p>
4. Use as energy source	<p>Thermal energy from exothermic degradation reactions Thermal energy from incineration of wastes Use of methane generated during waste degradation Use of alcohols fermented from wastes Use of waste as stock feed Feeding wastes directly to stock especially pigs Use of wastes to produce protein for stock feed</p>

There is no completely acceptable solution for the eradication of wastes, and disposal methods such as landfills, land treatment, and other subsurface techniques may provide the best solution currently available.

The allocation of surface or near surface space for the disposal of solid wastes is a very common practice. The wastes are deposited on or into geological formations which are often valuable aquifers. Abandoned quarries and pits and mines, natural cavities and other low-lying areas such as alluvial flats are often chosen because of their convenience or low cost. Such sites are often water-filled and in hydraulic connection with local or regional groundwater and surface water systems.

Saturation of the wastes by water permits the ready solution of inorganic materials and favours anaerobic decomposition of organic wastes. This leads to the formation of undesirable organic and inorganic substances (Apgar and Langmuir 1971). Movement of water through the wastes results in the generation of contaminated liquids known as leachate. Carbon dioxide, produced as the waste decomposes, dissolves in water and forms carbonic acid which facilitates the solution and mobilisation of potential contaminants. Once leachate reaches the zone of saturation it moves with the local or regional groundwater flow. The impact of the leachate on groundwater quality generally decreases with increasing distance from its source, either by dilution, by reaction with the aquifer matrix or by bacterial activity. Leachate can discharge within a short distance of the source, however, if the site is not properly located.

Liquid wastes can be discharged directly into groundwater, either by gravity drainage through disposal bores or via shallow pits into unconfined aquifers. The liquids can be introduced at one or more points in a flow system. The regional movement of the liquids will be controlled by the regional groundwater flow. It will not differ greatly from the rate of movement of the native groundwater unless the liquid waste is of high density, in which case there will be a tendency for it to migrate toward the bottom of the aquifer, or a low density when it will float on the water table surface.

Liquid wastes can also be disposed of together with solid wastes in co-disposal operations. Solid waste landfill of primarily inert industrial and commercial solid wastes can be used as a receiver into which classified liquid wastes are introduced through specially prepared trenches or seepage ponds. The idea is that waste liquids percolate through solid wastes which act, through absorption, filtration, biodegradation, adhesion, and neutralisation to convert them into a homogeneous filtrate which is inert and innocuous.

Attenuation

Aquifers have the ability to alter the concentration of contaminants both in time and space. 'Attenuation' is the processes by which removal or reduction of the concentration of solutes in subsurface flow systems occurs. Attenuation is characterised by lowering the concentration of contaminants by a combination of dilution, mechanical filtration, sorption on earth materials, precipitation and co-precipitation, decay, and biological and biochemical degradation.

Although the unsaturated zone has the greatest attenuation potential, the passage of water through the saturated zone can also improve water quality. Degradation of groundwater occurs when the attenuation potential of the aquifer is exceeded.

Utilisation of aquifer system attenuation may be intentional, as in some waste disposal practices. It may also be unintentional as occurs when septic tank effluent or agricultural wastes infiltrate into the subsurface, or if an industrial waste disposal site is improperly

designed, constructed or operated. Use of an aquifer system to attenuate landfill leachate is more often than not unintentional, and the fact that it occurs is an unexpected and perhaps unappreciated bonus.

The approach to waste disposal in an aquifer system can be:

- **Dilute and Disperse.** The concentration of contaminants in the wastes is reduced to an acceptable level by dilution in the groundwater flow system.
- **Release and Confine.** Supernatant liquors are allowed to enter the local groundwater flow system but the natural hydrogeological conditions are used to restrict movement so that the contaminant is kept within the specific disposal layer,
- **Concentrate and Contain.** The wastes are firstly concentrated by volume reduction and then contained in a location engineered to preclude the entry of fluids into the local hydrologic system.

Any of these approaches can be implemented for any of the disposal operation types discussed earlier. The adoption of one of these policies as a method of disposal for a particular waste or mixture of wastes necessitates consideration of a number of factors such as the type of waste, its volume, composition, toxicity, degradability, persistence and, in particular, the hydrogeology of the location.

The essential point about use of an aquifer system for waste disposal is that there will be some impact on the groundwater. The magnitude and extent of the impact will depend on the particular circumstances of the site, the aquifer, and the waste material. In some cases, the impacts will be unacceptable to the community, and in other cases they will be acceptable. It will not be possible for the community to judge whether the impacts will be acceptable if insufficient information about all three factors is available. Waste disposal should not be approved without there first being enough investigation to provide this information.

2.4 Renovation of waste water

Aquifers can be used as an effective and economic method for the treatment or renovation of water. The procedures are usually applied to wastewater which has been subjected to some level of treatment, but are commonly also used for treatment of stormwater, or for river water which is merely turbid. The aquifer (including the surface soil and unsaturated zone above the watertable) acts as a physical filter which removes bacteria, viruses and suspended solids from wastewater. Other attenuation processes can effectively remove heavy metals, phosphorus, fluorides, and nitrogen from the groundwater, which can then be pumped for re-use. An alternative use for such water is to create a groundwater mound in coastal areas where fresh water aquifers are being used for water supply purposes.

This process involves the infiltration and percolation of raw or partially treated wastewater through undisturbed aquifer material, generally soil, sand or gravel. The wastewater is generally introduced into the aquifer by surface spreading techniques and withdrawn at some distance down the hydraulic gradient.

Important site conditions include the geology, topography and climate of the location, groundwater flow paths, aquifer mineralogy, and travel distance in both the unsaturated and the saturated zone. Aquifer systems used for renovating wastewater should be unconfined, porous media types that are amenable to artificial recharge. The depth to the water table should be sufficient to allow for attenuation in the unsaturated zone. Guidelines for use of reclaimed wastewater for use in artificial recharge projects were prepared by the Australian Water Resources Council (AWRC 1990).

The characteristics of the wastewater strongly influence the degree of treatment required. High concentrations of toxic industrial wastes inhibit the effectiveness of the method. Pre-treatment of sewage effluent facilitates percolation through the aquifer and decreases the likelihood of clogging of aquifer space. An indication of the degree of renovation of secondary and tertiary treated domestic sewage which can be achieved after infiltration into a porous aquifer is given in Table A2.10.

Table A2.10: Effectiveness of sewage renovation by filtration through a porous media aquifer, Dan Region System, Israel (after Hancock, 1981)

Parameter	Per cent removal	Parameter	Per cent removal
Turbidity	100	Virus	100 (none detectable)
TDS	60 by dilution	Total organic carbon	70-80
Total N ₂	60-90	Dissolved Oxygen	40-70
NH ₃	10	Mn, Cr, Hg, Cd	Partial removal
NO ₃	10-40	Co	40-70
PO ₄	98	Se	Unaffected

2.5 Infiltration of Septic Tank Effluent

Use of septic tank systems is the most common method of disposing of domestic liquid wastes in areas that are not serviced by reticulated sewerage. In these systems, sanitary wastes, and sometimes sillage, are piped to a tank where scum and grease rise to the surface and settleable solids sink to the tank bottom. Anaerobic bacteria partially purify the liquid. The effluent passes into absorption trenches or sandfilters in the adjacent soil where it is further purified by bacterial action before being released into the soil. The natural earth materials further treat the effluent. Discharge rates from septic tanks are about 150 to 200 litres per person per day. Typical composition of effluent from such systems are given in Table A2.11.

