

NATURAL RESOURCES ANALYSIS PROGRAM (NRAP)

GROUNDWATER RESOURCES OF CAPE YORK PENINSULA

A.M.Horn, E.A. Derrington, G.C. Herbert, R.W. Lait and J.R. Hillier Queensland Department of Primary Industries and

Australian Geological Survey Organisation

1995





CAPE YORK PENINSULA LAND USE STRATEGY (CYPLUS)

Natural Resources Analysis Program

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Due to the timing of publication, reports on other CYPLUS projects may not be fully cited in the BIBLIOGRAPHY section. However, they should be able to be located by author, agency or subject.

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CAPE YORK PENINSULA LAND USE STRATEGY STAGE I

PREFACE TO PROJECT REPORTS

Cape York Peninsula Land Use Strategy (CYPLUS) is an initiative to provide a basis for public participation in planning for the ecologically sustainable development of Cape York Peninsula. It is jointly funded by the Queensland and Commonwealth Governments and is being carried out in three stages:

- Stage I information gathering;
- Stage II development of principles, policies and processes; and
- Stage III implementation and review.

The project dealt with in this report is a part of Stage I of CYPLUS. The main components of Stage I of CYPLUS consist of two data collection programs, the development of a Geographic Information System (GIS) and the establishment of processes for public participation.

The data collection and collation work was conducted within two broad programs, the Natural Resources Analysis Program (NRAP) and the Land Use Program (LUP). The project reported on here forms part of one of these programs.

The objectives of NRAP were to collect and interpret base data on the natural resources of Cape York Peninsula to provide input to:

- evaluation of the potential of those resources for a range of activities related to the
 use and management of land in line with economic, environmental and social
 values; and
- formulation of the land use policies, principles and processes of CYPLUS.

Projects examining both physical and biological resources were included in NRAP together with Geographic Information System (GIS) projects. NRAP projects are listed in the following Table.

Physical Resource/GIS Projects	Biological Resource Projects
Bedrock geological data - digitising and integration (NR05)	Vegetation mapping (NR01)
Airborne geophysical survey (NR15)	Marine plant (seagrass/mangrove) distribution (NR06)
Coastal environment geoscience survey (NR14)	Insect fauna survey (NR17)
Mineral resource inventory (NR04)	Fish fauna survey (NR10)
Water resource investigation (groundwater) (NR16)	Terrestrial vertebrate fauna survey (NR03)
Regolith terrain mapping (NR12)	Wetland fauna survey (NR09)

Physical Resource/GIS Projects	Biological Resource Projects
Land resource inventory (NR02)	Flora data and modelling (NR18)
Environmental region analysis (NR11)	Fauna distribution modelling (NR19)
CYPLUS data into NRIC database FINDAR (NR20)	Golden-shouldered parrot conservation management (NR21)
Queensland GIS development and maintenance (NR08)	
GIS creation/maintenance (NR07)	

^{*} These projects are accumulating and storing all Stage I data that is submitted in GIS compatible formats.

Research priorities for the LUP were set through the public participation process with the objectives of:

- collecting information on a wide range of social, cultural, economic and environmental issues relevant to Cape York Peninsula; and
- highlighting interactions between people, land (resource use) and nature sectors.

Projects were undertaken within these sector areas and are listed in the following Table.

People Projects	Land Projects	Nature Projects
Population	Current land use	Surface water resources
Transport services and infrastructure	Land tenure	Fire
Values, needs and aspirations	Indigenous management of land and sea	Feral and pest animals
Services and infrastructure	Pastoral industry	Weeds
Economic assessment	Primary industries (non-pastoral, non-forestry)	Land degradation and soil erosion
Secondary and tertiary industries	Forest resources	Conservation and natural heritage assessment
Traditional activities	Commercial and non commercial fisheries	Conservation and National Park management
Current administrative structures	Mineral resource potential and mining industry	
	Tourism industry	

EXECUTIVE SUMMARY

Introduction

The study area covered by this report, is of some 143 000 km² and is remote and isolated from Australian population centres. The area covered includes Cape York Peninsula north of approximately Cooktown and some selected Torres Strait Islands in limited detail. The area has a small sparsely settled population of around 10 000 (1986 census). The principle resource uses are rangeland grazing, mining and tourism.

This report presents an overview of the nature of the Peninsula's groundwater resources and those features intrinsically related to their ongoing use and protection. It collates summarises and interprets available information from published reports, drilling, geophysics and an extensive groundwater chemistry analysis program that occurred as the first systematic collection and analyses of data on the region's groundwater quality.

This information has helped to provide a more comprehensive understanding of the hydrogeological characteristics of the Peninsula, including flow rates, water usage, current water qualities and present and potential uses. From this information, more reliable and accurate planning for use of the groundwater resources can be made.

In general, Cape York Peninsula currently has abundant quantities of groundwater. Although difficulties may be encountered in some areas in obtaining supplies, overall reserves are large. With the monsoonal weather patterns having a particularly pronounced effect on surface water resources, groundwater is generally a more reliable year round source of water for most of the peninsula. As a resource it is also generally more widely available than surface water supplies.

Within the area, groundwater resources provide 90% of the water supplies. All of the major communities except Bamaga and Wujal Wujal rely on groundwater for at least part of their domestic water supplies. It is the major source of water supply for agricultural purposes, particularly stockwatering, and for bauxite mining at Weipa. Data on actual groundwater use in the study area is sparse, with only eight locations where bores are metered. Use by the smaller communities, most mines, tourist locations and pastoral holdings can only be estimated.

The availability and quality of the groundwater resources of the study area are closely related to the geology of the host rocks with the main resources occurring in Cainozoic and Mesozoic sedimentary rocks. The study area has been divided into several major groundwater regions based on both formal and informal tectonic units. These are the lower Palaeozoic Coen and Yambo Inliers, the Palaeozoic Hodgkinson Province and Cape York Pyroclastics, the Mesozoic Carpentaria and Laura Basins and the Cainozoic Karumba Basin. Other geological features that are significant to the nature of the study area's groundwater resources include alluvial fan, river alluvium and coastal dune deposits. Coastal dunes and beach ridge deposits may prove a significant resource if groundwater demands increase.

The principal aquifers exist within the Cainozoic Bulimba Formation and Wyaaba Beds (Karumba Basin), the Mesozoic Gilbert River Formation (Carpentaria and Laura Basins) and Dalrymple Sandstone (Laura Basin), with additional significant supplies obtained from fractured rock aquifers.

Reliable and significant groundwater supplies are available in the western Peninsula areas and the Laura Basin to the east though in some areas larger flows are only available by drilling to depths in excess of 500m. Other areas have the potential to supply minor stockwater though with lesser reliability. Some of the groundwater resources are isolated from areas of demand, and some of the shallow resources may become depleted during times of greatest demand such as in the September to November period.

Quality of groundwater throughout the study area is usually very good with salinity levels commonly very low. The most common water types are sodium bicarbonate and sodium chloride type or minor variations of these. This general category accounts for 90% of all samples used in this analysis. The groundwater is predominantly acidic with some alkaline groundwater occurring in the Karumba and Laura Basins.

Quality is generally adequate for mining and agricultural purposes. Some isolated water quality problems occur including saltwater intrusion at Pormpuraaw and Cooktown, nitrate pollution at Laura, high manganese and iron levels in the Laura Basin. High fluoride levels precluding use for human consumption from some deeper Mesozoic sandstone aquifers.

Groundwater Characteristics

Potential recharge areas give a broad indication of areas vulnerable to groundwater pollution, though a detailed assessment of groundwater vulnerability for a particular location would require more intensive local studies.

The principal potential recharge areas for the Carpentaria Basin lie along the western margins of the Great Dividing Range. Similarly, for the Laura Basin, they lie in the ring of Mesozoic outcrop areas that occur west of the eastern uplands between Cooktown and Cape Melville, as well a north of the Hodgkinson Province and east of the Great Dividing Range (between approximately Hann River Roadhouse and Cape Sidmouth). Recharge areas are present in the Karumba Basin along the Weipa Peninsula and in various sections of the central western Cape York Peninsula. Fractured rock and unconsolidated sedimentary rock aquifers principally recharge vertically.

The quantity of groundwater recharge is influenced by climate, vegetative cover, extent of evapotranspiration and the soil depth and composition. In the more arid areas, which include much of the peninsula, low recharge means that future groundwater development will depend on abstraction from historical groundwater storage, rather than replenishable supplies.

The geology of Cape York Peninsula is diverse and strongly influences groundwater characteristics. Fractured rock aquifers are those that derive their groundwater storage capability from secondary porosity features, these include joints, faults and voids and some of the features derived from weathering action. These aquifers provide, through a large number of low yielding bores, significant groundwater supplies for domestic and stockwatering purposes and also as a supplementary water supply for Cooktown.

The principal fractured rock aquifer locations are in the Hodgkinson Province (in the south east of the study area) and the Coen and Yambo Inliers (which form a north-south spine through the central study area). A minor fractured rock aquifer occurs in the (informally named) Cape York Pyroclastics (located at Cape York).

Groundwater supplies in these terrains are recharged vertically and consequently the quality and quantity of groundwater is strongly influenced by rainfall, soil cover and vegetation conditions. This close dependence on rainfall commonly increases the potential of these aquifers in the wetter parts of the study area. Additionally water levels in fractured rock aquifers can vary significantly during the year and can become completely depleted of water during the dry season.

The Hodgkinson Province consists of deepwater siltstones, arenites, conglomerates and basalts. Groundwater yields from the principal aquifer units are, from the Hodgkinson Formation 0.5 L/s - 30 L/s but more commonly 5 L/s, from the Piebald Basalt at the Hopevale community are around 5 L/s and from the McLean Basalt usually less than 1 L/s. Groundwater from the Hodgkinson Province is generally of good quality (average conductivity of the Hodgkinson Formation is 700 μ Scm⁻¹) and suitable for all purposes. However in some coastal areas aquifers in the province have been intruded by saltwater.

The Coen and Yambo Inliers are composed of metamorphics and acid intrusives (mainly granite). Groundwater yields from the Coen Inlier vary from less than 0.5 L/s to 5 L/s. The higher yields are from bores located in the higher rainfall areas such as around Lockhart River. Groundwater yields for the Yambo Inlier are only known for the acid intrusive areas and are less than 0.5 L/s.

The groundwater quality in the Coen Inlier is generally good and suitable for all purposes. Conductivity of water sourced from the metamorphic units is up to $700~\mu \text{Scm}^{-1}$ and from the acid intrusives is up to $1550~\mu \text{Scm}^{-1}$. High fluoride values from acid intrusive sourced groundwater in the southern Coen Inlier can preclude this water for human consumption. From limited samples, groundwater quality in the Yambo Inlier also appears good and suitable for most purposes. Further testing would be required to determine general fluoride levels before comment could be made on its suitability for human consumption.

The Carpentaria and Laura Basins, which contain porous aquifers, were formed contemporaneously and are lithostratigraphically connected. The Carpentaria and Laura Basins are composed principally of two predominantly quartz sandstone formations overlain by an extensive and thick argillaceous (clayey) unit. These units tend to thicken towards the centre of their respective basins and usually overlie an uneven basement topography.

Groundwater supplies 95% of the population in the Laura Basin with potable water. The major aquifers in the Laura Basin are the Dalrymple Sandstone and the overlying Gilbert River Formation. These units are composed of sandstones, mudstones and conglomerates and are overlain by a thick argiliaceous unit (the Rolling Downs Group).

Aquifers are continuous across the basin with artesian supplies occurring in many areas. Supplies are generally reliable and of fair to excellent quality water. Average flow rates are speculative but flows up to 12 L/s have been recorded (from holes that have only partially penetrated the Mesozoic aquifers) and higher flows are likely with deeper drilling.

The quality of groundwater from the Mesozoic sandstones in the Laura Basin is usually acceptable for most purposes with the conductivity averaging 900 μ Scm⁻¹. The water quality of the Cainozoic sediments overlying the Laura Basin is generally good with an average conductivity of 350 μ Scm⁻¹, though manganese and iron concentrations can be too high for domestic use and some pollution from septic systems has occurred.

The Carpentaria Basin is the most northern tectonic unit in the Great Artesian Basin. The major aquifers in the Carpentaria Basin are the Gilbert River Formation and the Garraway Beds with some groundwater occurring in the Helby Beds. Similarly to the Laura Basin the major aquifer units are composed of sandstones, mudstones and conglomerates and are overlain by a thick argillaceous unit (the Rolling Downs Formation).

The Garraway Beds and the Helby beds generally contain subartesian aquifers in their outcrop areas that have the potential to supply useful quantities of good quality water. However few bores exploit these aquifers in these areas owing to the ready availability of surface water. Flows up to 43 L/s have been recorded from the Carpentaria Basin near Weipa. Stockwatering is the main use of Carpentaria Basin water in the study area.

The quality of groundwater from the major Carpentaria Basin aquifers, the Gilbert River Formation and the Garraway Beds, when they are unconfined, is generally good and suitable for most purposes. When these aquifers become confined, the water quality deteriorates. This feature is attributable more to the water residence time in the aquifer than to its confined state. Generally the conductivity varies from around $400 \mu \text{Scm}^{-1}$ to $1400 \mu \text{Scm}^{-1}$ in deep artesian bores.

Elevated levels of sodium and bicarbonate in the groundwater generally make it unsuitable for irrigation of the clayey soils derived from the Rolling Downs Group. High Fluoride levels in water from the Mesozoic sandstones often precludes it from use for human consumption. The Weipa and Aurukun deep bores were drilled to provide water for mining purposes. However these are no longer used for that purpose owing to the corrosive nature of their water and the ready availability of good quality groundwater from the commonly overlying Karumba Basin aquifers.

The Karumba Basin is the major water resource of the study area providing water supplies to 60% of the study area's population. This resource provides domestic supplies for Weipa, three Aboriginal communities and for the region's largest mining and industrial complex and stockwater for over one third of the Peninsula. Over 150 bores presently tap both artesian and subartesian aquifers in the Basin.

The Karumba Basin overlies the majority of the Carpentaria Basin in the study area. Within this basin the Bulimba Formation and the Wyaaba Beds contain the major aquifers. The Bulimba Formation is the more significant in terms of areal extent and capacity.

The Bulimba Formation is composed predominantly of interbedded clayey quartzose sandstone, granule conglomerate and sandy kaolonitic claystone. The Wyaaba beds consist of coarse to fine grained sandy claystones with a lower marine section.

The hydrology of the Karumba Basin is poorly understood. It is considered the assessment and management of the groundwater resources of the Karumba Basin is essential to any strategy developed for Cape York Peninsula.

The Bulimba Formation contains variable quantities of subartesian water across its entire extent in the study area and artesian supplies in some areas. Artesian flows up to 30 L/s have been recorded. Within the limited extent of the Wyaaba Beds' aquifer within the study area it is a reliable producer of fair quality water producing at rates of 0.5 to 6.0 L/s from either flowing or pumped bores.

Groundwater quality in the Karumba Basin is good although some highly saline water occurs with the Wyaaba Beds. This formation generally has higher conductivity values than the Bulimba Formation. The quality of water from the Bulimba Formation aquifers is in general, excellent and suitable for all purposes with conductivity values averaging around $420 \, \mu \text{Scm}^{-1}$. The Wyaaba Beds' aquifer reflects the marine origins of its sediments with conductivities ranging from $700 \, \mu \text{Scm}^{-1}$ to $2500 \, \mu \text{Scm}^{-1}$. Low pH levels may be of concern in some shallow aquifers in the Karumba Basin (<5.0) at Aurukun.

Beach ridge and coastal dunes are extensive around most of the coastline of the study area. These contain groundwater resources of variable quality, but can be suitable for stockwatering and domestic use, though little detailed work on these resources has been done. These groundwater resources often occur in isolated locations and would require significant infrastructure to be of use at the present demand locations. In the current tourism trend, these aquifers may become significant for recreational developments.

The quality of groundwater from sand dune aquifers is considered to be potentially good. However only one reliable sample from beach ridge aquifers is available and it is difficult to extrapolate broad aquifer type characteristics from this.

Alluvial deposits, include river bedload, channel and minor deltaic deposits. These are often of shallow depth, with high permeability and storativity and are of variable degrees of homogeneity. Water supplies from alluvial deposits are probably limited and of variable quality in the study area. Most of the larger rivers in the study areas have sandy beds which can provide small supplies though in a few localities there is some prospect of obtaining high yielding bores. Good water supplies were found in shallow alluvial sand and gravel deposits that probably represent old channels of the Mitchell River. Additionally there may be prospects for groundwater in the more extensive flood plain deposits in the eastern rivers.

Groundwater Management Issues

There are significant complexities in groundwater management of this area, including the provision of water in appropriate quantity, quality and at the appropriate time needed by users. The markedly seasonal rainfall patterns of the peninsula, and the prevalent drought conditions often lead to a large difference in time between when groundwater from some of the less reliable sources is available and when this resource may be in demand. This is particularly so for fractured rock aquifers such as those in the Coen Inlier or the Hodgkinson Formation, the lateritic aquifers around Weipa which are directly recharged by rainfall and the shallow river bed alluvial aquifers throughout the Peninsula.

There are some basic strategies which facilitate management of the groundwater resources of the Peninsula. However many of the issues are site specific and ubiquitous management solutions are inappropriate. In such situations detailed evaluation of potential problem areas is usually required. With such technical limitations, appropriate conservation and management strategies are difficult to determine. Specifically, the Peninsula's aquifers need to be protected from over exploitation, saline water intrusion into fresh groundwater (from both seawater and adjacent saline aquifers), point source pollution (e.g. from industrial and sewerage plants) and diffuse contaminants (e.g. agricultural fertilisers/pesticides).

Most of the problems are likely to be exacerbated by extraction rates that, through a lack of knowledge or appropriate management strategies, may be greater than those the groundwater system can safely bear. This may occur with expanding industrial, agricultural and population trends putting an increasing burden on these limited natural water resources.

Particular issues relating to resource protection have been identified. These include the potential of increased abstraction of resources to cause a deterioration in water quality. However this has not been identified as a major problem at present (though it appears to be occurring on a small scale) as the abstraction rates of the resource in the study area are, except at Weipa, generally low. At present over exploitation of small fractured rock resources appears to be of concern to local users. These aquifers are usually small and isolated.

There is a paucity of groundwater data away from the population centres of the Peninsula. This point was highlighted during the CYPLUS drilling program when artesian water was discovered at Frenchman's Road (Batavia Downs), an area previously unknown to contain artesian water supplies. Because of a lack of data, groundwater hydrological mechanisms in this area are not sufficiently well understood to explain this occurrence precisely.

In managing this resource, consideration also needs to be given to the relationship between groundwater abstraction and natural discharge areas i.e. springs. Groundwater contributions to stream flows and wetlands is important in some areas and protection of these areas is a major groundwater management issue. These areas may be of cultural significance and of concern to tourism particularly if there is a significant reduction in size and quality of these natural discharge sites. It should be noted that in many areas any use of this resource will reduce the outflow from springs.