Migration of effluent to underlying aquifer systems is assisted by:

- An overload treatment system in which the disposal rate exceeds the design capacity,
- Flat terrain which encourages vertical percolation,

- A lack of vegetation which would otherwise be responsible for the uptake of some of the water and nutrients from the absorption bed,
- A light soil to facilitate seepage; and,
- A shallow water table.

**Table A2.11: Typical composition of domestic waste effluent
(pers. comm. John Leonard)**

Parameter	Effluent from septic tanks and sandfilters (mg/L)	Sullage water (mg/L)
Suspended solids	16	-
Biochemical Oxygen Demand (5 days)	14	290
Nitrogen (mostly as NH ₃)	130	165
Phosphorus (measured as PO ₄)	15	25

Of the common chemicals in septic tank effluent, heavy metals and detergents are mostly absorbed by clay or organic particles in the soil but phosphates and nitrogen may enter the groundwater. Phosphates generally are transmitted to groundwater only through sandy soils. Nitrates are not attenuated in most soils, dilution being the principal mechanism for lowering their concentration. Other constituents of sewage effluent are pathogenic micro-organisms of which viruses are the most persistent. Depths to groundwater of 20 to 30 metres appear adequate for the removal of a majority of virus particles. Even when injected into aquifers, viruses have not been observed to travel more than 60 metres as discussed by AWWA (1979).

2.6 Infiltration of Irrigated Wastewater

Raw or partially treated wastewater may be further purified by land or grass filtration. In land filtration, permanent pasture bays are irrigated, often with raw sewage. The wastewater infiltrates through the soil, where most of the nutrients and heavy metals are removed. The effluent can then be collected in a system of drains, removed by evapotranspiration, or allowed to seep into the lower subsoil. When spray irrigation is used as a means of wastewater treatment, the amount of water applied is generally far in excess of the plant requirement. The result may be a substantial rise in the water table. In grass filtration, the wastewater is passed continuously over grassed areas and the suspended matter filtered out and the organic matter removed by a biologically active film built up on the vegetation. The purified effluent is collected and discharged to a drainage system.

Percolation to groundwater is influenced by factors similar to those for septic tank effluent discussed in Section 2.5.

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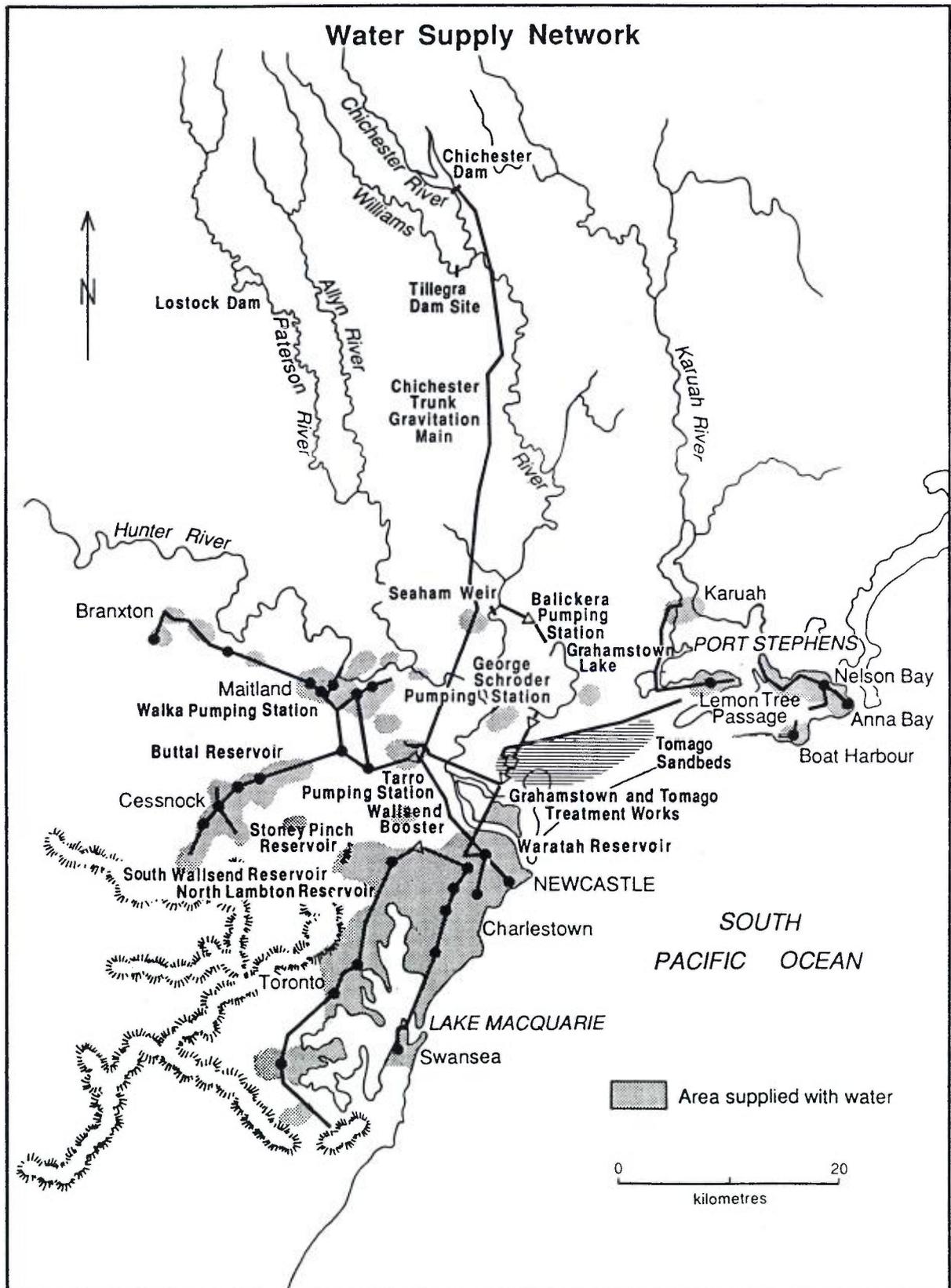
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APPENDIX 3

**WATER SUPPLY WORKS
HUNTER WATER CORPORATION**

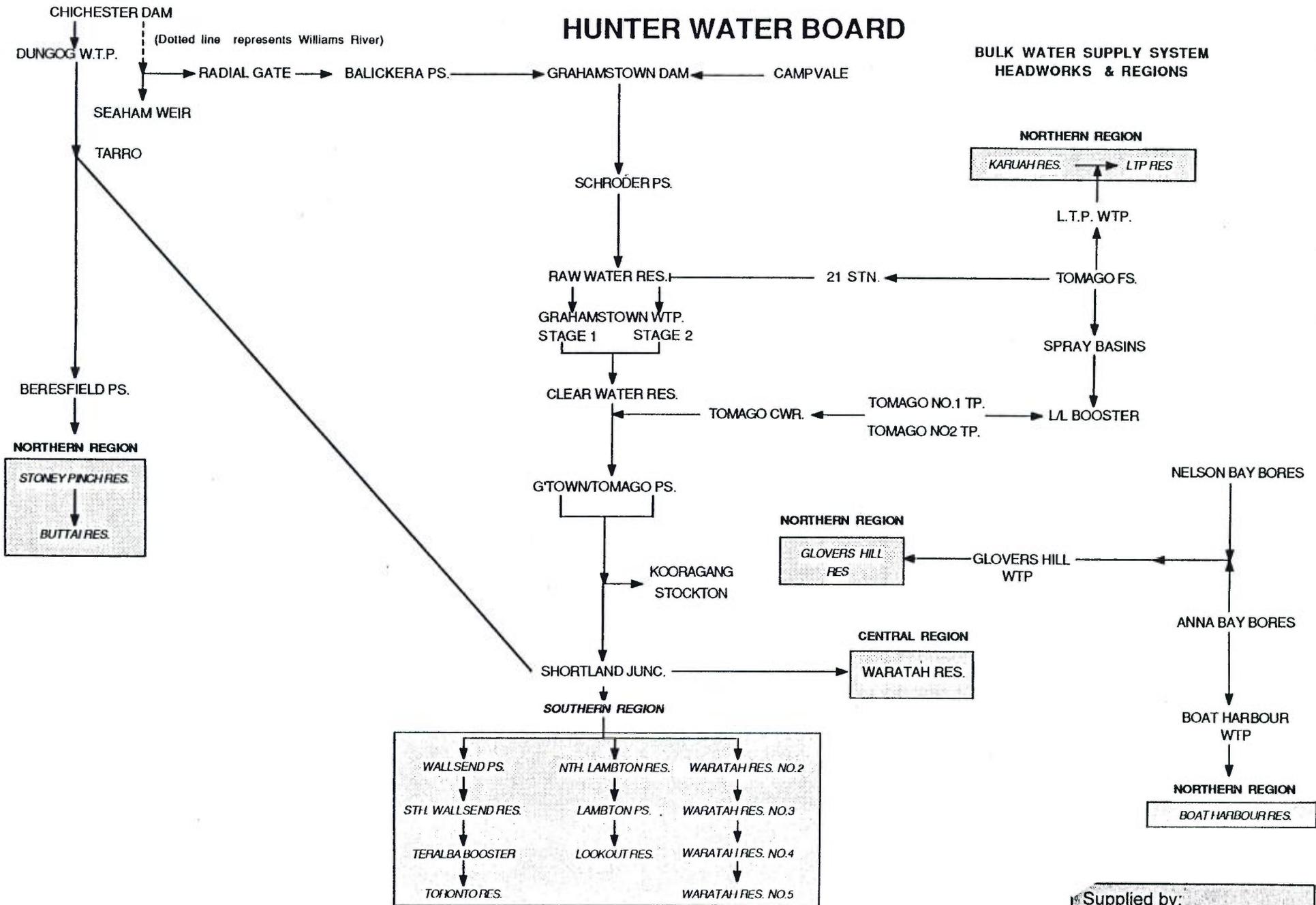
**Water supply networks controlled by
the Hunter Water Corporation, including regional works,
and the Tomago and Nelson Bay-Anna Bay
groundwater systems**

August 1993



Source: Lloyd, Troy & Schreiner (1992).