In the Laura Basin spring flow maintains the region's only perennial stream, the Hann River, and provides nearly continuous supply to other rivers such as Little Laura, Normanby and Endeavour Rivers. Spring flow from the Bulimba Formation contributes to base flows in several rivers and maintains wetland environments near Weipa and Aurukun.

Pollution has not been identified as a major problem at present, with the exception of the upper aquifers at Laura which have suffered bacteriological contimination. However, few areas at present support intensive agricultural crops or other ludustries that have high nutrient, pesticide and other chemical uses. The Weipa area (with its mining activities and township) posses significant potential pollution risks to groundwater. This situation is requiring careful management as it is located on the recharge area of the Bulimba Formation which is the major source of potable water for the local regions.

Groundwater in the Peninsula is generally of very good quality and virtually pollution free. However in comparison to other areas in Queensland little is understood of the processes operating including water chemistry, aquifer characteristics and the hydraulic mechanisms. Additionally little work has been done on planning for sustainable use of this resource. Such planning is becoming more and more important with the increasing demands being placed on this resource from agriculture, tourism and with the potential for increased mining. Further information, particularly in areas of importance either for development or from the perspective of resource vulnerability, will need more thorough and site specific investigations to ensure the continued integrity of this resource.

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TABLE OF CONTENTS

Page	No.
5-	

1.0	INTRODUCTION1.		
1.1	Location and Access		.3.
1.2	Natural Feat	ures	. 6.
1.3	Methodology		13.
2.0	GEOLOGY.		19.
2.1	Basement Ge	elogy (Fractured Rock Aquifers)	23.
	2.1.1	Coen Inlier	24.
	2.1.2	Yambo Inlier	26.
	2.1.3	Hodgkinson Province	26.
	2.1.3.1 Hodgl	cinson Province - Tertiary Volcanics	27.
	2.1.4	Cape York Pyroclastics	28.
2.2	Laura Basin	***************************************	28.
2.3	Carpentaria	Basin	33.
2.4	Karumba Ba	esin	37.
2.5	Cainozoic Sediments Associated with the Coen Inlier44.		
2.6	Surficial De	osits	<u>4</u> 5.
	2.6.1	Alluvial Deposits	, 45.
	262	Coastal Sand Dune Denosits	. 46.

FIGURES

		Page No.
1.1	Location Map	3.
1.2	Land Tenure Map	5.
1.3	Physiographic Units	8.
1.4	Climatic Data	
1.5	Five Year Average Rainfall	
1.6	River Basins	
1.7	CYPLUS Bore Census and Drill Hole Locations	
1.8	Drill Holes	
2.1	Tectonic Units	20.
2.2	Tectonic Unit Age Relationships	21.
2.3	Stratigraphic Table	
2.4	Stratigraphy of the Great Artesian Basin in Queensland	22.
2.5	Laura Basin - Gilbert River Formation - Initial Structure Contours and Bores	31.
2.6	Laura Basin - Rolling Downs Group - Initial Structure Contours and Bores	32.
2.7	Carpentaria Basin - Gilbert River Formation - Initial Structure Contours and Bo	
2.8	Carpentaria Basin - Rolling Downs Group - Initial Structure Contours and Bore	
2.9	Karumba Basin - Bulimba Formation - Initial Structure Contours and Bores	
2.10	Karumba Basin - Wyaaba Beds - Initial Structure Contours and Bores	
3.1 3.2	Schematic Hydrological Cycle - Cape York Peninsula	
3.3	Licensed Bores - Major Water Usage	
3.4	Drinking Water Bores	
3.5	Artesian Bore Discharge Rates	
3.6	Groundwater Temperature Trend	
3.7	Typical Weathering Profile Developed on Crystalline Basement Rocks	
3.1	Typical weathering Profile Developed on Crystaline Basement Rocks	61.
4.1	Simplified Dendrogram of Water Types	88.
4.2	Groundwater Types	
4.3	Water Type by Tectonic Unit	94.
4.4	Water Type by Aquifer	<u>95</u> .
4.5	Ionic Variation Between Water Types	96.
4.6	Concentrations of Major Ions - Water Type A	97.
4.7	Concentrations of Major Ions - Water Type B	97.
4.8	Concentrations of Major Ions - Water Type C	98.
4.9	Concentrations of Major Ions - Water Type D	98.
4.10	Concentrations of Major Ions - Water Type E	
4.11	Concentrations of Major Ions - Water Type F	
4.12	Concentrations of Major Ions - Water Type G	
4.13	Conductivity and Hardness Variations Between Water Types	
4.14	Groundwater Conductivity	
4.15	Groundwater Hardness Levels	105.

FIGURES (cont.)

	P	age No.
4.16	Groundwater Alkalinity Levels	106.
4.17	Groundwater Fluoride Concentrations	
4.18	Groundwater Sodium Adsorption Ratios	109.
4.19	Trilinear Diagram - Basaltic Aquifers	110.
4.20	Trilinear Diagram - Acid Intrusives Aquifers	110.
4.21	Coen Inlier - Conductivity and Hardness Variations	112.
4.22	Coen Inlier - Trilinear Diagram - Metamorphic Aquifers	113.
4.23	Hodgkinson Province - Conductivity and Hardness Variations	115.
4.24	Hodgkinson Province - Trilinear Diagram Metamorphic Aquifers	116.
4.25	Laura Basin - Conductivity and Hardness	117.
4.26	Laura Basin - Trilinear Diagram - Gilbert River Formation/Dalrymple Sandstone	:117.
4.27	Carpentaria Basin - Conductivity and Hardness	120.
4.28	Carpentaria Basin - Trilinear Diagram - Mesozoic Sandstones	120.
4.29	Karumba Basin - Conductivity and Hardness Variation	122.
4.30	Karumba Basin - Trilinear Diagram Bulimba Formation/Wyaaba Beds	122.
5.1	Potential Recharge Areas	126.
5.2	Data Logger Record - Strathmay	
5.3	Data Logger Record - Holroyd	128.
5.4	Data Logger Record - Batavia Downs	129.
5.5	Data Logger Record - Wolverton	129.
5.6	Data Logger Record - Edward River 1	130.
5.7	Data Logger Record - Edward River 2	130.
5.8	Groundwater Discharge (Spring) Areas	

TABLES

		Page No.
1.1	Land Tenures of CYPLUS Study Area	4.
1.2	Major Physiographic Units	
1.3	General Soil Types	
3.1	Community Water Usage	53.
3.2	Geothermal Gradients - Weipa and Rutland Plains Areas	
3.3	Laura Basin - Mesozoic Sandstones Aquifers	68.
3.4	Laura Basin - Rolling Downs Group Hydrogeological Parameters	69.
3.5	Carpentaria Basin - Mesozoic Sandstones - Aquifer Parameters	74.
3.6	Karumba Basin - Bulimba Formation - Aquifer Data	79.
3.7	Karumba Basin - Wyaaba Beds - Aquifer Data	80.
4.1	CYPLUS Area Aquifers	86.
4.2	Sample Availability by Aquifer	88.
4.3	Summary of Water Types by Geographical Location	
4.4	Summary of Occurrences and Potential Limitations of Water Types	93.
4.5	Water Types - Average Analyses	93.
4.6	Average pH Values	
4.7	Sodium Adsorption Ratio (SAR) Toxicity Levels	108.
4.8	Coen Inlier - Average Groundwater Analyses	111.
4.9	Yambo Inlier - Average Groundwater Analyses	114.
4.10	Hodgkinson Province - Average Groundwater Analyses	
4.11	Laura Basin - Average Groundwater Analyses	119.
4.12	Carpentaria Basin - Average Groundwater Analyses	119.
4.13	Karumba Basin - Average Groundwater Analyses	
4.14	Beach Ridge - Groundwater Quality	
5.1	Average Annual Water Balances	131.

1.0 INTRODUCTION

The Cape York Peninsula study area¹ is remote and isolated, covering some 143 000 km² with a small sparsely settled population of around 10 000 (1986 census) and no major population centres. The principle resource uses are rangeland grazing, mining and tourism. These activities have had comparatively little obvious impact to date on the physical environment, though some accelerated soil erosion from grazing leading to sediment and nutrient losses into the near coastal environment do occur. Tourism is expected to become a major growth industry, particularly in the coastal areas (Connell Wagner, 1989).

Groundwater comprises those water resources that occur in the sub-surface and completely saturate the host material. These resources are usually hydraulically connected over a sufficient area to constitute a useable resource for an intended purpose.

Groundwater is a vital component of the natural environment. It provides base flow for some rivers, lakes and wetlands and sustains a variety of ecosystems. It is extensively used for agricultural, mining and urban purposes throughout Australia.

Within the Cape York Peninsula study area, all of the communities except Bamaga and Wujal rely on groundwater for at least part of their domestic water supplies. Groundwater is the major source of water supply for agricultural purposes, particularly stockwatering, and for mining at Weipa.

It is only recently that groundwater has been recognised as a limited resource and that both its quality and quantity have been regarded as finite.

Consequently, the social and economic importance, the significance to the environment, and vulnerability to degradation (through both mismanagement and pollution) of groundwater, is generally poorly understood by the majority of the population. Australia's groundwater resources have not been fully investigated, though State Governments have undertaken specific detailed investigations in many more highly developed areas.

This report presents an overview of the nature of the Peninsula's groundwater resources and those features intrinsically related to their ongoing use and protection, including the nature, and availability of groundwater. It summarises available information from published reports, drilling, geophysics and an extensive water analysis program. It should serve to highlight the importance of the Peninsula's groundwater resources and to lay the foundation for any subsequent detailed groundwater assessment.

The study area has variable climatic conditions and extremely diverse geology, and subsequently complex groundwater processes. Direct information on groundwater quality, quantity and host rock geology is sparse.

¹ The Cape York Peninsula Land Use Strategy study area was extended in the southwest to include the Staaten River for this report. See Section 3.

Most available information is clustered around the areas of Weipa, Cooktown and Kowanyama. Elsewhere, detailed information has been collected for only a short period of time. Natural variations to the groundwater resources over longer periods are poorly understood.

Groundwater quality can be affected dramatically by human influences as well as by natural processes. Prudent management of water resources is a principal factor in both integrated and sustainable resource use. Difficulties occur in determining (and achieving) an appropriate balance between groundwater resource utilisation and the broader environmental and social requirements while maintaining water quality and sustainable conservation practices. Poor land and water management practices can result in both deterioration of groundwater quality and a concentration of soil contaminants.

There are some basic strategies which facilitate management of the groundwater resources of the Peninsula. However, many of the issues are very site specific and ubiquitous management solutions are inappropriate. In such situations, detailed evaluation of potential problem areas is usually required. With such technical limitations, appropriate conservation and management strategies are difficult to determine. Specifically, the Peninsula's aquifers need to be protected from over exploitation, saline water intrusion into fresh groundwater (from both seawater and adjacent saline aquifers), point source pollution (e.g. from industrial and sewage plants) and diffuse contaminants (e.g. agricultural fertilisers/pesticides).

The geographical boundary of the associated CYPLUS projects (which includes for example, Soils, Vegetation, Insect Fauna, Fish Fauna) is similar to this one. In general, all projects were conducted during the period April 1992 to June 1994.

The Groundwater Resources project was undertaken by the Department of Primary Industries (DPI) and Australian Geological Survey Organisation (AGSO) with the DPI operating as project leader. The broad project responsibilities for each organisation were as follows.

DPI: Project leadership, office based research and stratigraphic interpretation, associated drilling, interpretation and pump testing of boreholes, bore hole census (including routine chemical analyses).

AGSO: Detailed groundwater chemistry sampling and analysis, and landsat imagery interpretation.

In this work approximately 250 field days were completed, excluding approximately six weeks of operations by a drilling crew.

1.1 Location and Access

The study area includes the entire mainland Peninsula and adjacent coastal islands, and is bounded to the south by approximately the 16°S latitude and the southern boundary of the Cook Shire (Figure 1.1).

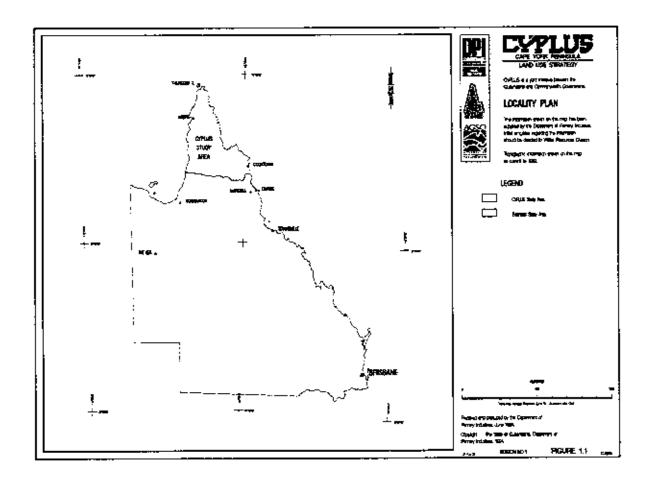


Figure 1.1 Location Map

The area is large and sparsely settled with all towns except Coen and Laura (population 200 each) located on the coast. Such demographics, combined with the harsh environment and remoteness, have resulted in the development of only a basic infrastructure and communications system.

The area is served by road, air and sea facilities, all of which are limited to some extent by the wet season. The larger coastal settlements have been established generally where there were suitable harbours or barge landing sites (Connell Wagner, 1989). The only comprehensive wharf facilities are located at Weipa, the largest port in the study area and at Cape Flattery. Coastal conditions are good during the dry season but the often cyclonically influenced wet season can limit shipping.

Air travel is an important means of transport, with all major properties containing at least one serviceable airstrip. Navigation facilities are almost nonexistent with the only airports at Weipa (multi-engine jet standard) and Cooktown (multi-engine propeller standard). Airstrips to larger multi-engine propeller craft standard are located at Coen, Pormpuraaw and Kowanyama.

Road access to the region is provided by the Peninsula Development Road from Mareeba to Cooktown, by the Burke Development Road from Normanton to Dunbar (just south of the central western study area), and by the Cape Tribulation Road from Mossman to Cooktown. These roads are usually only open for six to eight months of the year with the exception of the Peninsula/Cooktown Development Road which is accessible for most of the year.

The internal roads in the study area are constructed to varying standards and maintained by several government entities, aboriginal councils and mining companies. Without extensive local knowledge and experience and for other than short journeys the area is traversable only by 4WD vehicles. Access along the northern Peninsula Development Road from Cape York south to Heathlands (using the Jardine River ferry) and the Cooktown Development Road is available most of the year. Large tracts of area around such locations as the northern Laura Basin and Northern Hodgkinson Basin are inaccessible by land most of the year.

A significant portion of the study area has been gazetted for special use, including National Parks and Aboriginal Tenures. The Infrastructure and land tenure of the study area are shown in Table 1.1 and Figure 1.2.

Land Tenure	km²	%
Aboriginal and Torres Strait Islander Lands	20 200	15
Crown Lands and Crown Reserves	5 500	4
Freehold	5 600	4
National Parks	13 500	10
Pastoral Holdings	78 300	57
Perpetual Mining Tenures	4 000	3
Road and Natural Features	1 100	1
State Forest and Timber Reserves	2 300	2
Other	6 200	4
Total	136 700	100

Table 1.1 Land Tenures of CYPLUS Study Area (does not include extended study area) (Courtesy, Queensland Department of Lands)

1.2 Natural Features

Topography/Physiography

The study area is of comparatively low relief, with broad plains comprising around 75% of the total area. These broad plains slope gently seaward, both to the east and west from a ridge of low mountains and hills which is located closer to the east coast. This divide extends from the southern study area boundary northward along the section of the eastern coast immediately north of Cooktown and is expressed as a plateau in the south east of the study area.

The western and eastern lowlands overlie the Carpentaria and Laura Geological Basins respectively. The higher relief terrain of the Central Peninsula Ridge through to the south eastern study area boundary and including the south eastern seaboard (north from Cooktown) is formed by the Coen and Yambo Inliers and the Hodgkinson Basin.

The soils reflect their parent material and are highly susceptible to erosion. Generally, the soil types are complex and varied, with low fertility and nutrient levels, are weakly structured and prone to erosion when cleared (Connell Wagner, 1989).

The study area contains a number of large seasonally variable rivers, most of which flow east or west, with only the Kennedy and Normanby Rivers flowing northwards. Most have extensive floodplains in their lower reaches and in the coastal belt, and meander across broad mudflats. In these areas, the rivers are a dominant landscape feature, though their alluvial deposits are relatively thin.

The drainage pattern in the Carpentaria and Laura lowlands is widely spaced and appears to be governed by the soil type. Sandy soils have a denser drainage pattern and radiating distributaries often develop from the large alluvial fans that occur on the western Peninsula in the study area. The black soils have a more widely spaced drainage system (Smart, 1980).

The higher relief Central Peninsula Ridge has a gentle westward slope towards the Gulf of Carpentaria. The eastern boundary of this ridge north of the Laura Basin is steep, and in some areas forms steep escarpments. Some tablelands also occur through this central area. The highest sections of the Central Peninsula Ridge are around 800 m above sea level in the Coen/Iron Range areas and in the area south of Laura around Mount Lukin,

Several large dunefields occur along the eastern Peninsula seaboard, the most significant being the Olive River/Cape Flattery dunefield. Beach ridge dunefields also occur near Cape York. The Torres Strait Islands are principally volcanic in the west with sand, beach rock and coral cays in the eastern area.

Topography can have a significant influence on groundwater flow and generally determines flow gradients. In hard rock areas, the comparatively thin weathered layer and water tables both usually follow the surface morphology. Unless the depth of weathering is below the surface drainage level, aquifers in these zones rapidly dry up after the wet season (Ackworth, 1987).

The major physiographic units in the study area are briefly described in Table 1.2. and are shown in Figure 1.3.