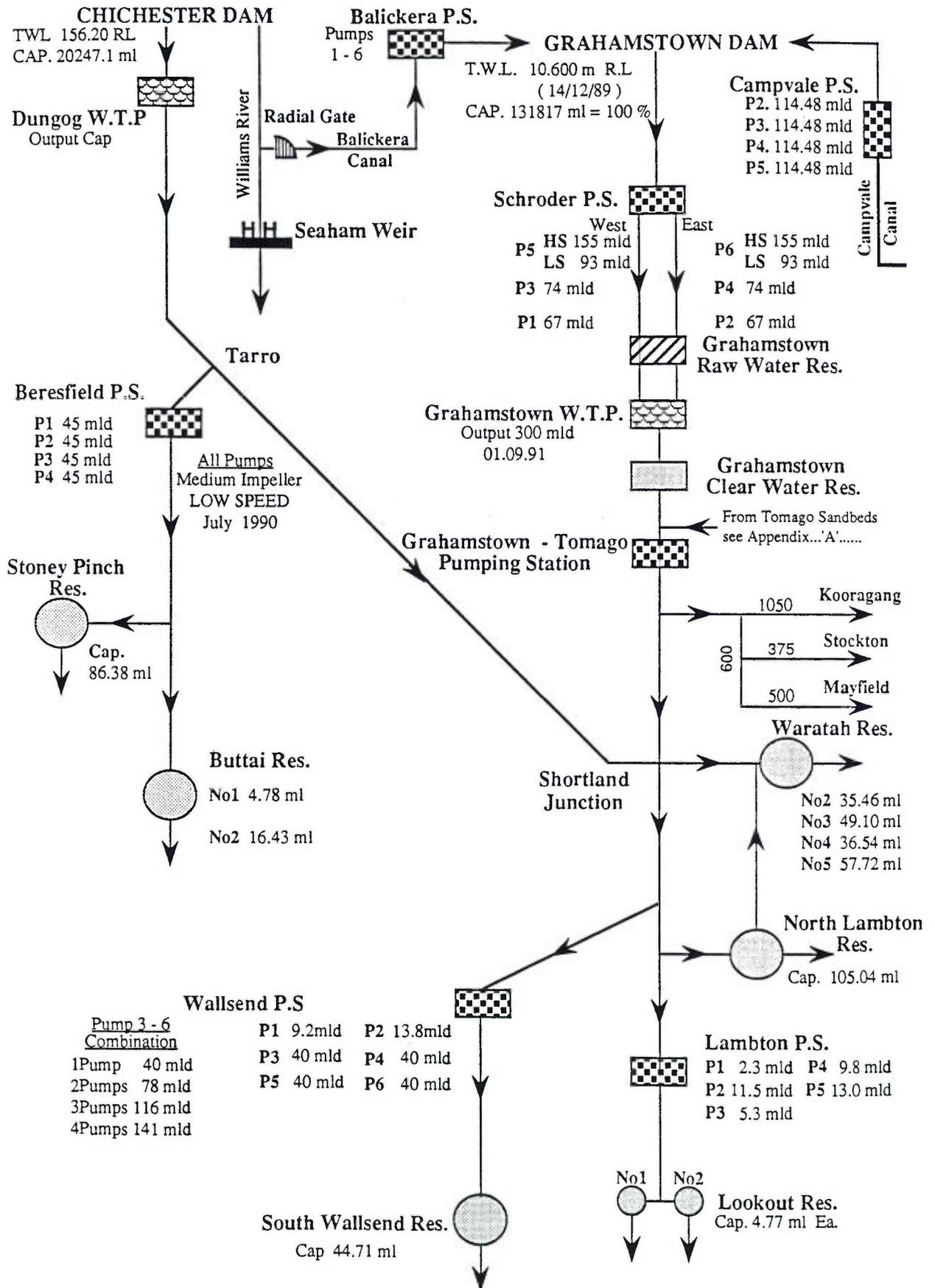
HUNTER WATER BOARD



Supplied by:
Hunter Water Corporation
 25 August 1993

HEADWORKS BULK SUPPLY

UPDATE: 18.06.91



Supplied by:
Hunter Water Corporation
 25 August, 1993

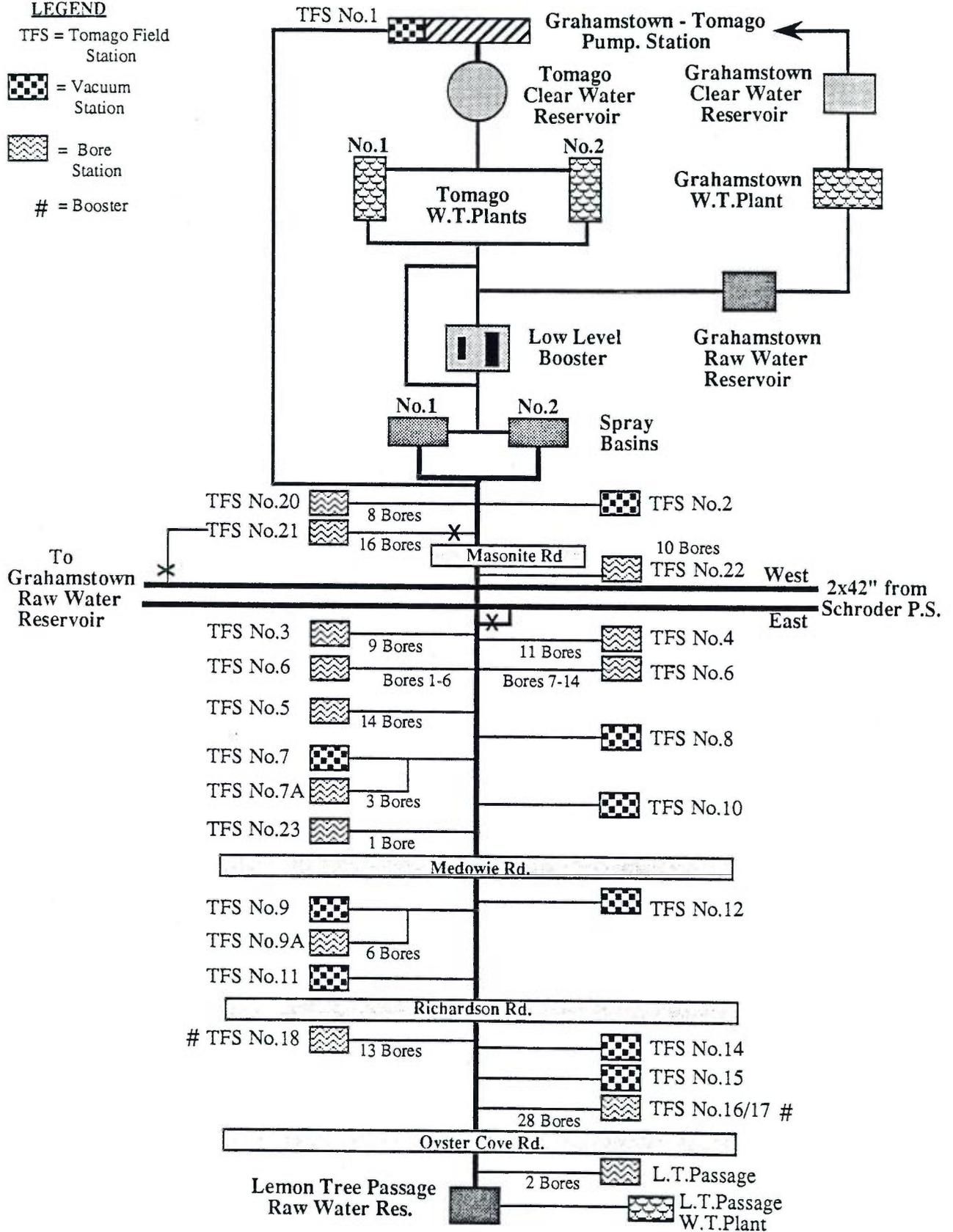
LEGEND

TFS = Tomago Field Station

 = Vacuum Station

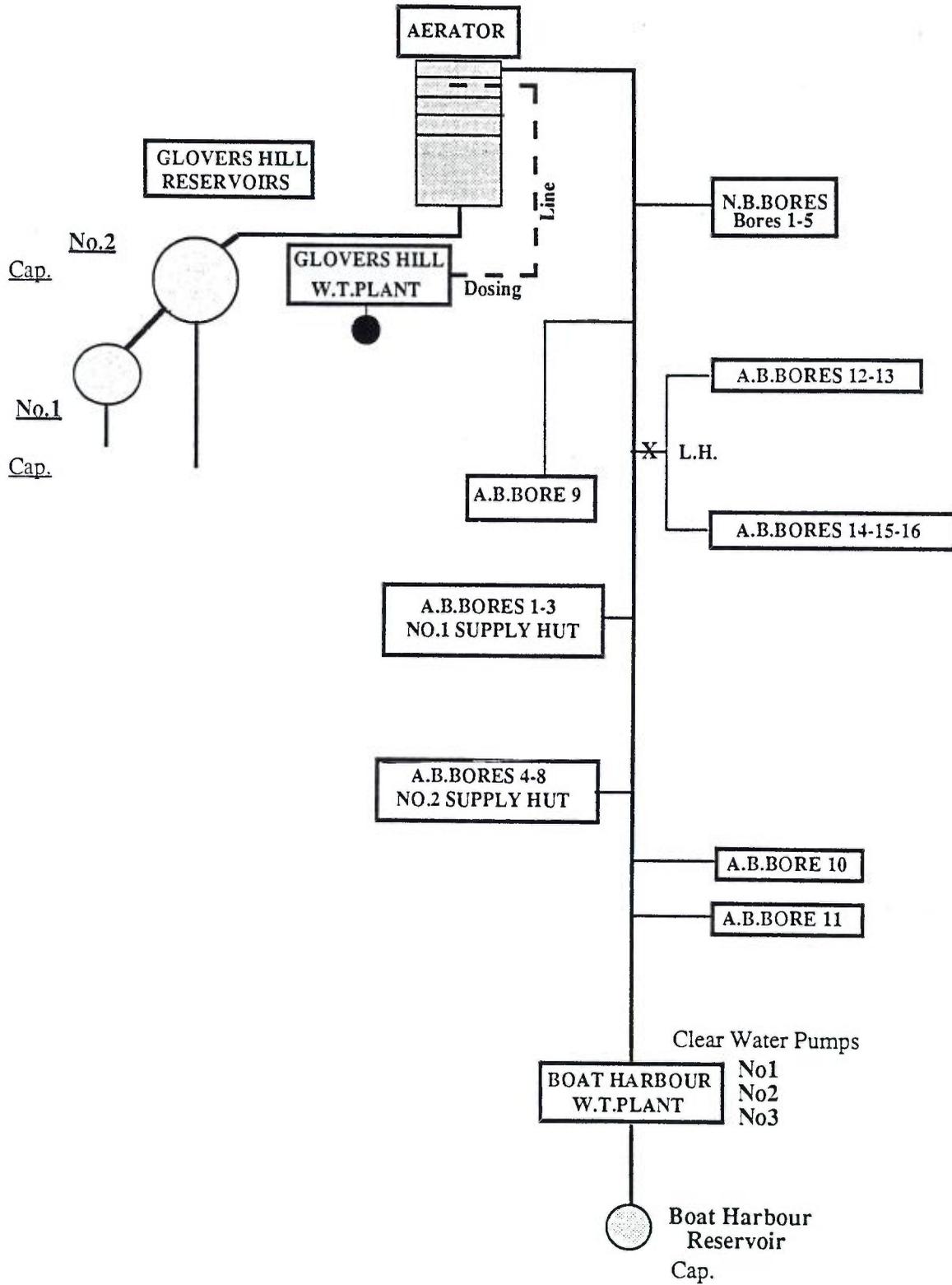
 = Bore Station

= Booster

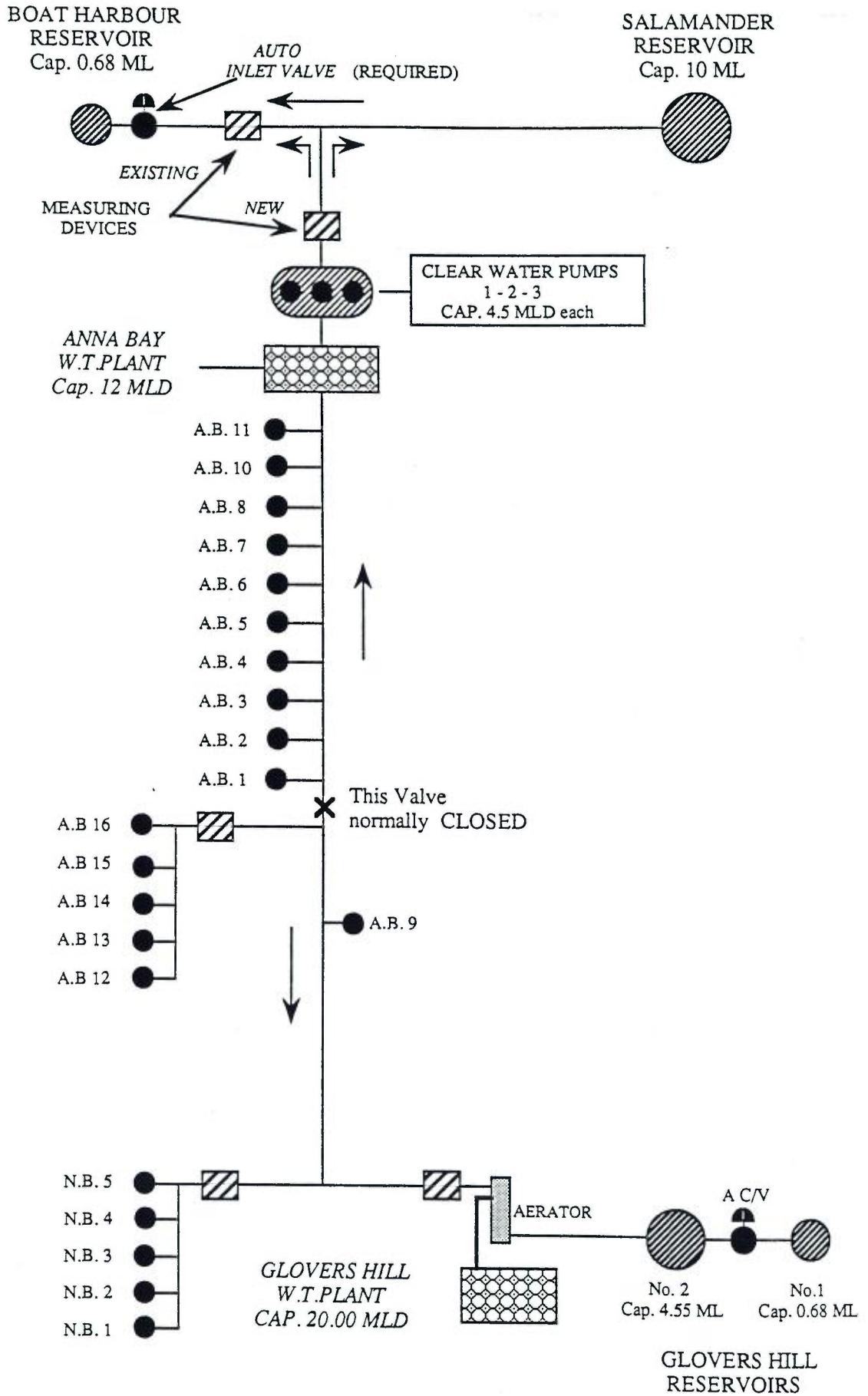


Supplied by:
Hunter Water Corporation
 25 August, 1993

NELSON BAY / ANNA BAY WATER SYSTEM



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Hunter Water Corporation
 25 August, 1993



Supplied by:
Hunter Water Corporation
 25 August, 1993

APPENDIX 4

LICENSED GROUNDWATER WORKS

**Summary of licensing information held by the Department of
Water Resources NSW for bores, wells, spearpoints, or
excavations accessing groundwater* within the
Tomago/Tomaree/Stockton.**

(*Note: normally, any private structure accessing groundwater is subject to licensing by the Department of Water Resources under Part 5 of the Water Act 1912.)

September, 1993

DEPARTMENT OF WATER RESOURCES: LICENSED GROUNDWATER WORKS

Bore	License	Holder	Portion	Parish	County	Purpose	Allocation (ML/y)	Expiry date
59317	126654	Genkem Pty Ltd	LT 141 DP 570135	Stockton	Gloucester	E	6	06.06.93