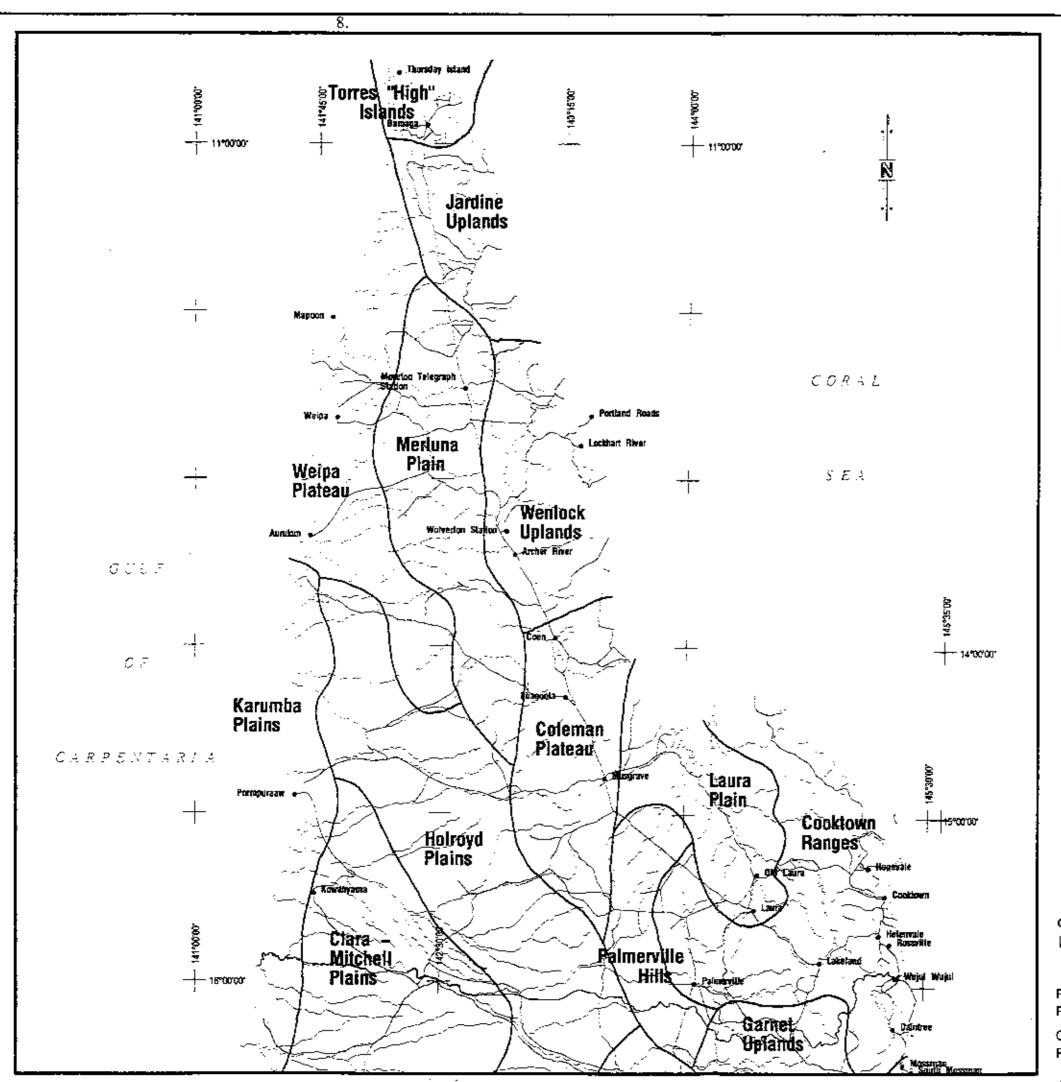
PENINSULA UPLANDS PROVINCE		
Torres 'High' Islands		
Jardine Uplands	Locally dissected rolling sandstone upland with transgressive coastal dunes along an Eastern lateritic cliffed margin.	
Wenlock Uplands	Complex of tablelands and low plateaux with North-South lowlands, prominent scarp, and outlying coastal hills on the Eastern side.	
Coleman Plateau	Rolling sandy granitic plateau with low ridges of metamorphic rocks, prominent Easterly scarp.	
Laura Plain	Soft-rock lowlands, alluvial plains of centripetal drainage, and littoral plain.	
Cooktown Ranges	Deeply dissected sandstone plateaux, with mountain ranges of granite and metamorphic rocks to the East, small 'high' islands.	
Palmerviile Hills	Granite hills and plateaux and sandstone mesas with intervening plains, steeper fall on the Easterly side.	
Garnet Uplands	Hilly uplands, with dissected greywackes and volcanics in the North and undulating country on granite and metamorphic rocks in the South.	
	CARPENTARIA LOWLANDS PROVINCE	
Weipa Plateau	Laterite-capped plateau on clayey sand and sandstone.	
Merluna Plain	Undulating clay plains with lateritic rises.	
Holroyd Plains	Slightly dissected sandy plains, partly lateritic.	
Karumba Plains	Littoral plain.	
Clara-Mitchell Plains	Clara-Mitchell Plains Sloping sandy plains with minor clay plains along distributary drainage.	
Bulimba Plateau Dissected low sandstone plateau.		

Table 1.2 Major Physiographic Units (Modified from Jennings and Mabbutt, 1977)

Vegetation

The study area has a diverse range of vegetation types, resulting from the large range of soils, rainfall patterns and landforms. Eucalypt woodland and open forest areas are the principal vegetation coverages and significant areas of melaluca woodland also occur.

This natural vegetation is considered fragile and vulnerable to rapid change from human influences including introduced exotic species, overgrazing, changed fire regimes, intensive development of unstable landforms, and diversion of, or interference with, existing hydrological systems (Conneil Wagner, 1989).





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PHYSIOGRAPHIC UNITS

WATER RESOURCES

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(dassification from Jennings and Mabbut, 1977)
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Topographic information shown on this map is current to 1989.

LEGEND

Rivers
1:250 000 Geology
Sheet Boundaries

Physiographic Unit Boundary

CYPLUS Study Area

Extended Study Area

Figure 1.3: Major Physiographic Units

	KILDMETRES		
0	100	200	250
		. : <u> </u>	<u> </u>
	Transverse Mercator Projection Zone 54 : Aust	га б ал Мар Grid	

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FIGURE 1.3

arunanea

The majority of the central Peninsula area is semi-arid and is covered with eucalypt woodlands, open savanna woodlands, grasslands and melaleuca woodlands. The northern inland areas have extensive areas of Recent and Quaternary sand cover, and experience a greater monsoonal influence. Here, open heathlands dominate. The Laura Basin is mostly covered by open eucalypt and stringybark woodlands.

The far north-western Peninsula contains significant woodlands, freshwater swamps, whereas far north-eastern coastal areas host mangrove swamps. These northern reaches also exhibit more tropical eucalypt woodlands and some rainforests. Vine scrubs also tend to occur on the northern Peninsula, and are usually confined to areas of better quality soil.

Along the east coast, particularly in the Iron Range area, dense tropical rainforests (vine forests) also occur.

The higher relief sections of the study area, generally on the margins of the Laura Basin and through the Coen Inlier (Central Peninsula Ridge and associated uplands), support ironbark and bloodwood. A comprehensive discussion of the plant communities is provided in Pedley and Isbell (1970). The CYPLUS vegetation mapping project has reported in significant detail on the vegetation of the study area.

Soils

The broad soil types of the study area are diverse, generally widespread and related to the major physiographic units and usually reflect the nature of the underlying geology. Table 1.3 provides a summary of soil information supplied by the CYPLUS Land Resource Inventory Program. A more detailed analysis of the Peninsula's soils occurs in the report for that program.

General Location	Soil Type	Comments
North and North Eastern Peninsula	Bleached sandy soils	Derived from coarse grained sandstones
	Sandy alluvial soils	Alluvial soils associated with major streams
Western Coast (approximately from Vrilya Point South to the Kendall River)	Bauxitic and ferruginous red and yellow earths	Formed on lateritic plateau
Merluna Plain Area	Predominantly clay soils	Formed on Rolling Downs Group
Coen Inlier, Cape York Pyroclastics (Northern tip of Peninsula)	Shallow and rocky soils with some red and yellow clay areas	Derived principally from metamorphic and intrusive rocks
Eastern edge of Coen Inlier	Coarse sandy soils	Extensive alluvial fans and plains

General Location	Soil Туре	Comments
Yambo Inlier	Shallow rocky soils and red clays	
Clara-Mitchell Plains and Northern and Central Laura Basin	Alkaline grey clays	Extensive palaeostream deposits
Holroyd Plains	Residual red and yellow sandy soils	Frequently dissected by convergent to non-directional drainage features Plateaux containing red and yellow sandy soils
Northern and South Eastern Laura Basin	Shallow rocky soils and red and yellow earths	Formed on sandstone
Hodgkinson Province	Sodic and non-sodic yellow and grey soils (more arid areas) Red clays (high rainfall areas - south eastern corner)	
	Red and brown structured clay soils (on basalt flows)	Support dryland and irrigated cropping at Lakeland
Cape Flattery Cape Grenville	Large dunefields	
Western Coastline (lower half)	Dominated by large expanses of marine clays and saltpans interspersed by Holocene and Pleistocene Beach Ridges	Also on southern and eastern borders of Princess Charlotte Bay

Table 1.3 General Soil Types (Summarised From CYPLUS Soil Survey and Land Suitability Assessment Program - Courtesy, Department of Primary Industries)

<u>Climate</u>

The study area lies between latitudes 10°30'S and 16°30'S, exclusively within the tropical region. The climate in the region varies from humid tropical along the eastern coastal strip to semi arid tropical in the central and western Peninsula area. Information on climate has been drawn from the Bureau of Meteorology and Department of Primary Industries climate monitoring stations.

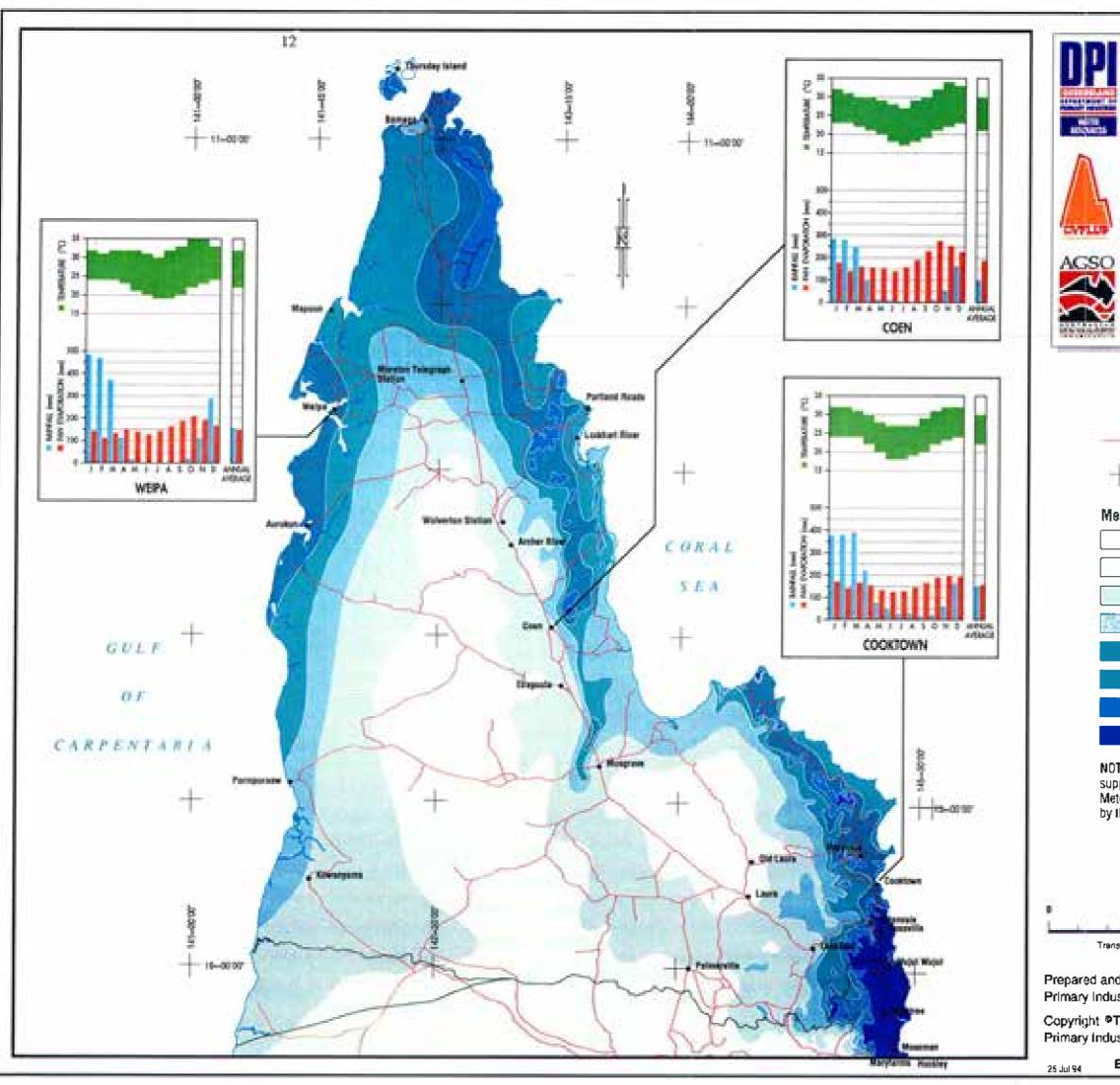
Throughout the Peninsula, mean daily temperatures are moderate in winter and high in summer. The area has high evaporation rates aided by persistent winds in most areas. Pan evaporation figures indicate the greatest average evaporation rates are during October, November and December and the lowest are generally in February, May, June and July. Frequent and lengthy droughts occur and result in sparse and unreliable surface water resources.

Rainfall is monsoonal, highly variable and sometimes unreliable, with marked wet and dry seasons. The wettest months are from November to March, with April to October being a significantly drier period. Cyclone activity is common in the summer months.

There is a wide range of average rainfall throughout the Peninsula. Rainfall is more consistent along the eastern coastal areas where it is more evenly distributed by prevailing south easterly winds. West of the coastal range, there is a sharp decrease in rainfall and an increase in rainfall seasonality. The local rainfall distribution of these inland areas is also patchy, with some stations recording high registrations during storm events while adjacent properties receive no rainfall at all.

Figure 1.4 displays general climatic data for the study area, shows a composite display of rainfall, and indicates yearly rainfall variations.

A five-year moving average of rainfall data for Coen, Cooktown and Weipa was calculated using composite data from the stations in these regions (Figure 1.5). Composite data was used as no specific rainfall station provided a continuous record over a sufficiently long period for this analysis. It should be noted that this composite approach has given a slightly lower rainfall figure for Cooktown than is illustrated in Figure 1.4.





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CLIMATIC DATA

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Roads

1:250 000 Geology Sheet Boundaries

Mean Annual Rainfatt (mm)

0 - 800

800 - 1000

1000 - †200

1200 - 1400

1400 - 1600

1600 - 1800

1800 - 2000

> 2000

NOTE: This data is based on information supplied by the Commonwealth Bureau of Meterology combined with records obtained by the department for the period 1920-1969.

Figure 1.4 Climatic Data

Transverse Mercetor Projection Zone 54 : Australian Map Gnd

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FIGURE 1.4

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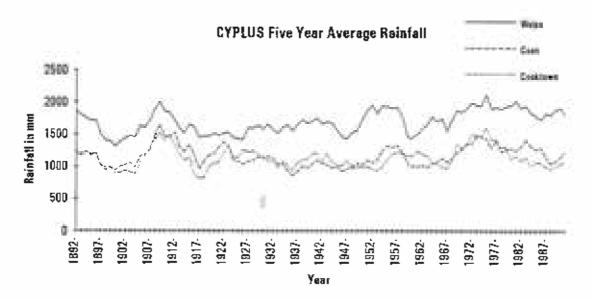


Figure 1.5 Five Year Average Rainfall

East coast streams are generally perennial including the Normanby, Pascoe, Jacky Jacky and Gunshot Creeks.

Surface Water

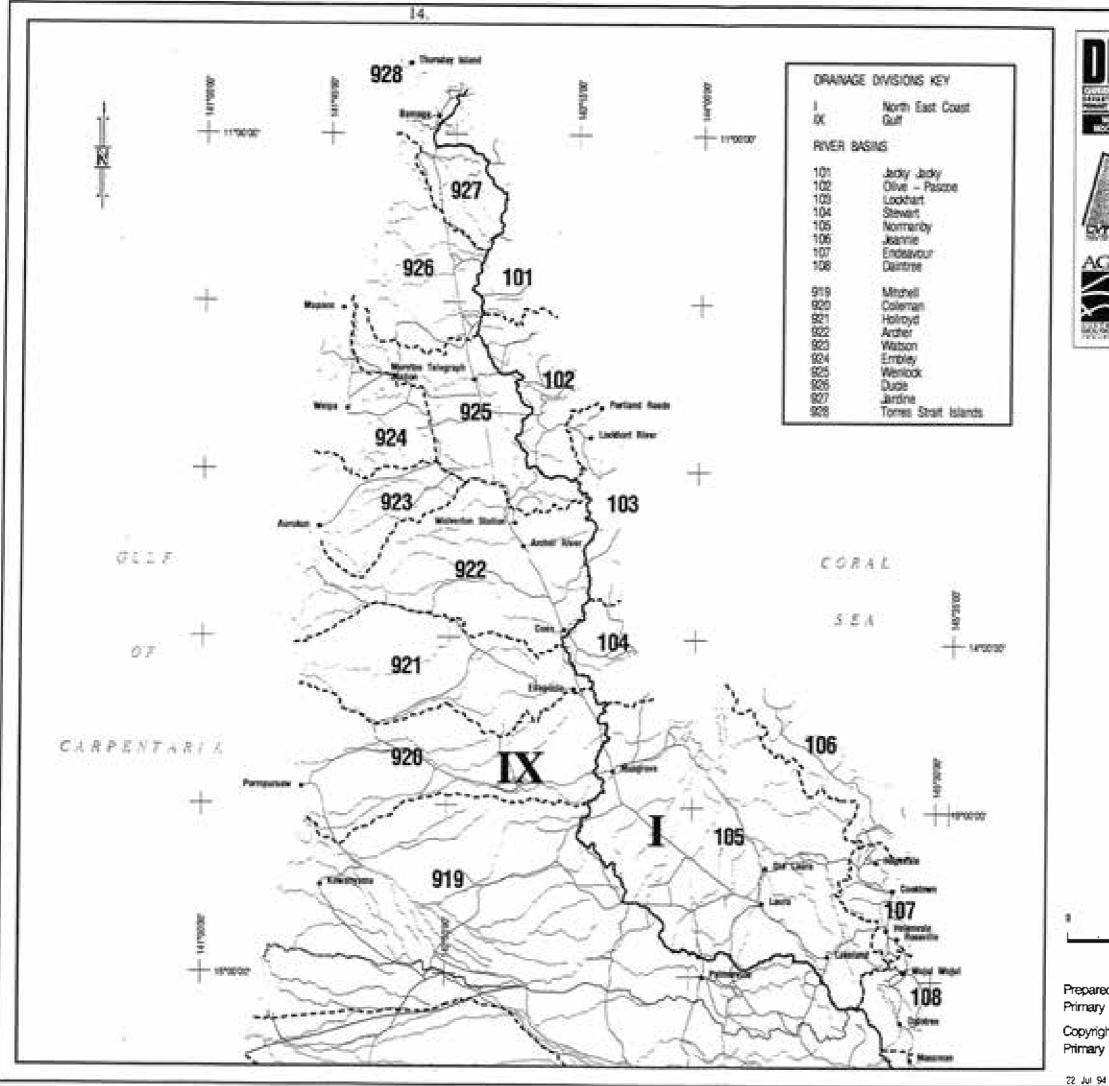
Surface water resources occur in the study area as perennial, ephemeral streams, swamps, lakes and springs. Most west flowing rivers in the study area are ephemeral, with only the Wenlock, Holroyd, and Jardine Rivers occurring as major perennial watercourses. Springs also provide some low flow to the upper reaches of the Hann, Little Laura, Kennedy, Normanby, and Endeavour Rivers. Each of these surface flows is provided from groundwater in the dry season. Significant swamplands occur in the lower reaches of the Jardine River.

Surface water resources are currently being documented in detail in the CYPLUS Surface Water Resources Project and will appear in a separate report. The main River Basins are shown in Figure 1.6.

1.3 Methodology

The research strategy was based on an evaluation of target audience groundwater information needs. This audience is principally the Cape York Community and the CYPLUS project team with additional usage being envisaged by other government departments, universities and private consultants. The information presented here is mainly technical, although it is in a form that should be easily adapted for groundwater enquiries of a more general nature.

A review of the available data, including DPI and AGSO reports and the DPI groundwater database was conducted. Acute data shortfalls were identified in the central Peninsula. Consequently a drilling program was designed and completed to reduce this data deficiency.







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RIVER BASINS

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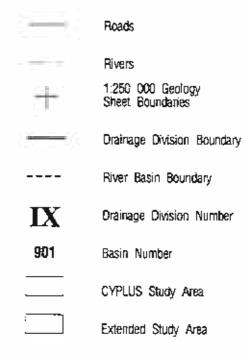
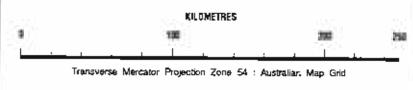


Figure 1.6 River Basins



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FIGURE 1.6 A3-103385

Water quality characteristics of aquifers in the study area were identified in a major field sampling program. This information was combined with a comprehensive review of available literature and an analysis of relevant geophysical data.

Data storage, manipulation and presentation has been essentially computer driven. Key components of the system included a principle data storage system, the DPI groundwater database, and two "state-of-the-art" computer based storage retrieval and evaluation systems, Systat (produced by Systat Inc.) and a Geographic Information System (GIS) - ARC/INFO (produced by Environmental Systems Research Inc).

Information for this report was obtained from the following sources:

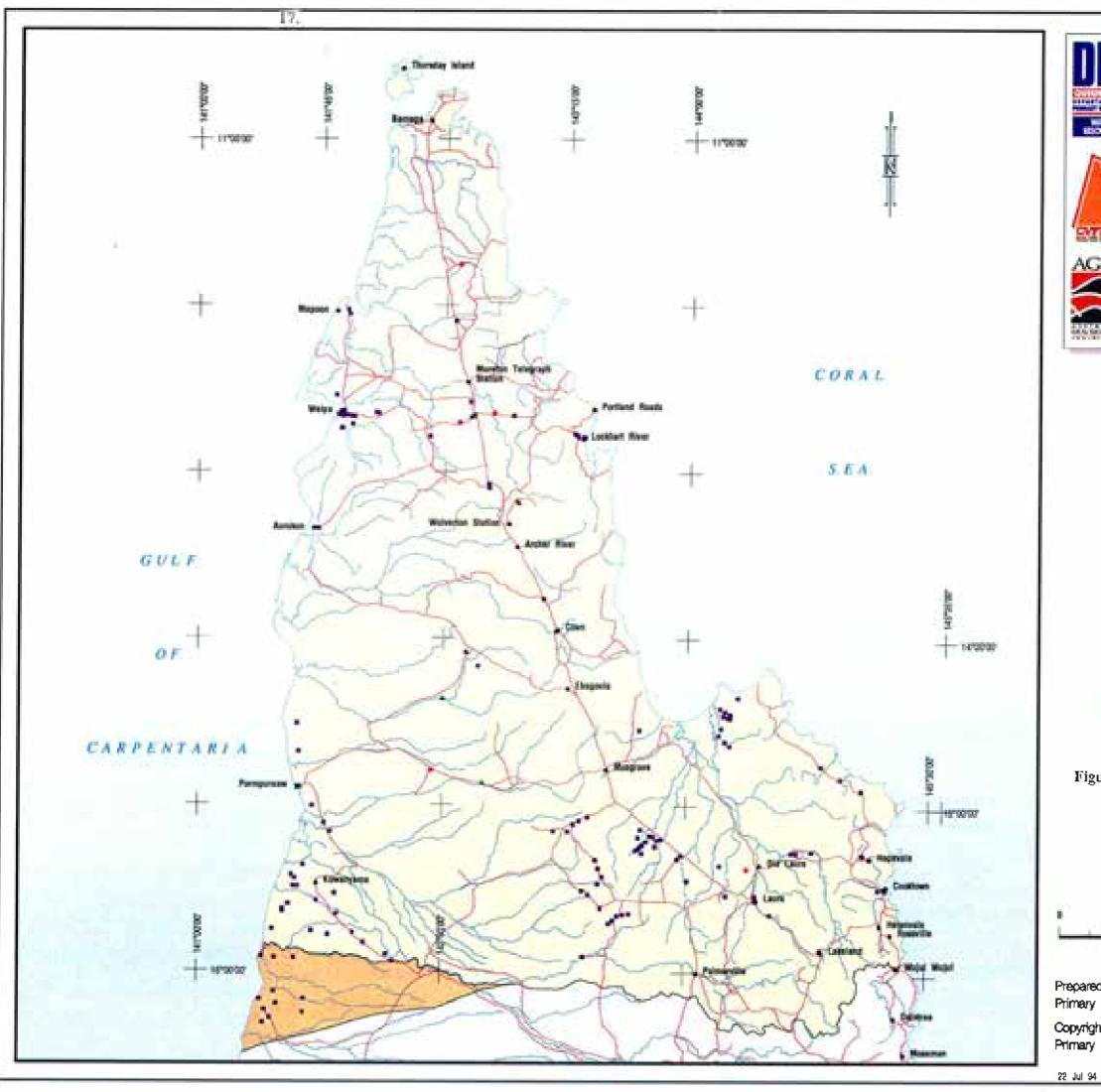
- Original field data obtained by an extended field program of locating and sampling as many boreholes as possible in the region. Information obtained included detailed water analyses, accurate location of boreholes, evaluation of the bore's physical condition (including headworks), bore yields and use.
- Twelve bore holes drilled specifically for this project to fill knowledge gaps in the
 hydrogeology and stratigraphy of the central Peninsula. These bores were logged in
 detail and correlated with adjacent holes. Figure 1.7 shows bores sampled during the
 bore census, and bores drilled as part of this project.
- A comprehensive literature review of the geology and hydrogeology of the region.
 Information was accessed from DPI-WR reports, mineral exploration company reports, AGSO records, Department of Minerals and Energy (DME) records and maps, University library holdings and Hydrogeological Consultants' reports.
- Seismic information contained in DME reports and company libraries. This
 information was interpreted mainly in-house, although some company interpretations
 were incorporated. A total of 28 representative seismic lines was used to correlate
 between existing drillholes.
- The DPI-WR groundwater database. This database contains data for 1025 drill holes, many of which were entered as part of this project. Information ranged from hole location only, to comprehensive stratigraphic and water quality analysis. Figure 1.8 indicates drillholes used in this project.
- Information from associated CYPLUS projects, principally the Land Resource Inventory, Digitising and Integration and Regolith Terrain Mapping.

The DPI-WR database contains virtually all information available on registered boreholes (RNs) in the study area. The entire study area is a Proclaimed Area under the provisions of the Water Resources Act (1989). All bores in the area, with the exception of most domestic bores, are required to be licensed and all bore data is required to be supplied to the Department of Primary Industries. This database was updated significantly as part of this study.

The groundwater resources of the study area have been analysed in detail by tectonic province and major aquifers. Also hydrogeological units were determined as three broad aquifer types similar to those categorised by Jacobson (1983).

- Surficial aquifers including unconsolidated sediments and calcrete.
- Deeper aquifers in large sedimentary basins.
- Shallow aquifers in fractured rock provinces.

The information available shows that groundwater occurrence and quality is highly variable. This is a result of the diverse geology, past and present climatic conditions and hydrogeological processes. These factors and the complexities added by surficial aquifers overlying deeper aquifers and variable recharge conditions complicate analysis and the presentation of results.







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CYPLUS BORE CENSUS & DRILL HOLE LOCATIONS

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LEGEND

Roads

Rivers

1:250 000 Geology Sheet Boundaries

 Bore Sampled during CYPLUS Program

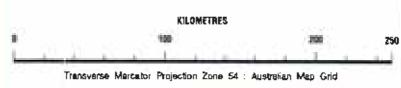
 Bore Drilled during CYPLUS Program

> Bore Drilled during CYPLUS Program and equipped with data logger

CYPLUS Study Area

Extended Study Area

Figure 1.7 Bore Census and Drill Hole Locations

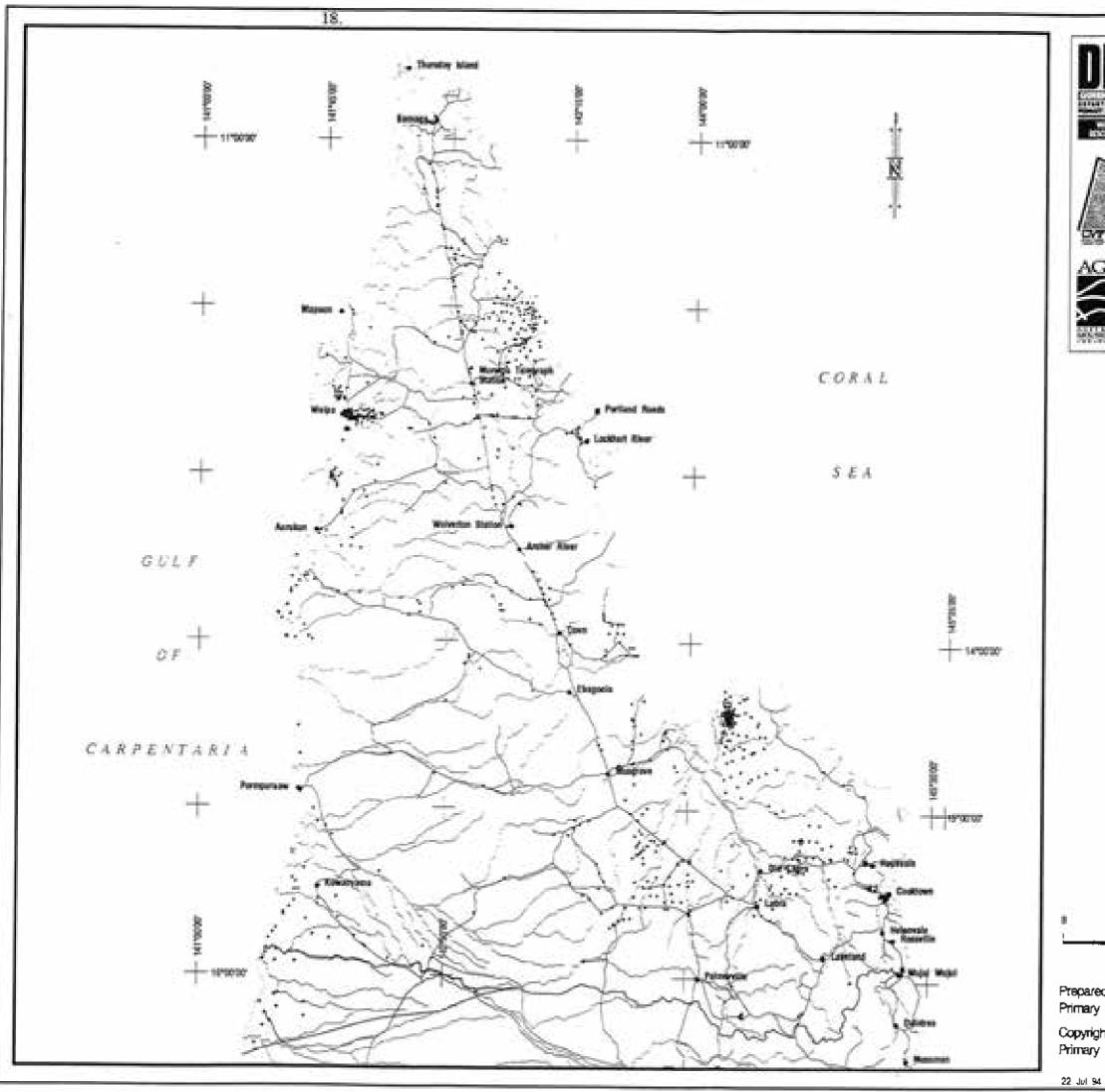


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FIGURE 1.7 A3-105321







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DRILL HOLES

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LEGEND

Roads Rivers 1:250 000 Geology Sheet Boundaries Drill Holes CYPLUS Study Area Extended Study Area

Figure 1.8 Drill hole locations

KILOMETRES Transverse Mercator Projection Zone 54: Australian Map Grid

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FIGURE 1.8 A3-105320

2.0 GEOLOGY

The groundwater resources of the study area are closely related to the geology with the main resources occurring in Mesozoic and Cainozoic sedimentary rocks.

Surface locations of geological units are detailed in the associated CYPLUS on Bedrock Geology.

The Mesozoic and Cainozoic geology has evolved through a complex sequence of depositional and erosional events with significant geological variations occurring regionally and locally. Because of these variations, the geological interpretations presented are only accurate in the broadest scale and detailed local interpretations would require further site specific data.

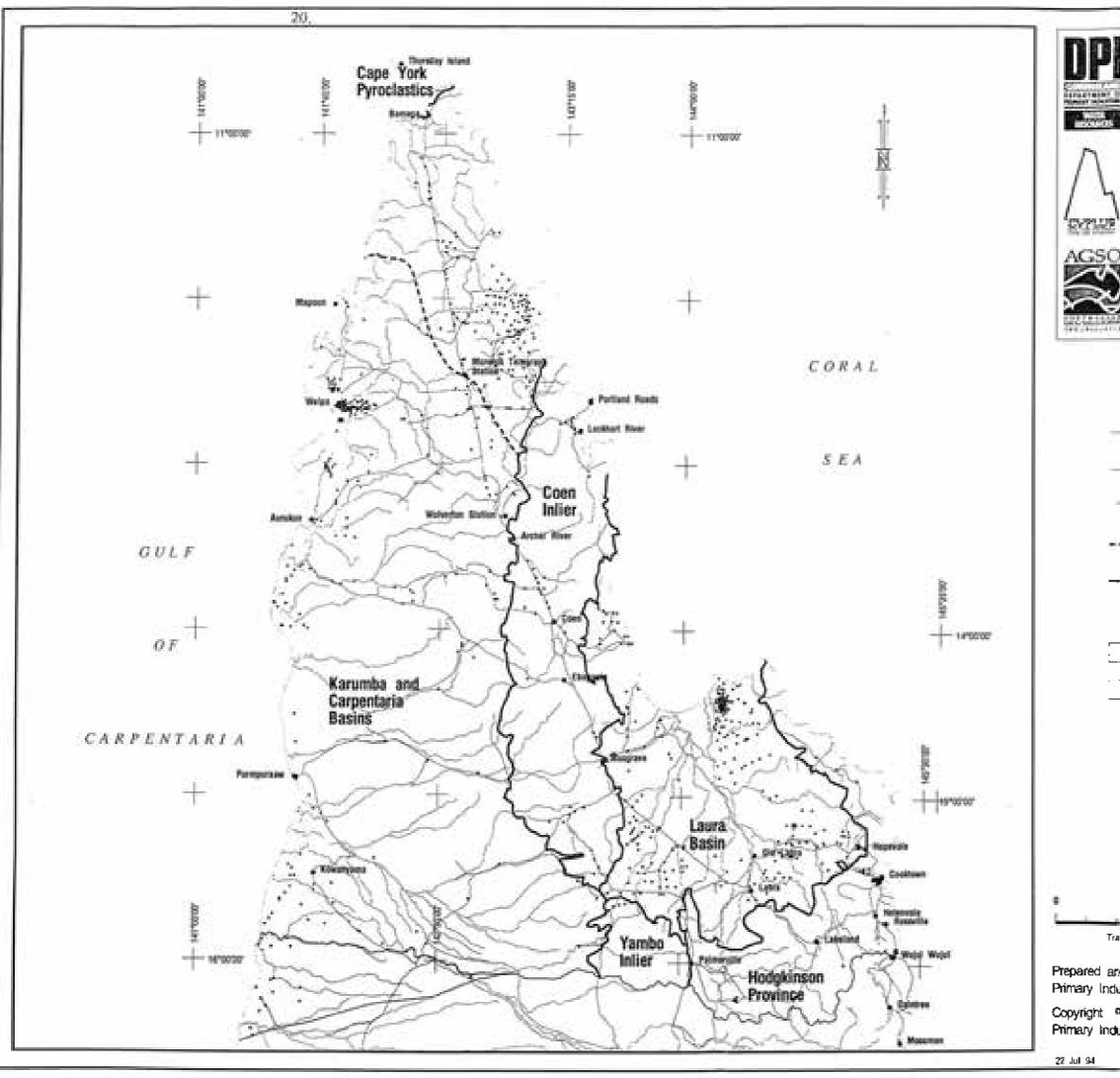
Current mapping programs by the Geological Survey of Queensland and the Australian Geological Survey Organisation are increasing the understanding of surface geology and airborne geophysical interpretations are helping to provide a broad understanding of basement depths. However, detailed knowledge of the intervening geology between the ground surface and basement is clustered around a few localities such as Weipa, Kowanyama and Cooktown. Knowledge of the sub-surface geology in other locations which represent over 90% of the study area is sparse.

Using groundwater characteristics as the major criteria, the study area can be divided into several major geological features that represent both formal and informal tectonic units. These are the Proterozoic and Lower Palaeozoic Coen and Yambo Inliers, the Devonian to Permian Hodgkinson Province, the Carboniferous Cape York Pyroclastics, the Jurassic/Cretaceous Carpentaria Basin and Laura Basin, and the Tertiary Karumba Basin. Tectonic unit boundaries are illustrated in Figure 2.1. and age relationships of the tectonic units in Figure 2.2. Figure 2.3 provides a stratigraphic table of the major Cainozoic and Mesozoic Units. Figure 2.4 displays the relationship between the Carpentaria Basin and other major basins in Queensland.

Quaternary and Recent history has modified the surface geological expression of Cape York Peninsula extensively. Features that are significant to the nature of the study area's groundwater resources include alluvial fan, river alluvium and coastal dune deposits.