60008	130263	Stockton Hospital	40	Stockton	Gloucester	I Y	a	17.07.92
60009	130265	Stockton Hospital	40	Stockton	Gloucester	I Y	a	17.07.92
60010	130266	Stockton Hospital	40	Stockton	Gloucester	I Y	-	Lapsed
60011	130268	Stockton Hospital	40	Stockton	Gloucester	I Y	-	Lapsed
*	144360	Erhart Graham	LT 133 DP 734906	Stockton	Gloucester	V	-	Perpetuity
*	144361	Erhart Graham	LT 133 DP 734906	Stockton	Gloucester	J	3	Perpetuity
26942	19910	Rutile & Zircon Mines	PT 7	Stockton	Gloucester	I	Unrestricted	Perpetuity
54780	117125	Chauncy Keith Arthur	LT 3 DP 238507	Stockton	Gloucester	C	19	Perpetuity
50254	110977	Akers Ingeborg	248	Stockton	Gloucester	C	19	Perpetuity
55114	119291	Nevins Robert Bruce	LT 16 DP 32344	Stockton	Gloucester	J	3	Perpetuity
54990	118203	Wild Douglas	LT 13 DP 39356	Stockton	Gloucester	J	3	Perpetuity
54882	118327	George Douglas William	LT 1 Sec 19	Newcastle	Northumberland	J	3	Perpetuity
54683	117311	Devereux Robert Martin	LT 14	Stockton	Gloucester	J	3	Perpetuity
54639	116994	Franks Pastoral (Dickson G)	LT 5 DP 500831	Stockton	Gloucester	J	3	Perpetuity
52226	115674	Davis John	14 REM	Stockton	Gloucester	C J	19	Perpetuity
23079	15958	Mordue Stewart William	11	Stockton	Gloucester	I	Unrestricted	Perpetuity
*	150290	Murden David	LT 6 DP 174437	Stowell	Gloucester	C J	19	Perpetuity