The Lower Palaeozoic Coen and Yambo Inliers form a north-south spine through the central study area (see Figure 2.1). These inliers are composed of low to high grade metamorphics (greenschist to amphibolite facies) and mainly Permian intrusives. These inliers have experienced multiple and complex deformation principally related to tectonic compression, with some local deformation having occurred associated with igneous emplacement.

The Devonian to Permian Hodgkinson Province is situated in the south-east of the study area. In this area, it consists of deep water siltstones, arenites, conglomerates and basalts. These units have subsequently experienced tectonic compression and have undergone low grade metamorphism (greenschist facies). The beds are now tightly folded and are usually steeply dipping.





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TECTONIC UNITS

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LEGEND

Pavers

1:250 000 Geology Sheet Boundaries

Roads

Northern Limit of Karumba Basin

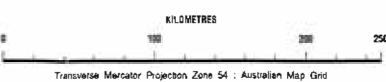
Tectonic Unit Boundary

Bores

CYPLUS Study Area

Extended Study Area

Figure 2.1 Tectonic Units



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FIGURE 2.1 A3-104001

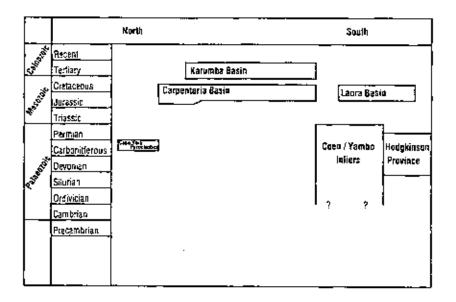


Figure 2.2 Tectonic Unit Age Relationships

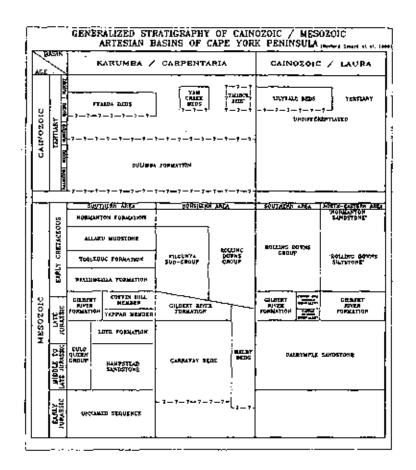


Figure 2.3 Stratigraphic Table (Revised Smart et al 1980)

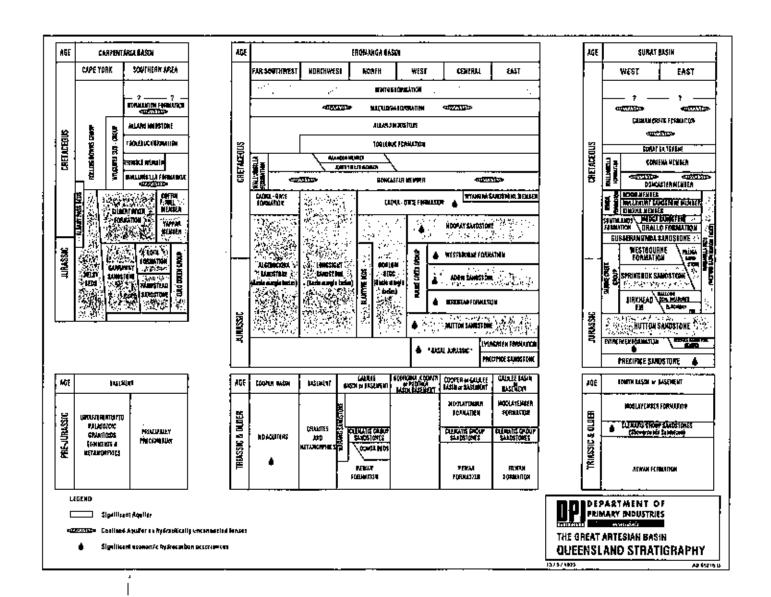


Figure 2.4 Stratigraphy of the Great Artesian Basin in Queensland

The Jurassic/Cretaceous Carpentaria and Laura Basins occur in the western and south-eastern areas of the study area respectively. These basins were deposited contemporaneously as epicratonic basins following basement downwarping and local block faulting. They are composed of equivalent formations and are lateral and contemporaneous equivalents to the Eromanga Basin (the largest sub-basin of the Great Artesian Basin). The Carpentaria Basin is also part of the Great Artesian Basin. The Carpentaria and Laura Basins are composed principally of two predominantly quartz sandstone formations overlain by an extensive and thick argillaceous unit. These units generally thicken towards the centre of their respective basins and usually overlie an uneven basement topography.

The Carboniferous Cape York Pyroclastics occur in the most northern section of the study area adjacent to the Carpentaria Basin. They have been distinguished as a separate unit for this work because of their differing hydrogeological nature from the adjacent Carpentaria Basin. The Cape York Pyroclastics are composed almost exclusively of tuffs and ignimbrites. Little work has been done on their nature, structure or depositional history and they are of minor significance to the groundwater resources.

The Tertiary Karumba Basin overlies most of the Carpentaria Basin in the south western and central western study area. It is composed principally of quartz arenites and siltstones. Apart from areas around Kowanyama, Weipa and Aurukun, few boreholes contain detailed interpretations of this formation. Little is known about its structure and internal nature.

Quaternary, Recent and ongoing erosional and depositional processes have extensively modified the surface geology of the study area. These processes have formed the depositional plains that are currently active along much of the western side of the peninsula and have initiated scarp retreat processes on the eastern side. Floodplain and river alluvial deposits occur over much of the Peninsula. Additionally, extensive Holocene and Pliestocence beach ridge deposits are common around much of the shoreline.

The geology of the Coen and Yambo Intiers has been documented extensively in the work of the North Queensland Mapping Accord (for example Anon., 1992). The Hodgkinson Province has been reported in detail in de Keyser and Lucas (1968), Bultitude et. al. (1990), Bultitude, et al, 1991. Little detailed work has been done on the Cape York Pyroclastics, with the best overview of these units occurring in the notes of the Torres Strait-Boigu-Daru 1:250 000 geology sheet (Willmott and Powell, 1975). The geology of the Laura Basin has been extensively documented in de Keyser and Lucas (1968), Passmore (1979), Smart and Rasidi (1979), Hawkins and Williams (1990) and Blake (1992). Similarly, the Carpentaria Basin geology has been documented in Meyers (1969), Smart (1976), Smart and Senior (1980) and Lait (1990). The geology of the Karumba Basin has been discussed in more detail in Doutch (1976), Smart and Senior (1980) and Lait (1990).

2.1 Basement Geology (Fractured Rock Aquifers)

Basement geology for the purpose of this report refers to those areas that either constitute outcropping basement or similar material such as metamorphics or acid intrusives that are potential aquifers, in which the chief hydrogeological mechanism operating is that of a fractured rock aquifer system.

These areas principally include the Coen and Yambo Inliers and the Hodgkinson Province as well as the Cape York Pyroclastics and some areas of the Torres Strait Islands as defined in Figure 2.1.

2.1.1 Coen Inlier

The Coen Inlier is located in central northern Cape York Peninsula and covers 18,830 km². It is composed largely of variably metamorphosed and deformed sedimentary rocks of Early to Middle Proterozoic age intruded by Middle Proterozoic granitoids (Bain et al, 1990). The eastern and western margins are sublinear, in part fault bounded (Smart and Senior, 1980) and at least partially underlie the Carpentaria Basin in the west and the Laura Basin in the east as basement. The Coen Inlier extends northwards under the Coral Sea.

The Coen Inlier is a metamorphic, magmatic and deformational complex, with complex secondary structures (Anon., 1992). It is composed of Early Proterozoic metasediments and metavolcanics, Silurian - Devonian granites and Carboniferous - Permian acid intrusives and volcanics (Anon., 1992). The geology of the Coen Inlier is similar to the older Georgetown Inlier (to the south of the study area) with this older inlier probably having provided the original source material for the Coen Inlier (Anon., 1992).

Continuous degradation of at least parts of the Coen Inlier (identified through regolith distribution) has occurred since the end of the Cretaceous (Anon., 1992) with Cainozoic erosion of provenance areas having exposed sections of the Coen Inlier (Doutch, 1976). The quartzite components in the metamorphic units can crop out as strike ridges up to 150 m high with the less resistant rocks being poorly exposed, deeply weathered and covered with sand (Willmott et al, 1973).

In the Ebagoola 1:250000 sheet (in the central Peninsula) most of the regolith is in situ weathered bedrock with little transported material. The granite terrains have a cover of deep residual sands that overlie mottled and pallid zones which reflect in situ chemical weathering (Anon., 1992). Such weathering profiles and lack of transport history are common throughout the Coen Inlier.

The following descriptions of the component units of the Coen Inlier are summarised from Willmott et al (1973) unless otherwise referenced:

Coen Metamorphics

The Coen Metamorphics principally crop out in two northerly trending belts south and east of Coen (Bultitude and Rees, 1994), are principally Pre-Cambrian biotite-muscovite-quartz schist, quartzite and biotite-quartz-feldspar gneiss (with lenses of calc-silicate material), (Stevens-Hoare, 1980), and are generally of upper amphibolite facies.

Holroyd Metamorphics

The Holroyd Metamorphics are of Pre-Cambrian age and comprise indurated sandstone and siltstone, phyllite, mica schist, felspathic schist, quartzite gneiss, greenstone and amphibolite. The suite has been subdivided into more detailed units. The western portion of the Holroyd Metamorphics is of greenschist facies (slate, siltstone, sandstone, phyllite and greenstone), grading eastward into amphibolite facies (schist, quartzite and amphibolite) (Bain et al, 1990).

Sefton Metamorphics

The Sefton Metamorphics are of Pre-Cambrian age and are composed of fine grained muscovite-quartz schist and quartzite with extensive interbands of other metamorphic rocks. The Sefton Metamorphics are similar to the amphibolite facies rocks of the eastern Holroyd Metamorphics (Bain et al, 1990). The dominant structural feature of the Sefton Metamorphics is a set of large NNW trending folds, which are locally overturned to the east (Bain et al, 1990).

Dargalong Metamorphics

The Dargalong Metamorphics occur in the Coen and Yambo Inliers, and consist of biotite and augen gneiss, amphibolite, biotite-muscovite schist, migmatite and quartzite (Bultitude and Rees, 1994).

Cape York Peninsula Batholith

The Cape York Peninsula Batholith is of Middle Paleozoic (Devonian) age and comprises several component plutonic units including the Flyspeck Granodiorite, Kintore Adamellite, Lankely Adamellite, Wigan Adamellite and Morris Adamellite.

Janet Ranges Volcanics

The Janet Ranges Volcanics is of Permo-Carboniferous age and is a suite of extrusive units. It is composed of rhyolitic welded tuff, rhyolite and welded pumice flow breccia. In the more eastern outcrop areas sections up to 500 m thick occur.

Weymouth Granite

The Weymouth Granite is of Pennian age and is a medium or coarse grained, homblendebiotite granite or adamellite and occurs principally in a large suboval batholith with several smaller stocks cropping out.

Wolverton Adamellite

The Wolverton Adamellite is of Permian age and is a massive fine or medium grained, grey or pink, leucocratic, biotite adamellite and granite.

Puckley Granite

The Puckley Granite is of Permian age and is a grey medium grained tourmaline porphyritic adamellite (Stevens-Hoare, 1980).

2.1.2 Yambo Inlier

The Yambo Inlier occupies an area of 2000 km² along the central southern margin of the study area. It is located south west of Laura between Palmerville and Strathleven. The Yambo Inlier is geologically similar to the Coen Inlier being principally composed of metamorphic and acid intrusive rocks. The Yambo Inlier in the study area is principally composed of the Dargalong Metamorphics (gneiss, quartzite and migmatite) the Late Silurian to Devonian Aralba Adamellite (porphyritic biotite muscovite adamellite) and Kintore Adamellite (biotite muscovite adamellite) (Whitaker and Grimes, 1977).

2.1.3 Hodgkinson Province

The Palaeozoic Hodgkinson Province covers a narrow strip around the south eastern study area boundary from Maytown to Cape Melville. The province is bordered to the west by the Palmerville Fault. The north eastern and eastern boundaries extend out to sea for an unknown distance and the province underlies most of the Laura Basin to the north (de Keyser and Lucas, 1968). The Hodgkinson Province contained within the study area covers 11 700 km².

The province is part of the Tasman Geosyncline (Arnold and Fawckner, 1980) and consists of north west trending deformed and metamorphosed Silurian to Devonian trough and shelf sediments and Carboniferous to Permian acid intrusives (Davis, 1994) (Miezitis and Bain, 1991).

The Hodgkinson Province was probably formed in an extensional tectonic regime where east west thrusting has produced steepened beds and north south trending structures (Davis, 1994). Many discrete cauldron subsidence areas and extensive granite emplacement areas were formed during the early Carboniferous to early Permian (Bultitude et al, 1990).

The province in the study area is principally composed of the Upper Silurian to Lower Devonian Chillagoe Formation, the Middle Devonian to Lower Carboniferous Hodgkinson Formation, the Permian Normanby Formation, Permian Almantoui, Puckley and Finlayson Granites and the Permian Little River Coal Measures (Lucas and de Keyser, 1965 a & b).

The Hodgkinson Province has been complexly deformed with major faulting occurring during the Early to Middle Carboniferous. Major fault zones were active after the Carboniferous and extensive faulting has occurred along the tectonic grain of the province (Swarbrick, 1976).

Chillagoe Formation

The Silurian to Lower Devonian Chillagoe Formation occurs in the western part of the province and within the study area is composed predominantly of metabasalts but also contains limestone, arenite, mudstone and minor conglomerate (Bultitude et al, 1990). The granites are all of Permian age and have been previously described in the section on the Coen and Yambo Inliers.

Hodgkinson Formation

The Hodgkinson Formation is extensive within the Hodgkinson Province, extending within the study area from its southern boundary to Cape Melville. The formation is a deep water marine sequence and comprises an extensive siliclastic et al sequence principally composed of arenite, slate, chert, volcanics and limestone (Bultitude, 1990). The beds are predominantly moderately dipping to subvertical. The formation is tightly folded and has been regionally metamorphosed (Bultitude et al, 1991). The formation is considered to be in the order of thousands of metres thick (de Keyser and Lucas, 1968).

Normanby Formation

The Normanby Formation is locally exposed west of Cooktown and unconformably overlies the Hodgkinson Formation (Bultitude et al, 1991). The formation is steeply dipping to subvertical and is composed of volcanics, conglomerate, arenite, siltstone and mudstone that are commonly extensively foliated.

2.1.3.1 Hodgkinson Province - Tertiary Volcanics

Small Tertiary basalt flows occur in the study area. These are generally located to the west and south west of Cooktown and comprise the following units.

Piebald Basalt

The Piebald Basalt covers an area of approximately 140 km². It is located between 15 and 50 km west and north west of Cooktown. The unit consists mainly of basalt and pyroclastics (de Keyser and Lucas, 1968). The Piebald Basalt consists of two outcrops separated by the McIvor River. Both are approximately equal in area.

McLean_Basalt

The McLean Basalt is located in the Lakeland Downs area south west of Cooktown. It covers an area of approximately 300 km² and is lithologically similar to the Piebald Basalt although it includes gravelly sediments at its base (de Keyser and Lucas, 1968).

2.1.4 Cape York Pyroclastics

The term Cape York Pyroclastics is used here to refer to a distinct hydrogeological area composed principally of the mainland Torres Strait Volcanics. The Torres Strait Volcanics were grouped by Whitaker and Willmott, (1969), cover approximately 350 km², and are of Carboniferous age, and include the Endeavour Strait Ignimbrite, Eborac Ignimbrite and the Goods Island Ignimbrite. The volcanics consist of welded tuff, agglomerate, volcanic breccia, rhyolite, andesite and interbedded sediments that have undergone various metamorphic processes and grades (Willmott et al, 1973). The thickness of the Torres Strait Volcanics is not known but on the mainland is probably over 400 m (Willmott et al, 1973).

2.2 Laura Basin

The entire onshore Laura Basin occurs within the south eastern study area and covers approximately 23 000 km². It is connected to the Carpentaria Basin across the Kimba Arch (Smart and Senior, 1980). The Laura Basin overlies the Hodgkinson Province to the south and east. The basin is bounded to the west by the Coen Inlier and in some areas by the Palmerville Fault zone (Willis, 1991) and to the south west by the Yambo Inlier. It extends offshore under Princess Charlotte Bay and seismic data implies a connection with the Papuan Basin (Passmore, 1978).

The Laura Basin is composed of Mesozoic sediments which have been relatively undisturbed (Passmore, 1979), with the only known folding being drape folding over Pre-Jurassic highs near the western margin (Willis, 1991).

The basin has a similar depositional history, lithology and stratigraphy to the Carpentaria Basin (Smart and Senior, 1980), (Hawkins and Williams, 1990). The two basins have undergone parallel evolution, and have similar stratigraphic nomenclature (Smart and Senior, 1980).

Structure

The Palmerville Fault is the major structural feature in the basin and was initiated in the Jurassic (Hawkins and Williams, 1990) and remained active until the Late Cretaceous (Smart and Rasidi, 1979). The structure runs through the central western basin from north to south, and probably forms the eastern boundary of the basement Proterozoic metamorphic rocks (Stevens-Hoare, 1980). Permian and Triassic sedimentary rocks contained in graben structures underlie the Laura Basin locally (Blake, 1992). A basement high occurs in the southern portion of the basin, dividing this area into an eastern and western section.

The Basin increases in depth and thickness principally to the north but also to the east (Smart and Rasidi, 1979). Basin sediments dip gently to the north towards the depocentre off Princess Charlotte Bay (Passmore, 1979) with basement highs occurring in the southern part of the basin. These gentle dips are depositionally controlled but are locally increased by compaction or drapes over basement highs (Smart and Senior, 1980).

Stratigraphy

The Laura Basin Mesozoic sequence began with the predominantly fluvial/deltaic Dalrymple Sandstone, overlain by the fluvial and marginal marine Gilbert River Formation. The sequence terminates with the entirely marine Rolling Downs Group (Hawkins and Williams, 1990) or, locally, with the Normanton Sandstone.

In the central northern section of the Laura Basin stratigraphy is reasonably well understood from one stratigraphic hole, several petroleum exploration wells and seismic surveys. Similarly in the north east section the local stratigraphy is reasonably well understood from coal investigation programs. Little work has been done on the northern arm adjacent to the Coen Inlier.

Dalrymple Sandstone

The Dairymple Sandstone is the basal Mesozoic unit in the Laura Basin (de Keyser and Lucas, 1968) and is of Middle Jurassic age (Blake, 1992). Within the study area the Dairymple Sandstone occurs only in the Laura Basin, however the unit is lithostratigrapically similar to the Garraway Beds in the Carpentaria Basin (Powell et al, 1976). The formation is 527 m thick in GSQ Ebagoola 1 (Williams, 1988).

The formation lies unconformably on the Hodgkinson Formation to the east of the Palmerville Fault Zone and overlies Proterozoic Metamorphics to the west of this feature (Pinchin, 1973). Locally the unit overlies Triassic and Permian sediments. It is often difficult to distinguish the Dalrymple Sandstone from the Gilbert River Formation in outcrop around the basin margins except in the eastern areas where the upper Dalrymple Sandstone surface is ferruginised (de Keyser and Lucas, 1968).

The Dairymple Sandstone exhibits a gentle dip towards the north and comparatively minor structural deformation. Drilling indicates it thickens towards the centre of the basin, with the upper formation surface being nearly planer (de Keyser and Lucas, 1968).

The Dalrymple Sandstone is composed of fluvial, paralic and shallow marine sands (Smart and Senior, 1980). Generally the Dalrymple Sandstone fines upwards from conglomerate into sandstones and siltstones (Hawkins and Williams, 1990). It consists of fine to coarse grained (pebbly in part) quartzose to sub-labile sandstone with minor mudstone, siltstone and conglomerate (Hawkins and Williams, 1990). It is thick bedded, unstratified and cross bedded and generally well sorted (de Keyser and Lucas, 1968). Coal seams occur in the sequence with up to ten thin seams encountered in the Bathurst Range area (Henry and Benade, 1982).

The Formation thickness varies from around 60 m near the outcrop in the eastern part of the basin to over 500 m near the coast.

Gilbert River Formation

Deposition of the Gilbert River Formation was continuous across the Kimba Arch in both the Laura and Carpentaria Basins (Hawkins and Williams, 1990). The term Battle Camp Sandstone was originally used in the Laura Basin prior to upgrading of the unit to the Gilbert River Formation by Powell et al (1976).

In the south west and west over the Palmerville Fault zone the Gilbert River Formation onlaps the Proterozoic and Paleozoic basement (Passmore, 1979). The depositional environment of the Gilbert River Formation varies from fluviatile at the base to marginal marine at the top (Hawkins and Williams, 1990).

The formation is conformable over the Dalrymple Sandstone based on drillhole data (Hawkins and Williams, 1990) for most of the basin except in the eastern sections where there is an apparently unconformable boundary expressed in outcrop (Powell et al, 1976).

The Gilbert River Formation comprises mainly very fine to coarse grained, light green-grey to white, quartzose to sublabile sandstones with minor mudstone, sandstone, siltstone and conglomerate (Hawkins and Williams, 1990). The unit is frequently marine and glauconitic near the top. Drilling has established formation thicknesses from 60 m in the east to over 200 m in the central part of the basin.

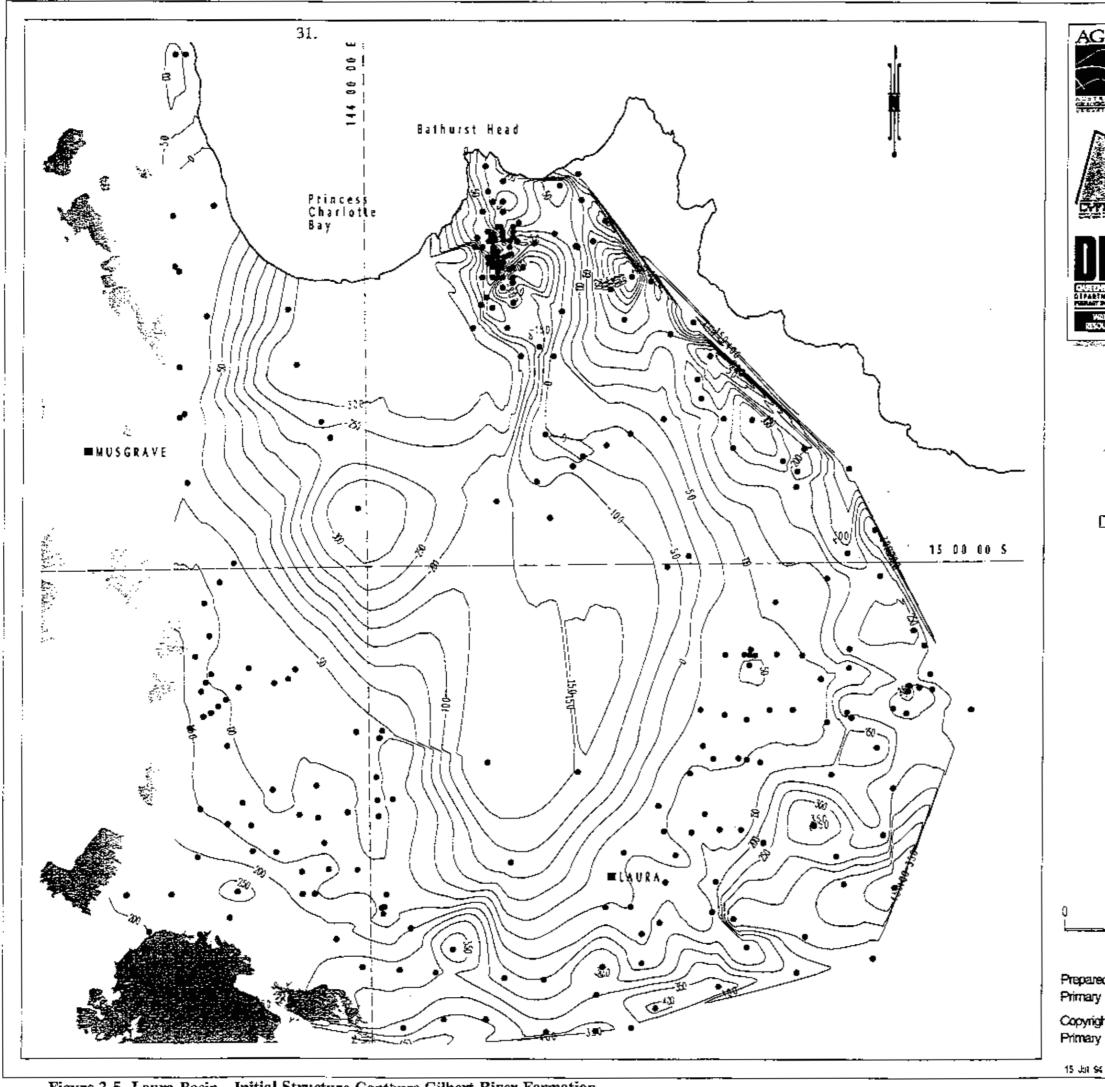
The Gilbert River Formation in the Laura Basin has a lower interbedded siltstone and sandstone interval and an upper sandstone unit, with more minor siltstone and conglomerate. Equivalent units to the Coffin Hill and Yappar Members of the Gilbert River Formation in the Carpentaria Basin have been identified in GSQ Ebagoola 1 (Hawkins and Williams, 1990). These units have been correlated using spore pollen associations (Helby, 1977). Initial structure contours for the Gilbert River Formation are presented in Figure 2.5. These and other structure contours presented have been plotted using a triangulation contouring package.

Rolling Downs Group

Deposition of the Rolling Downs Group was continuous across the Kimba Arch between the Carpentaria and Laura Basins.

The Rolling Downs Group is generally flat lying, and exhibits little deformation. However a ?Late Cretaceous movement of the Palmerville Fault has locally displaced the group down to the west by about 100 m (Smart and Rasidi, 1979). There is an unconformable? boundary between the Rolling Downs Group and the underlying Gilbert River Formation. This boundary can be identified, at least locally by the change from predominantly glauconitic mudstone to a dominantly sandstone unit of the Gilbert River Formation (Hawkins and Williams, 1990).

The formation was deposited in shallow marine and paralic environments that were prevailing during the Cretaceous marine transgression (Smart and Senior, 1980). Its thickness ranges from around 40 m near Kalpowar to over 200 m in the central part of the basin. Initial structure contours for the Rolling Downs Group in the Laura Basin are presented in Figure 2.6.









LAND USE STRATEGY

CYPLUS is a joint initiative between the Queensland and Commonwealth Governments.

Laura Basin GILBERT RIVER FORWATION STRUCTURE CONTOURS & BORES

The information shown on the map have been supplied by Department of Primary Industries. Initial enquiries regarding the information should be directed to Water Resources Division.

LEGEND

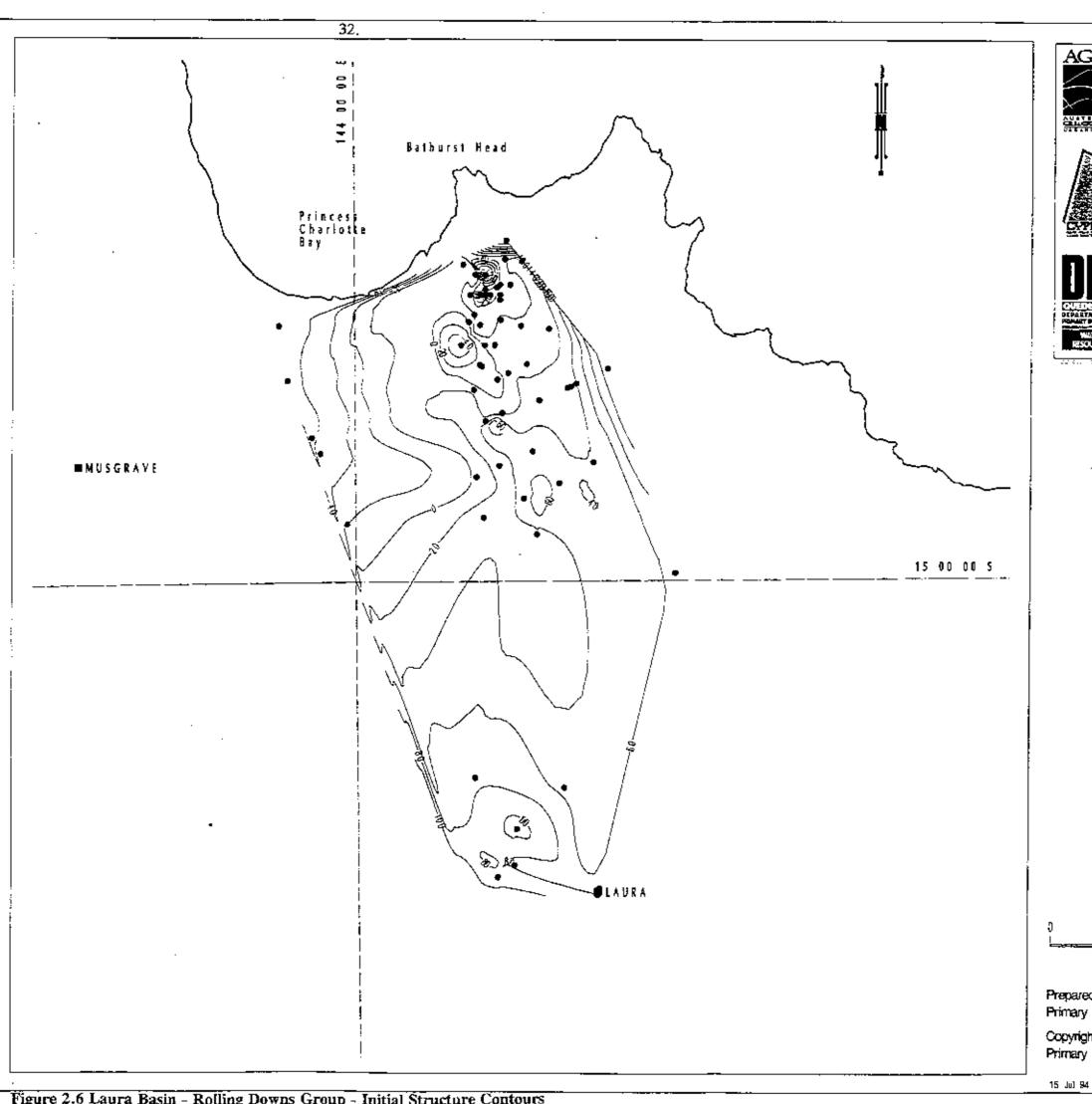
- Structure Contour (Showing level in metres to A.H.D. datum)
- Bore Location
- Outcrop

Transverse Mercator Projection Zone 54 : Australian Map Grid SCALE (km) : 750000 Before Reduction

Prepared and produced by the Department of Primary Industries, July 1994.

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EDITION NO 1 FIGURE 2.5









CYPLUS is a joint initiative between the Queensiand and Commonwealth Governments.

LAURA BASIN ROLLING DOWNS GROUP STRUCTURE CONTOURS & BORES

The information shown on the map have been supplied by Department of Primary Industries. Initial enquiries regarding the information should be directed to Water Resources Division.

LEGEND

Structure Contour (Showing level in metres to A.H.D. datum)

Bore Location

75 Transverse Mercator Projection Zone 54 : Australian Map Grid SCALE (km) 1: 750808 Before Reduction

Prepared and produced by the Department of Primary Industries, July 1994.

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EDITION NO 1 FIGURE 2.6

In the eastern onshore area, at Bathurst Range, an upper unit of quartz rich sandstone is present and was referred to as the Normanton Sandstone by geologists of the Utah Development Company. Generally the Normanton Sandstone was deposited as a sequence of beach sedimentation, dune deposits and fluvial deposits (Hawkins and Williams, 1990). It is interbedded with the upper glauconitic sandstone of the Rolling Downs Group (Hawkins and Williams, 1990). In this north eastern area it is over 95 m thick and is composed of "clean grey quartz sandstone with medium and large scale cross bedding" (Hawkins and Williams, 1990).

Cainozoic Units

The upper units of the Laura Basin comprise a thin Cainozoic veneer that covers most of the basin and is composed of Tertiary sediments and alluvial deposits. These deposits are of a restricted locality, but occur up to a known 71 m total thickness in GSQ Ebagoola 1 (Williams, 1988).

The Tertiary sediments in general consist of clayey silty sandstones and claystones with some rounded quartz gravels (Herbert, 1993). These units are characterised by a deep weathering profile typically close to the surface and this is particularly pronounced in elevated areas (i.e. Fairview Plateau). Sediments, however, can be quite consolidated at depths of 20 to 30 m.

Surficial sands and gravels are dispersed across the southern and western parts of the basin. These sands are usually less than 10 m thick.

Alluvial sands and gravels are associated with all the major river systems in the basin. They are generally cleaner and fairly coarse grained in the south east but become siltier towards the north western onshore margins.

2.3 Carpentaria Basin

The Carpentaria Basin underlies all of the western side of Cape York Peninsula and is the most northerly tectonic unit within the Great Artesian Basin. It is predominantly Early/Middle Jurassic to Early Cretaceous in age.

The basin limits are defined to the south east by the Georgetown Inlier and the Hodgkinson Province and to the east by the Coen and Yambo Inliers. The basin extends to the north under Torres Strait to the Papuan Basin is open to the west under the Gulf of Carpentaria, and covers some 85 800 km² (including the extended study area).

This study has sought to address a data shortfall by drilling 10 boreholes (Total 1575 m) in the Carpentaria Basin, and by fine tuning the stratigraphic correlation using sophisticated computer interpretation and plotting routines. To provide the most up to date data possible a bore census program that obtained all available data on existing boreholes was undertaken for this study.

Even with this approach there remains significant distances between data points, especially in the deeper aquifers. Interpretations have been tied into data from the isolated deep drill holes which include three GSQ stratigraphic holes and four deep petroleum wells. Several deep water bores exist but their lithological descriptions usually have little detail, making stratigraphic interpretations and correlation difficult. Most data from these deep holes is clustered around Weipa and Kowanyama and little data is available over other parts of the basin. Because of this paucity of direct geological data the local subsurface geology of the basin is still not well defined.

The Carpentaria Basin is an epeirogenic, epicratonic saucer shaped downwarp, oval in shape with its major axis running approximately north south. The basin reaches a thickness of 1700 m at its depocentre offshore from Weipa and has a maximum thickness of 900 m onshore (McConachie et al. 1990).

Basement comprises a wide range of Paleozoic and Precambrian intrusives and metamorphics which impose significant variations on structural style (Bourke et al, 1987) within the basin. Most structures are resultant from block faulting or draping over basement blocks (Smart et al, 1980).

On a basin-wide scale, the Carpentaria Basin has reasonable formational and broad lithological continuity. However, there is significant regional geological variation, resulting from basement highs and valleys and from transgressive and regressive depositional environments. Differing provenances sometimes overprint features of these depositional environments.

The Garraway Beds

The Garraway Beds and the partially equivalent Helby Beds form the basal units of the Carpentaria Basin. The Garraway Beds are equivalent to the Eulo Queen Group, are of Late Jurassic age and were deposited in a fluvial environment. The formation rests unconformably on the Pre-Mesozoic basement and could be up to 130 m thick in the Sir William Thompson Range area (Smart and Senior, 1980). The Garraway Beds outcrop/subcrop near the south-western margin of Coen Inlier. The general lithology is described as "clayey, micaceous, quartzose sandstone, granule and pebble conglomerate, locally carbonaceous, increasingly conglomeratic towards base" (Smart and Senior, 1980).

The Gilbert River Formation

The Gilbert River Formation is the main Carpentaria Basin aquifer unit in Cape York. It extends south beyond the CYPLUS study area to its type area near Gilberton, south east of the town of Croydon. It correlates with the Hooray Sandstone, a major aquifer in the Eromanga Basin. The formation was deposited principally in fluviatile conditions in the Late Jurassic to Early Cretaceous and conformably overlies the Garraway Beds and its equivalents in the study area.

Smart and others (1971) sub-divided the Gilbert River Formation into the lower Yappar Member, which accumulated in freshwater, terrestrial conditions, and the upper Coffin Hill Member which accumulated in marine and marginal marine conditions.

The Yappar Member is composed of clayey coarse to medium-grained, quartzose sandstone grading upwards to a medium and fine-grained quartzose sandstone. In its type area it is pebbly at its base and tends towards conglomerate.

The Coffin Hill Member conformably overlies the Yappar Member. It consists of coarse to fine-grained, clayey, quartzose sandstone with interbedded siltstone. Glauconite is a common accessory mineral.

In the majority of drill holes these two members cannot be distinguished. Two fully-cored stratigraphic holes have been drilled in the CYPLUS area - GSQ Weipa 1 and GSQ Rutland Plains I (Derrington, (1988, 1989)). The dominant lithologies present in the Gilbert River Formation interval in these holes are silty sandstone and sandy siltstone.

The Gilbert River Formation outcrops along the western edge of the Great Dividing Range adjacent to the Coen Inlier where the average thickness is 45 m. The Gilbert River Formation thickness locally in the Weipa area. In general, however, this unit is of relatively uniform thickness throughout the study area. Initial structure contours for the Gilbert River Formation in the Carpentaria Basin are presented in Figure 2.7.