DEPARTMENT OF WATER RESOURCES: LICENSED GROUNDWATER WORKS

Bore	License	Holder	Portion	Parish	County	Purpose	Allocation (ML/y)	Expiry date
47309	109007	Ehmann W	178	Stowell	Gloucester	C I J	18	Perpetuity
47973	116556	Abbes B	LT 6 PT 178	Stowell	Gloucester	C I J	19	Perpetuity
53267	119293	Wilson Donald Ross	148	Stowell	Gloucester	C I J	38	05.05.91
60358	132708	Mineral Deposits Ltd	173	Stowell	Gloucester	H	60	02.07.93
*	132987	Bailey Vincent Edward	LT 1 DP 245171	Stowell	Gloucester	J	3	Perpetuity
35926	133396	Komorowski Lucian	PT 178	Stowell	Gloucester	J	3	Perpetuity
60459	134880	Mineral Deposits Ltd	ML 23 SL 599	Stowell	Gloucester	H	b	17.11.91
60460	134935	Mineral Deposits Ltd	ML 23 SL 599	Stowell	Gloucester	H	b	17.11.91
62439	136178	Mineral Deposits Ltd	SL 599 PH 173	Stowell	Gloucester	H	750	18.06.92
60359	*	-	-	-	-	-	-	-
60360	*	-	-	-	-	-	-	-
56107	121672	Rowsell Trevor	LT 5 DP 245171	Sutton	Gloucester	J	3	Perpetuity
62123	136648	Port Stephens Flower Co P/L	LT 163 DP 239144	Stowell	Gloucester	I	c	28.09.92
62124	136649	Port Stephens Flower Co P/L	LT 163 DP 239144	Stowell	Gloucester	I	c	28.09.92
62125	136650	Port Stephens Flower Co P/L	LT 163 DP 239144	Stowell	Gloucester	I	c	28.09.92
64363	136651	Port Stephens Flower Co P/L	LT 163 DP 239144	Stowell	Gloucester	C J	19	Perpetuity
	136923	Ekert Donald	170	Stowell	Gloucester	I	19	21.06.93
47339	139775	Ringland Alan	146	Stowell	Gloucester	C J	19	Perpetuity

b = 600 ML/y for bore Lic. No 134880 and 134935

c = 150 ML/y for bore Lic. No. 136648, 136649, and 136650

(collated by L. Persehais, Sept. 1993)

DEPARTMENT OF WATER RESOURCES: LICENSED GROUNDWATER WORKS

Bore	License	Holder	Portion	Parish	County	Purpose	Allocation (ML/y)	Expiry date
65016	139865	Daish Graham Frederick	LT 219 DP 17437	Stowell	Gloucester	I	19	Perpetuity
*	139866	Daish Graham Frederick	LT 219 DP 17437	Stowell	Gloucester	I	19	Perpetuity
*	139874	Biztap Pty Ltd	LT 1 DP 540529	Stowell	Gloucester	I	500	11.01.95
*	143977	Wilson Donald Ross	148	Stowell	Gloucester	C J	19	Perpetuity
56048	144796	Krywenko Alexij	LT 177 DP 17437	Stowell	Gloucester	C J	19	Perpetuity
13359	5515	Boyd JL & JA	PT 144	Stowell	Gloucester	-	-	Perpetuity
22498	15239	Bertram R	PT 178	Stowell	Gloucester	C I	Unrestricted	Perpetuity
11961	5008	Bertram Robert Arnold	PT LT 185 DP 17437	Stowell	Gloucester	C J I	Unrestricted	Perpetuity
11962	5009	Bertram Robert Arnold	PT LT 185 DP 17437	Stowell	Gloucester	C J I	Unrestricted	Perpetuity
11963	5010	Bertram Robert Arnold	PT LT 185 DP 17437	Stowell	Gloucester	C J I	Unrestricted	Perpetuity
13016	5421	Pegg Bert	LT 225 PT 146	Stowell	Gloucester	C I J	Unrestricted	Perpetuity
58143	126181	Cairns Brian James	LT 7 PT 24	Stowell	Gloucester	C J	19	Perpetuity
54682	117304	Jelfs Neveille Frederick	LT 25 DP 251567	Stowell	Gloucester	J	3	Perpetuity
48708	109154	Clark Kevin Francis	Site D	Stowell	Gloucester	K	3	Perpetuity
50968	108810	Salt Ash Symons Pty Ltd	LT 22 DP 533736	Stowell	Gloucester	K	3	Perpetuity
47490	112543	Port Stephens Shire Council	129	Tomaree	Gloucester	C I J	19	Perpetuity
47491	112546	Port Stephens Shire Council	171	Tomaree	Gloucester	C I J	19	Perpetuity
59151	121578	Rakus Karol & Valda	355	Tomaree	Gloucester	C I J	10	Perpetuity

DEPARTMENT OF WATER RESOURCES: LICENSED GROUNDWATER WORKS

Bore	License	Holder	Portion	Parish	County	Purpose	Allocation (ML/y)	Expiry
53762	122233	Nelson Bay Golf Club Pty Ltd	121	Tomaree	Gloucester	Y	d	15.06.92
*	138086	Nelson Bay Golf Club Pty Ltd	121	Tomaree	Gloucester	Y	d	28.08.94
61596	132012	Loves Haydon Russell	LT 30 DP 264557	Tomaree	Gloucester	J	3	Perpetuity
60734	132061	Cooke Marcus Leo	LT 194 DP 20294	Tomaree	Gloucester	J	3	Perpetuity
61409	133698	Jordan Ronald Stanley	LT 42 DP 233265	Tomaree	Gloucester	J	3	Perpetuity
63584	134735	Mcintosh Angus William	LT 11 DP 9686	Tomaree	Gloucester	J	3	Perpetuity
63983	135855	Spence Thomas Albert	LT 285 DP 24131	Tomaree	Gloucester	J	3	Perpetuity
64220	136354	Robinson George Ernest	PT 66	Tomaree	Gloucester	J	3	Perpetuity
64221	136355	Robinson George Ernest	PT 66	Tomaree	Gloucester	J	3	Perpetuity
58690	130130	Thompson K	PT 127	Tomaree	Gloucester	J	3	Perpetuity
*	139130	Buffier Norris Charles	LT 592 DP 57382	Tomaree	Gloucester	J	3	Perpetuity
*	139194	Buffier Norris Charles	LT 597 DP 57382	Tomaree	Gloucester	J	3	Perpetuity
*	139739	Andana Units	LT 56 DP 233265	Tomaree	Gloucester	J	3	Perpetuity
*	139859	Haines Milton Leslie	LT 443 DP 772091	Tomaree	Gloucester	J	3	Perpetuity
*	139860	Davies Ronald	PT 120	Tomaree	Gloucester	J	3	Perpetuity
*	140935	GIO Property Investment	64	Tomaree	Gloucester	V	-	Perpetuity
*	141293	Port Stephens Uniting Church	139	Tomaree	Gloucester	J	3	Perpetuity
*	141319	GIO Property Investment	64	Tomaree	Gloucester	C E J	19	Perpetuity

d = 400 ML/y for bore Lic. No 122233 and 138086

(collated by L. Persehais, Sept. 1993)

DEPARTMENT OF WATER RESOURCES: LICENSED GROUNDWATER WORKS

Bore	License	Holder	Portion	Parish	County	Purpose	Allocation (ML/y)	Expiry
*	142164	Meaney Paul John	LT 223 DP 17731	Tomaree	Gloucester	J	3	Perpetuity
*	142965	Department of Education	LT 21 DP 181858	Tomaree	Gloucester	J	3	Perpetuity
*	143577	Nelson Bay Public School	LT 1 DP 216064	Tomaree	Gloucester	J	3	Perpetuity
*	143669	Australia Nid Pty Ltd	LT 152 DP 801973	Tomaree	Gloucester	I Y	e	31.03.97
*	143670	Australia Nid Pty Ltd	LT 152 DP 801973	Tomaree	Gloucester	I Y	e	31.03.97
*	143671	Australia Nid Pty Ltd	LT 152 DP 801973	Tomaree	Gloucester	I Y	e	31.03.97
*	143739	Buffier Norris Charles	52	Tomaree	Gloucester	J	3	Perpetuity
*	144112	Australia Nid Pty Ltd	LT 152 DP 801973	Tomaree	Gloucester	V	-	Perpetuity
*	145067	Port Stephens Shire Council	Frshr Res b.1	Tomaree	Gloucester	Y	f	27.07.97
*	145068	Port Stephens Shire Council	Frshr Res b.2	Tomaree	Gloucester	Y	f	27.07.97
*	145328	Kursa W	LT 50 DP 715013	Tomaree	Gloucester	C J	19	Perpetuity
*	145731	Kain Mavis	LT 22 DP 805228	Tomaree	Gloucester	J	3	Perpetuity
39390	-	Hunter Water District	Basin 209	Tomaree	Gloucester	A	-	-
39391	-	Hunter Water District	Basin 209	Tomaree	Gloucester	A	-	-
39392	-	Hunter Water District	Basin 209	Tomaree	Gloucester	A	-	-
39393	-	Hunter Water District	Basin 209	Tomaree	Gloucester	A	-	-
39394	-	Hunter Water District	Basin 209	Tomaree	Gloucester	A	-	-
51756	113588	Mankey RL & JA	LT 199 DP 19121	Tomaree	Gloucester	J	3	Perpetuity