The Helby Beds

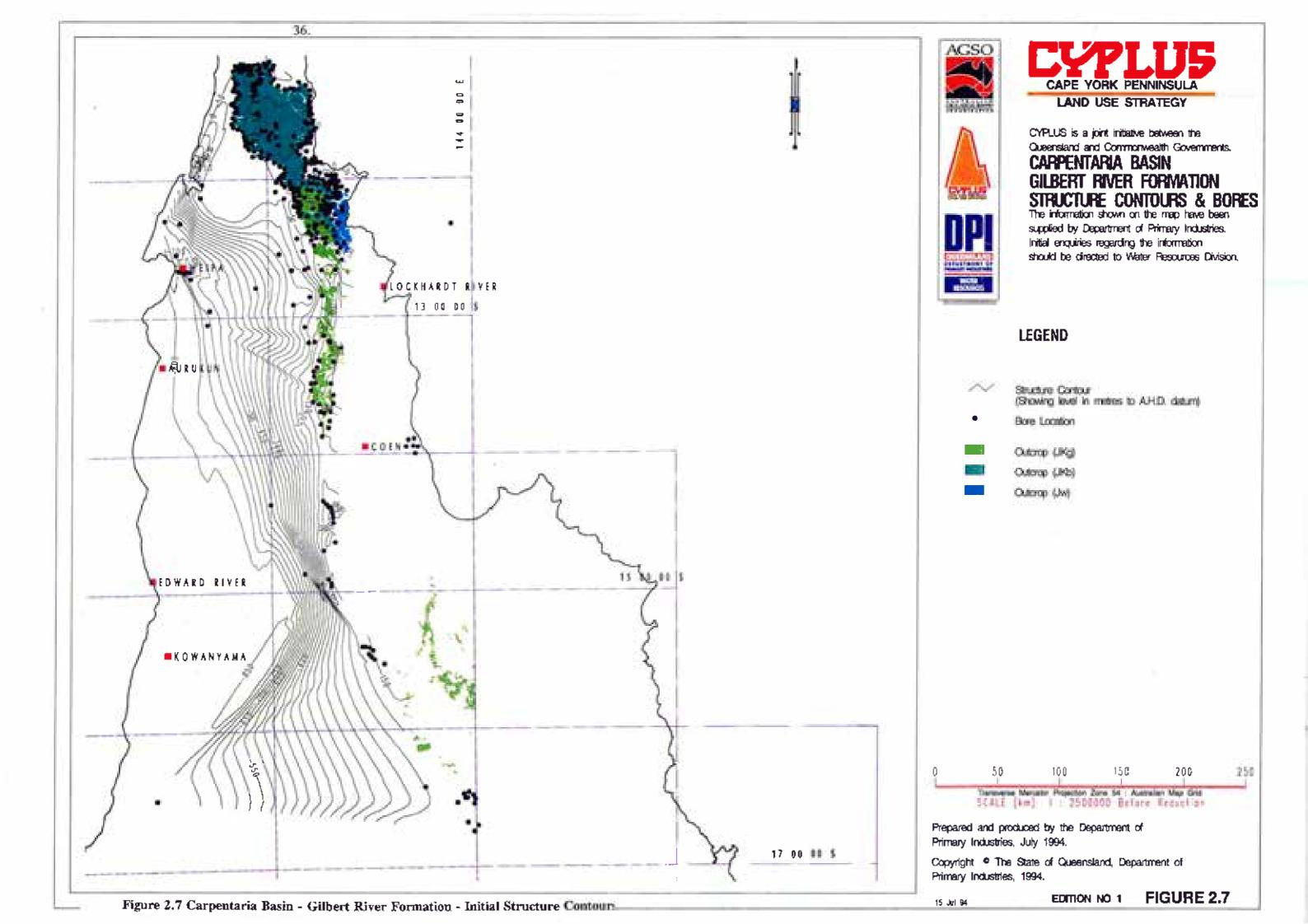
North of 12°S the Gilbert River Formation merges with the Helby Beds. Smart and Senior, (1980) considered the Helby Beds to be equivalent to parts of the Carraway Beds and the Gilbert River Formation and described the general lithology as quartzose sandstone, conglomerate, and siltstone. Tuff and tuffaceous sandstone occur in lower part. Powell et al., (1976) consider the thickness of the beds to be about 300 m.

The Rolling Downs Group

The Rolling Downs Group conformably overlies the Coffin Hill Member of the Gilbert River Formation.

The Group is predominantly composed of argillaceous marine sediments (Vine et al., (1967) in Wilmott and Powell, 1977), principally fine grained clastics and marine mudstones and some hydraulically unconnected sandstone lenses.

The Rolling Downs Group is mainly of Lower Cretaceous age. The Wilgunga Sub-group is principally of shallow marine origin. This unit is overlain by the Allaru Mudstone which is in turn overlain by an entirely lacustrine sequence, the Normanton Formation. The Wilunga Sub-group components, the Wallumbilla and Toolebuc Formations are continuous from the Eromanga Basin into the Carpentaria Basin (Smart, 1976).



The Allaru Mudstone is of Late Albian age and of shallow marine origin (Smart and Senior, 1980). The unit is usually only a few metres thick but it's lithological characteristics make it a useful stratigraphic marker in the study area. Smart and Senior, (1980) described the general lithology as "mainly bluish grey mudstone with interbeds of very thin to thin siltstone, minor very fine grained labile sandstone. Thin seams of cone in cone limestone occur. Initial structure contours for the Rolling Downs Group in the Carpentaria Basin are presented in Figure 2.8.

2.4 Karumba Basin

The Karumba Basin occupies the central western section of the Peninsula. The basin extends offshore below the Gulf of Carpentaria and into the southern part of Papua New Guinea (Grimes, 1980). The basin covers some 76 700 km² in the study area (this figure includes the extended section).

It is a shallow, intracratoric oval depression of uncertain maximum depth. The Karumba Basin unconformably overlies the Carpentaria Basin with the onshore boundaries approximately following the basement control of the Carpentaria Basin. Offshore the northern limits of the basin appear to extend well north of the Carpentaria Basin limits, however lack of drill-hole data and blanket Holocene sedimentation make basin limits uncertain.

Structure

In contrast to the Carpentaria Basin's multiple sites of deposition and significant structural controls, the Karumba Basin is a broad, saucer-shaped depression which has developed as a sag phase over the compacting Mesozoic sequence (McConachie et al, 1990).

The Karumba Basin was initiated in the Late Cretaceous via uplift of basin margins accompanied by penecontemporaneous downwarp within the basin, particularly in the Gilbert-Mitchell Trough (Bell, 1982). The eastern margins have been intermittently uplifted with associated minor folding and faulting since the cessation of Cretaceous deposition in the Carpentaria Basin.

Smart et al, (1980) proposed that three major cycles account for basin evolution. Each cycle is postulated to have consisted of an initial phase of tectonic uplift with subsequent erosion and deposition, followed by a passive phase of planation and lastly, a terminal phase of deep weathering.

Stratigraphy |

The Karumba Basin contains four main stratigraphic units (Bulimba Formation, Wyaaba Beds, Falloch Beds and Yam Creek Beds) that have a combined thickness of over 400 m (Doutch, 1976). Duyken No 1. drilled in the central portion of the Gulf of Carpentaria intersected 550 m of Karumba Basin sediments (Blake, 1992) whilst onshore up to 230 m have been penetrated (Bell, 1982).

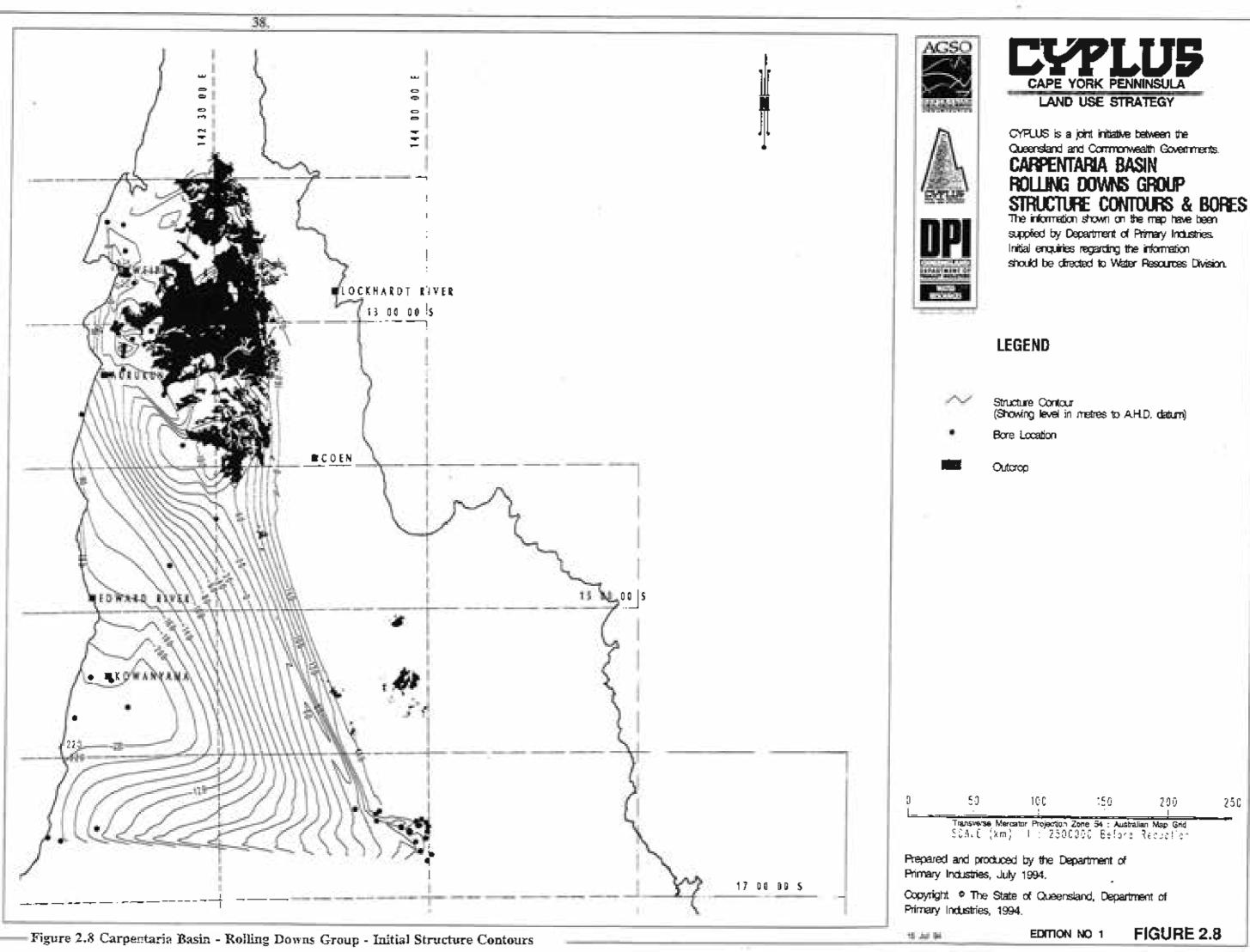


FIGURE 2.8

Both Grimes, (1980) and Smart, (1980) consider that three cycles of active erosion and deposition had resulted in planar land surfaces that experienced the necessary climatic conditions to form deeply weathered and lateritic sequences. These lateritic weathering effects are widespread throughout the Karumba Basin (and northern and western Queensland) and reach a depth of several tens of metres. These lateritic effects require "a sufficient time of a tectonically stable surface on which there is minimal erosion and deposition" (Grimes, 1980). Lateritic profiles occur as silcretes, siliceous duricrusts and lateritic profiles in the study area. The silcretes have not been observed north of 13°S and become more common and well developed towards the south. Their formation is climatically more than lithologically controlled (Grimes, 1979). Lateritic profiles are the most dominant weathering feature in the study area.

Smart, Grimes and Doutch, (1972) considered the Bulimba Formation and Wyaaba Beds distinct entities based upon the Bulimba Formation having "a more argillaceous nature" and the supposed existence of a major laterite horizon developed at the top of the Bulimba Formation. This marker horizon is well developed in the main part of the Gilbert-Mitchell Trough but is absent elsewhere.

The validity of initial sub-division of strata into the Bulimba Formation and the Wyaaba Beds is questionable for the following reasons, namely:

- (1) One of the stated criteria for sub-division is based upon the presence of a lateritic marker horizon. Results from recent studies into ferricrete occurrence and formation indicate that the presence of ferruginous cemented materials is not a reliable indicator of the age of either landforms or regoliths; nor are they useful for correlation purposes (Paine and Ollier, 1992).
- (2) Examination of lithologs penetrating the Bulimba Formation (the results of (1) above not withstanding) detail numerous weathered or lateritized intervals throughout the sequence with no one 'major' event of weathering immediately apparent.
- (3) Examination by the authors of numerous core/chip samples recovered from areas mapped as depositional sites for both units as well as examination of strata logs for the same, failed to reveal any perceivable change in argillaceous content throughout the combined interval.
- (4) There is no 'firm' evidence of actual age span of sediments. Due to the highly reworked and weathered nature of sediments, any spores/pollen or other micro-flora originally present when the sediments were being deposited, has long since been destroyed or fragmented to such an extent, that it is rendered useless for palynological age determination. To the authors' knowledge no palynological dating has ever proved successful in accurately determining the age of these fluvial sediments.

However, for the purposes of this study and to conform with the stratigraphic nomenclature, the Bulimba Formation and the Wyaaba Beds have been considered separately.

Distinction between these two units was based on:-

The first interval of white, sandy clay beneath marine, calcareous sediments (in portions of the basin where this marine unit exists) is taken to represent the initial cycle of deposition of the Wyaaba Beds. This same interval of white, sandy clay has been correlated at an equivalent adjusted depth in the terrestrial facies only of the Wyaaba Beds and has been used to define the top of the Bulimba Formation.

Bulimba Formation

The Bulimba Formation was defined by Smart and et al, (1972). The formation is of late Cretaceous or Tertiary age and is interpreted to have been deposited in a fluvial environment post-dating uplift of the eastern side of Cape York Peninsula. The provenance is believed to have been granitic rocks of the Coen, Yambo and Georgetown Inliers.

The Bulimba Formation is composed predominantly of interbedded clayey quartzose sandstone, granule conglomerate and sandy kaolinitic claystone. Characteristically the unit is partially mottled and ferruginized. This ferruginization of the upper part of the formation and development of ferricrete, bauxite or a lateritic profile occurs in regions climatically and chemically conducive to iron accumulation and hardening.

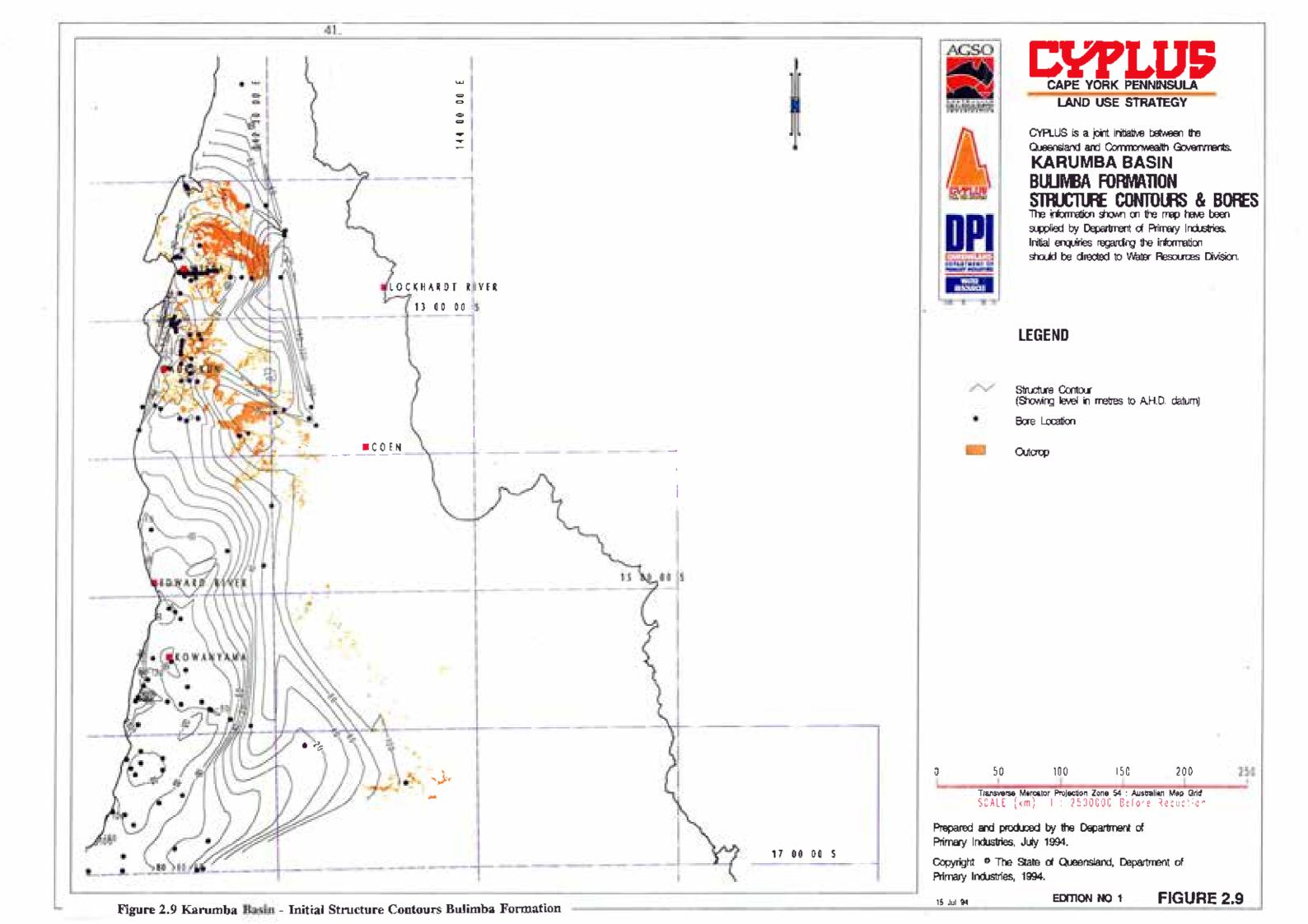
Lithological composition varies locally, related to the prevailing environmental conditions at the time of deposition (e.g. Coffey and Hollingsworth Pty Ltd drilling in the Aurukun Area in 1971 delineated areally restricted, permeable, sandy intervals within the formation; these westward-trending bodies are interpreted to be ancient stream channels filled with coarser, less argillaceous sediments).