e = 300 ML/y for bore Lic. No. 143669, 143670, and 143671

f = 22 ML/y for bore Lic. No. 145067, and 145068

(collated by L. Persehais, Sept. 1993)

DEPARTMENT OF WATER RESOURCES: LICENSED GROUNDWATER WORKS

Bore	License	Holder	Portion	Parish	County	Purpose	Allocation (ML/y)	Expiry
54401	115939	Matheson Jean Margaret	LT 20 Sec 2	Tomaree	Gloucester	J	3	Perpetuity
52444	117521	Cunningham Joyce & Gordon	LT 243 DP 238752	Tomaree	Gloucester	J	3	Perpetuity
56216	118373	Anderson Geoffrey Ronald	LT 183 PT 119	Tomaree	Gloucester	J	3	Perpetuity
56272	119086	Brittliff Una Lorina	LT 10 DP 9686	Tomaree	Gloucester	J	3	Perpetuity
56269	120013	Conway David Frederick	PT 161	Tomaree	Gloucester	J	3	Perpetuity
52644	120087	Thurston John James	LT 71 DP 20240	Tomaree	Gloucester	J	3	Perpetuity
55941	121716	Bodycott James Francis	LT 191 DP 20294	Tomaree	Gloucester	J	3	Perpetuity
56117	122157	Thomas Leroi Owen	117	Tomaree	Gloucester	J	3	Perpetuity
56271	122093	Fenton Ronald Beresford	LT101 DP 28772	Tomaree	Gloucester	J	3	Perpetuity
56572	122928	Prothero Neville Raymond	LT 185 DP 23873	Tomaree	Gloucester	J	3	Perpetuity
56098	122113	Boughton Trevor William	70	Tomaree	Gloucester	C J	19	Perpetuity
54635	116949	Pett Vernon	LT 172 DP 24132	Tomaree	Gloucester	J	3	Perpetuity
55575	119958	Whelan Bernard	LT 2 Sec 5	Tomaree	Gloucester	J	3	Perpetuity
49385	-	unlicensed	-	Tomaree	Gloucester	-	-	-
39308	-	file 81/20608	-	Tomaree	Gloucester	-	-	-
39309	-	file 81/20608	-	Tomaree	Gloucester	-	-	-
54085	-	unlicensed	-	Tomaree	Gloucester	-	-	-
57675	126403	Gemmel William	LT 576 PT 122	Tomaree	Gloucester	J	3	Perpetuity

DEPARTMENT OF WATER RESOURCES: LICENSED GROUNDWATER WORKS

Bore	License	Holder	Portion	Parish	County	Purpose	Allocation (ML/y)	Expiry
57633	126245	Dunlop Mervin	PT 118	Tomaree	Gloucester	J	3	Perpetuity
56276	121665	Reilly E C	LT 113 Sec 2(a)	Tomaree	Gloucester	J	3	Perpetuity
56277	120923	Van Wyk Edwin Dudley	LT 5 DP 25740	Tomaree	Gloucester	J	3	Perpetuity
55188	119521	Cutting Francis William	LT 119 Pt 125	Tomaree	Gloucester	J	3	Perpetuity
56270	119380	Koslowski L	PT 160	Tomaree	Gloucester	J	3	Perpetuity
56278	119479	Strata Plan No 7020	LT 16 DP 19120	Tomaree	Gloucester	J	3	Perpetuity
56279	119255	Snape S W	LT 7 Sec 2	Tomaree	Gloucester	J	3	Perpetuity
52615	119232	Schultz Johann	LT 346 DP 13134	Tomaree	Gloucester	J	3	Perpetuity
55010	118898	Freestone William Alfred	LT 121 DP 27047	Tomaree	Gloucester	J	3	Perpetuity
52343	118611	Bain John Trevenson	LT 144 DP 24132	Tomaree	Gloucester	J	3	Perpetuity
56274	118313	Sprogis & Choat Pty Ltd	PT118	Tomaree	Gloucester	J	3	Perpetuity
52672	117946	Strata Plan No 11461	LT 1 DP 9686	Tomaree	Gloucester	J	3	Perpetuity
56275	117827	Cooper Joan Stella	LT 186 DP 29873	Tomaree	Gloucester	J	3	Perpetuity
54718	117510	Murdie Joseph William	LT 99 DP 238666	Tomaree	Gloucester	J	3	Perpetuity
55412	117287	Smurthwaite W	LT 11 Sec 3	Tomaree	Gloucester	J	3	Perpetuity
52424	117132	Cook Marie Yvonne	LT 202 DP 243941	Tomaree	Gloucester	J	3	Perpetuity
56018	117169	Ruddy John Alexander	99	Tomaree	Gloucester	J	3	Perpetuity
58239	117210	Rodgers R onald	81	Tomaree	Gloucester	J	3	Perpetuity

DEPARTMENT OF WATER RESOURCES: LICENSED GROUNDWATER WORKS

Bore	License	Holder	Portion	Parish	County	Purpose	Allocation (ML/y)	Expiry
54638	116990	Chapman P J	118	Tomaree	Gloucester	J	3	Perpetuity
55411	117001	Lowe Thomas Dennis	LT 31 Sec 6	Tomaree	Gloucester	J	3	Perpetuity
51715	116850	Craven Kenneth Harold	LT 188 DP 23873	Tomaree	Gloucester	J	3	Perpetuity
54632	116937	Proprietors of Strata Plan 9024	PT 161	Tomaree	Gloucester	J	3	Perpetuity
54633	116939	Towers Peter John	LT 33 DP 240169	Tomaree	Gloucester	J	3	Perpetuity
54595	116666	Fearon James Bede	LT 36	Tomaree	Gloucester	J	3	Perpetuity
54400	115524	Parsons Harold Oswald	LT 3 Sec 6	Tomaree	Gloucester	J	3	Perpetuity
56273	118442	Jobling George Thomas	LT 165 DP 24132	Tomaree	Gloucester	J	3	Perpetuity
53763	122375	Nelsons Bay Golf Club	121	Tomaree	Gloucester	-	-	Lapsed
*	150052	Arundell John	LT 535 DP 10716	Sutton	Gloucester	C J	application	-
*	150053	Abela David	LT 672 DP 10716	Sutton	Gloucester	C J	application	-
*	150175	Muxlow Neil Kevin	LT 105 DP 223671	Sutton	Gloucester	J	3	Perpetuity
*	151089	Bradley Robert	LT 1491 DP 560404	Sutton	Gloucester	J	2	Perpetuity
*	151090	Jonovsky S C	LT 354 DP 10716	Sutton	Gloucester	J	2	Perpetuity
47438	109737	ACI Raw Materials	265	Sutton	Gloucester	E	g	29.04.94
47439	109738	ACI Raw Materials	265	Sutton	Gloucester	E	g	29.04.94
*	139686	Towler Peter	LT 154 DP 223671	Sutton	Gloucester	C J	19	Perpetuity
*	139757	Miller Leonie	LT 256 DP 11392	Sutton	Gloucester	J	3	Perpetuity

g = 640 ML/y for bore Lic No. 109737 and 109738

(collated by L. Persehais, Sept. 1993)

DEPARTMENT OF WATER RESOURCES: LICENSED GROUNDWATER WORKS

Bore	License	Holder	Portion	Parish	County	Purpose	Allocation (ML/y)	Expiry date
*	139763	Miller Henry	LT 160 DP 11392	Sutton	Gloucester	J	3	Perpetuity
*	139974	Ringland Allen	LT 65 DP 731443	Sutton	Gloucester	C J	19	Perpetuity
*	142964	Wilton Leslie David	LT 174 DP 10716	Sutton	Gloucester	C J	19	Perpetuity
*	144590	Green John	LT 5 DP 225672	Sutton	Gloucester	C J	19	Perpetuity
*	144591	Sykes Henry Edward	LT 70 DP 229011	Sutton	Gloucester	J	3	Perpetuity
*	144694	Green Roy	LT 319 DP 10716	Sutton	Gloucester	J	3	Perpetuity
*	145329	Doherty Tony	LT 5 DP 10716	Sutton	Gloucester	C J	19	Perpetuity
*	145732	Burge Mark	LT 143 DP 225672	Sutton	Gloucester	J	3	Perpetuity
*	152645	RZM Pty Ltd	MLAS 135-138	Sutton	Gloucester	H	380	30.06.98
22286	14855	Atkins Henry Samuel	39	Sutton	Gloucester	I J	unrestricted	Perpetuity
22265	14856	Atkins Henry Samuel	39	Sutton	Gloucester	I C & Poultry	Unrestricted	Perpetuity
55943	121739	Crane Brian William	LT 139 DP 229621	Sutton	Gloucester	J	3	Perpetuity
55920	121636	Laut John Leslie	LT 143 DP 229621	Sutton	Gloucester	J	3	Perpetuity
55008	118884	Williams Rodney James	LT 762 DP 16365	Sutton	Gloucester	J	3	Perpetuity
52469	118941	Dine Roger Francis	LT 242 DP 16365	Sutton	Gloucester	J	3	Perpetuity
52470	118942	Snow John	LT 852 DP 16365	Sutton	Gloucester	J	3	Perpetuity
51713	117303	Hart Ernest	LT 107 DP 223671	Sutton	Gloucester	J	3	Perpetuity
51712	117305	Evans Arthur Sydney	LT 106 DP 223671	Sutton	Gloucester	J	3	Perpetuity

DEPARTMENT OF WATER RESOURCES: LICENSED GROUNDWATER WORKS

Bore	License	Holder	Portion	Parish	County	Purpose	Allocation (ML/y)	Expiry Date
51293	116626	Mundy Allan Henry	LT 313	Sutton	Gloucester	J	3	Perpetuity
50374	112964	McKenney Allan Edwin	LT 8002 pt 126	Sutton	Gloucester	J	3	Perpetuity
54084	112995	Maund Reginald Douglas	LT 12 DP 217567	Sutton	Gloucester	J	3	Perpetuity
*	150173	Basham R euben Roy	LT 6 DP 2287	Eldon	Gloucester	J	3	Perpetuity
*	150669	Scholz Wayne	LT 78 DP 814257	Eldon	Gloucester	J	3	Perpetuity
61003	132652	Farrow Jim Stafford	LT 5 DP 39287	Eldon	Gloucester	J	3	Perpetuity
*	136208	Stackman Gordon	LT 32 DP 18666	Eldon	Gloucester	J	3	Perpetuity
*	144264	Schmidt Michael	LT 27 DP 264023	Eldon	Gloucester	J	3	Perpetuity
*	145084	Cowley Guy	LT 21 DP 58671	Eldon	Gloucester	J	3	Perpetuity
*	145085	Escott Jack Edric	LT 30 DP 38113	Eldon	Gloucester	J	3	Perpetuity
*	145577	Little Stewart Stanley	LT 172B DP 17437	Eldon	Gloucester	I	6	Perpetuity
*	151938	Hope Mark Douglas	LT 93 DP 814257	Eldon	Gloucester	J	3	Perpetuity
57239	118691	Sorensen Christopher Thomas	LT 60 DP 28473	Eldon	Gloucester	J	3	Perpetuity
51395	116531	Bellamy Desmond Charles	PT 17	Eldon	Gloucester	J	3	Perpetuity
57300	124878	Roberts Richard Reginald	LT 15	Eldon	Gloucester	C J	19	Perpetuity
26403	16878	Pflug Harry Herman Louis	LT B being PT 12	Eldon	Gloucester	J	3	Perpetuity
26167	16879	Pflug Harry Herman Louis	LT B being PT 12	Eldon	Gloucester	-	-	Perpetuity
57248	-	Not licensed	-	-	-	-	-	-

DEPARTMENT OF WATER RESOURCES: LICENSED GROUNDWATER WORKS

Bore	License	Holder	Portion	Parish	County	Purpose	Allocation (ML/y)	Expiry date
53044	116830	Peters Jc &Nm	LT 4	Eldon	Gloucester	I C J	Unrestricted	Perpetuity
60834	132186	Fisher John	LT 22 DP 628579	Thornton	Gloucester	C	19	Perpetuity
60853	132203	Cusick Richard	LT 1 DP 628579	Thornton	Gloucester	C J	19	Perpetuity
*	142385	Dawes Renald Frank	LT 30 DP 255228	Thornton	Gloucester	C J	19	Perpetuity
*	132557	Machon Colin Henry	LT 30 DP 701174	Tarean	Gloucester	C K	19	Perpetuity
47488	132637	Howard Allan	PT95	Tarean	Gloucester	C J	19	Perpetuity
61116	132810	Merton John Francis	LT 156I DP 541011	Tarean	Gloucester	C J	19	Perpetuity
53074	134350	Bushell Frances Allan	LT 5 DP 243144	Tarean	Gloucester	C	19	Perpetuity
51914	115739	Burley Neville Howard	LT 11 DP 243144	Tarean	Gloucester	C J	19	Perpetuity
51435	115999	Reeves Thomas	40	Tarean	Gloucester	C J	19	Perpetuity
56478	122655	Wilgermain A & K	LT 7 PT 83	Tarean	Gloucester	C J	19	Perpetuity
57400	125352	Mcgregor RG & HA	LT 11 DP 250873	Tarean	Gloucester	C J	19	Perpetuity
55512	120621	Bushell Frances Allan	LT DP 243144	Tarean	Gloucester	C J	19	Perpetuity
51453	117047	Wilson John Leslie	PT 60	Tarean	Gloucester	C J	19	Perpetuity
54657	117097	Westernhagen Carl Joseph	PT 83	Tarean	Gloucester	C J	19	Perpetuity
51449	116843	Talbot Colin Rodgers	143	Tarean	Gloucester	C J	19	Perpetuity
51985	115788	Gillett John Alexander	83	Tarean	Gloucester	C	19	Perpetuity
51979	115697	Egginton Ernest William	5	Tarean	Gloucester	C	19	Perpetuity