The thickness of the unit onshore varies from around 30 m near outcrop in the Weipa region to 154.50 m in GSQ Rutland Plains 1 (RN 72275) located in the central Western portion of the basin. In general, the formation appears to thicken westward and thin northwards within the Karumba Basin.

The Bulimba Formation unconformably overlies sediments of the Mesozoic Carpentaria Basin and igneous and metamorphic rocks of the Georgetown Inlier. Initial structure contours for the Bulimba Formation are presented in Figure 2.9.

Wyaaba Beds

The Wyaaba Beds were defined by Smart et al, 1972. Different authors have assigned various geological ages to this unit. As previously discussed palynological dating of the terrestrial strata is not possible. Shelly fossils derived from marine sediments however, have yielded an approximate age of Pliocene or younger (Day et al, in Doutch et al, 1973). In this report the combined age of both fluvial and marine deposits has been assumed to be Early/Mid Miocene to Early/Mid Pliocene.



The continental facies of the Wyaaba Beds which constitutes much of its onshore extent is, as previously stated, lithologically indistinguishable from the Bulimba Formation. This fact reflects not only a similar environment and provenance but also the contribution made to the sediments from erosion of the Bulimba Formation (Smart et al, 1980). The unit is believed to have been derived from deposits of the ancestral Gilbert, Staaten, Mitchell and other adjacent rivers (Powell et al, 1976).

Marine sediments have also been deposited within the Wyaaba Beds in areas as the sea transgression response to both eustatic sea level rise and tectonic down-warping. This transgression was not basin-wide but rather was laterally restricted to areas close to the bounds of the present day coastline.

On-shore depositional limits of marine strata are imprecisely known. Based on available drill hole data, it is probable that marine beds were deposited in an approximate arc-like form. The northern arm extends to just south of Cape Keer Weer, and the southern arm to somewhere in the general proximity of Rutland Plains Station, the eastern maxima reachs a depositional cut-off point at a distance not further than 50 km inland from Pormpuraaw.

Overall the Wyaaba Beds consist principally of clayey sandstone, granule conglomerate and interbedded clayey sandstone (Smart, 1980). In the Gilbert-Mitchell Trough the unit is comprised of fluvial clayey sandstone and sandy claystone.

As is the case in the Bulimba Formation, the top of the Wyaaba Beds is commonly ferruginized to some degree and partially mottled. The Wyaaba Beds rarely outcrop due to their loosely consolidated nature and poor resistance to weathering. The only known outcrops occur in creek cuttings or stream channels.

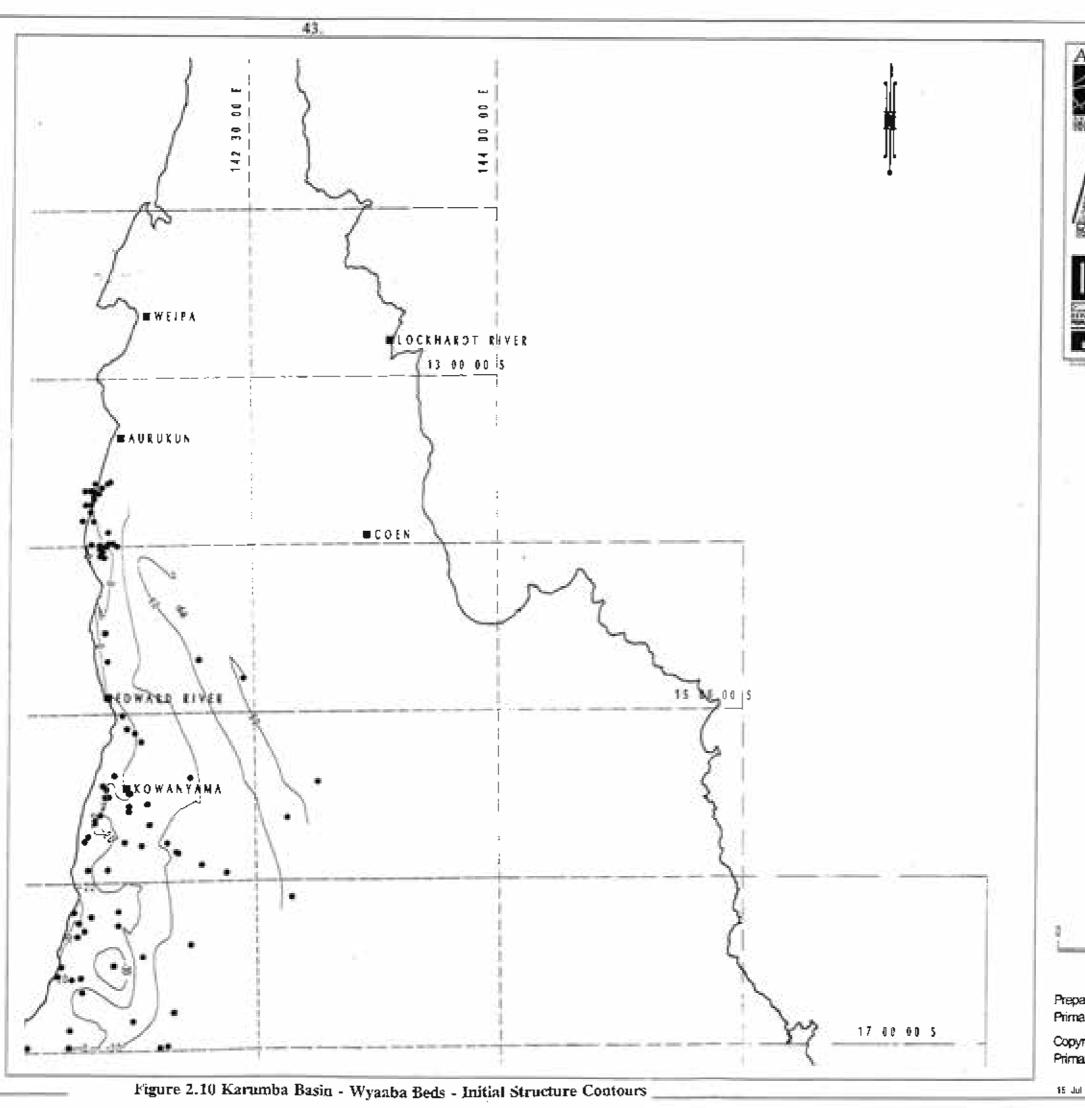
The thickness of the unit onshore varies, but in general a thickening westward towards the present coastline is evident. Bores drilled within the Rutland Plains/Galbraith 1:250000 Sheets have penetrated the greatest thicknesses with an interpreted thickness of 140.3 m recorded in Bluey's Bore No 3 (RN 38473) drilled on Rutland Plains Station.

The Wyaaba Beds are overlain by Quaternary colluvia and alluvia of the Gilbert and Mitchell Fans. Initial structure contours for the Wyaaba Beds are presented in Figure 2.10.

Wyaaba Bed Equivalents

The Falloch Beds and the Yam Creek Beds are considered to be correlatives to the Wyaaba Beds although it is believed that deposition of these units did not commence until mid to late Miocene times.

Both units are fluvial deposits accumulated in small intermontane basins within the axis of the main upwarped area of Cape York Peninsula (Smart et al., 1980).







CYPLUS is a joint initiative between the Queensland and Commonwealth Governments. KARUMBA BASIN WYAABA BEDS STRUCTURE CONTOURS & BORES

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LEGEND

Structure Contour (Showing level in metres to A.H.D. datum)

Bore Location

150

200

250

State (km) 1 + 2500000 Eafors Recuttor

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FIGURE 2.10

Falloch Beds

The Falloch Beds were recognised and defined by Powell et al in 1976 as separate from the Lilyvale Beds deposited in the Laura Basin because this accumulation of lithologically similar sediments occurred in a different basin. Distribution of this unit is restricted to the headwater basin of the Archer and Wenlock Rivers.

Lithologically the Falloch Beds consist of white, poorly consolidated, medium to very coarse grained, poorly sorted, angular, clayey, quartzose sandstones and sandy clay with sporadic, clayey granule and pebble conglomerate. The unit is ferruginized in part. The maximum known thickness is 55 m recovered from BMR Coen 24 (RN 92147) which bottomed out in the unit. The Falloch Beds overlie ?Proterozoic metamorphics and Palaeozoic granites and are in turn overlain by alluvia and residual sands.

Yam Creek Beds

The Yam Creek Beds were identified and named by Whitaker and Willmott, (1969). The unit is of ?Miocene to Pliocene age. Whitaker and Willmott, suggested that the sediments were lacustrine in origin, whilst Stainton and Cucuzza, (1980), argue that detailed examination in the field and air photo interpretation indicate the sediments to be primarily aeolian in distribution.

The Yam Creek Beds form a thin, widespread veneer over predominantly flat, 'peneplained' surfaces probably produced by the ancient Pascoe River and its tributaries. Lithologically the unit is similar to both the Falloch Beds and the Wyaaba Beds and has been partially ferruginized.

Thicknesses are varied, ranging from less than 1 m to 46 m in Comalco drill hole 237C/DH-1 (RN 92080). The beds are unconformable over Mesozoic, Palaeozoic and older surfaces.

2.5 Cainozoic Sediments Associated with the Coen Inlier

Lilyvale Beds

The Lilyvale Beds is a unit of Cainozoic age and occurs as scattered outcrops on the Holroyd Metamorphics on the Coen and Yambo Inliers. It is composed of poorly bedded sandstone and conglomerate, which are massive, friable and poorly sorted. The beds may be of alluvial origin. The weathered Lilyvale Beds have a characteristic honeycomb pattern and are generally covered by residual sand or alluvium.

Yam Creek Beds

The Yam Creek Beds is a unit of Cainozoic age and is composed of poorly consolidated clayey sandstone and conglomerate. These beds form elevated dissected plains around the Pascoe River area up to 60 m in thickness (average of 15 m) with up to 3 m of ferricrete capping. The Yam Creek beds contain less conglomerate and are generally finer grained than the Lilyvale Beds.

2.6 Surficial Deposits

Surficial aquifers cover about 25% of the Australian continent (Jacobson, 1983) and commonly overlie the deeper aquifers in sedimentary basins and fractured rock provinces.

These deposits in the study area have been categorised into:

- 1. Alluvial deposits, being river bedioad, channel and minor deltaic deposits. These are often of shallow depth, with high permeability and storativity and are of variable degrees of homogeneity. They have been classified on their surface consolidation levels. A distinction has been made with alluvial fan deposits that are more heterogeneous and of only localised and marginal value as a groundwater source. Previous workers (Doutch, 1976; Smart, 1980) have incorporated these units in geological reports (as opposed to hydrogeological work) where appropriate into their respective sedimentary basins.
- Beach Ridges and Coastal Dunes have been categorised into Holocene and Pleistocene ridges following Whitehouse, (1963), Smart, (1973 and 1976) and others. Additionally where possible distinction has been made between chemier type beach ridges and barrier island deposited ridges.

2.6.1 Alluvial Deposits

Approximately 197 000 km² of Queensland are covered by unconsolidated deposits (GSA/TWSC, 1973). Such unconsolidated deposits are invariably of Quaternary age. In the study area the Carpentaria Plains include the major area of alluvial plains (Doutch, 1976) with Quaternary deposits being largely restricted to the major streams and various coastal deposits on the Karumba and lower Claraville and Mitchell Plains (Coventry et al, 1980). Only minor Quaternary alluvial and colluvial deposits and some lacustrine deposits in areas dominated by basalts, have formed elsewhere in the Peninsula Uplands province (Coventry et al, 1980).

Little has been written on river alluvial deposits, with most previous work covering the nature of alluvial fan deposits. Catchment Basins 101-106 (Jacky Creek, Olive, Pascoe, Lockhart, Stewart, Normanby and Jeannie Rivers) contain sediments that are generally fine grained and of colluvial or alluvial origin (McEniery, 1980). Some of the shorter and steeper streams with significant areas of either indurated or crystalline rocks in their catchments might develop gravel size sediments providing the source rocks are capable of withstanding transport (McEniery, 1980).

Aliuvial fans cover a significant proportion of the south western study area. These fans slope gently towards the western coast at on average gradient of 1 in 1800 (Grimes and Doutch, 1978). The fans of the Mitchell and Gilbert River (south of the study area) and the smaller fans in between were formed as flood-out deposits where streams flowed out of the uplands and spread out across the plains. Quaternary sea level changes with corresponding changes to stream base levels would have been an important factor in stream incision or flood plain accretion (Grimes and Doutch, 1978).

Interpretation of drilling in the area (Warner 1968 reported in Grimes and Doutch, 1978) showed silty clay was the main lithology into which the bores spudded, though sand was common if not predominant in the top 30 m. The fans contain local linear sand bodies derived from old stream channels and levees (Grimes and Doutch, 1978). Such abandoned river channels have been identified by scattered lagoons in the flat lying silt, clay and sand surface of the Mitchell fan (Coventry et al., 1980).

The lithological similarities between the alluvial fans and the older Wyaaba Beds make the unconformity surface between them difficult to identify in some areas (Grimes, 1979). The differences in gross lithology between fan elements is much less than the variations within any one fan unit (Grimes and Doutch, 1978).

Most of the topographic and physiographic diversity of the eastern Carpentaria Lowlands can be attributed to the deposition and interrelationships of the late Cainozoic alluvial fan systems (Grimes and Doutch 1978 in Coventry et al, 1980).

In the Karumba Plains most of the sand plains lie above lateritised surfaces, these sands probably represent the A horizons of the laterite profiles and indicate a seasonal humid climate rather than aridity (Grimes, 1979). The Carpentaria Plains formed during the last of the three cycles in the development of the Cainozoic Karumba Basin (Doutch, 1976 in Grimes and Doutch, 1978).

Distinction between units has not been simplified by the fact that sedimentation was continuous across the Tertiary/Quartenary time boundary in a number of extensive areas (Coventry et al, 1980).

2.6.2 Coastal Sand Dune Deposits

Beach ridge and coastal dunes are extensive around most of the coastline of the study area.

Beach ridge deposits occur along the Charlotte, Karumba and Mapoon Plains, in the Jardine Swamps area and in the Newcastle, Orford Bay, and Olive River Dunefields. Other significant deposits occur at Cape Melville, Cape Direction, Cape Weymouth, Shelburne Bay, Archer Point near Cooktown, Colmer Point east of Coen and Escape River near Cape York.

In the 1:250 000 geological sheet mapping, beach ridge deposits were recorded as Qpm (Pleistocene deposits, of which the oldest ridges are 100 000 - 120 000 years b.p.). These are also recorded on some sheets as Qd (Quaternary deposits - sand dunes) e.g. Orford Bay sheet or as Czd (Cainozoic sand dunes), e.g. Cape Melville Sheet and as Qhm (Holocene deposits).

The Pleistocene ridges are all of Barrier Island type originating from long bordering sand bars, that are essentially long sand spits, incorporating former beach strand lines. These have formed by the winnowing of the intertidal zone and accumulation of shell material. The Pleistocene beach ridges consist of yellow or brown, locally red brown, slightly clayey quartzose sand, subhorizontally bedded and with local traces of shell material (Smart, 1976).

The older Pleistocene beach ridges of western Cape York Peninsula rest on Pliocene to Pleistocene alluvial fan deposits while on the eastern side the large Pleistocene dunefield deposits of Newcastle Bay, Orford Bay and Shelburne Bay all occur on Mesozoic sandstones. Little information is available on the younger western Pleistocene beach ridges.

The eastern dunefields have a thickness of 25 - 30 m and grain size ranges from fine sand to gravel, with the grains generally winnowed into a narrow size range (Cooper, 1993). The bulk of the dunefields are composed almost entirely of white quartz sand almost devoid of heavy minerals (Hopely et al, (1970) in Coventry et al, (1980), Cooper, 1993). The dunes where initiated on coastlines exposed to the prevailing south easterly winds. The material for these dunes was sourced from residual sand derived from underlying and adjacently outcropping Mesozoic Sandstones, including the Helby Beds and Gilbert River Formation (Doutch et al, 1973). This material was supplied continuously by an erosional shoreline in marine transgressions (Cooper, 1993).

The Holocene beach ridges (from 10 000 years before present (b.p.)) occur on coastal plains around most of the near shore study area. These ridges have been studied in most detail on the western Peninsula (Twidale, 1956 and 1966 in Doutch et al., (1973), Doutch, 1973, Whitehouse, 1963, Smart, 1976, Grimes, 1977). From the coast these ridges generally occur as a chenier ridge, then a barrier type ridge followed by a further chenier type ridge. The chenier ridges are sand bodies resting on coastal sediment associated with the progradation of the coastline tending to form on coasts of high sediment supply near major rivers. There is a progressive decrease of carbonate with depth. This is considered attributable to leaching by groundwater in the older Holocene ridges (Smart, 1976; Grimes, 1977). Holocene beach ridges on the Karumba Plain have been dated at 3320 ± 125 yrs b.p. (Twidale, (1956 and 1966) in Doutch et al, 1973).

Holocene ridges average around 4 m above sea level. The composition of beach ridges at the Pormpuraaw Community range from shell ridges at the beach to shell sand ridges 0.5 km inland and medium sand around 1 km inland (Whitehouse, 1963).

The Cape Bedford Dunefield, near the McIvor River mouth, contains, within the principle white sand dune mass, inliers of orange, yellow and white ferrunginised crossbedded sand, that are internally separated by white kaolinitic sand layers, and have a thin iron enriched capping (Coventry et al, 1980).

Older beach ridges occur between 20 - 30 kms inland with the recent beach ridges occurring up to 10 kms inland. Interestingly on the eastern Peninsula no abandoned river deposits (Qas) have been identified west of the older beach ridges (Doutch et al, 1973). The chenier plain around Princess Charlotte Bay is approximately 25 kms wide, consisting of ridges of sands, fine gravels and shell grit with a relief of only 2 m (Coventry et al, 1980)

There are extensive beach ridge deposits along the western Peninsula. Continuous beach ridge deposits occur along the Mapoon Plain, and these continue into and partially pond (behind successive sets of beach ridges) the Jardine Swamps in the far northern study area (Powell and Smart, (1977) in Coventry et al, 1980).

The Karumba Plain has continuous, extensive and conspicuous beach ridge deposits with the northern part being predominantly a beach ridge succession (Doutch, (1973), Grimes and Doutch, (1978), Coventry et al, 1980). This succession is composed of a series of beach ridges, salt flats and swamps that were sourced from the reworked sandy sediments of the Gilbert/Mitchell fan deposits (Coventry et al, 1980).

3.0 GROUNDWATER HYDROLOGY

The regional hydrogeology of Cape York Peninsula is complex, being influenced by a diverse range of rock types occurring within several tectonic units. The hydrological processes that occur are heavily influenced by climatic conditions, reflecting the monsoonal and drought regimes. A schematic diagram indicating the complexity and interdependency of many of these processes appears in Figure 3.1. For this work, the CYPLUS study area was extended in the south west to include the Staaten River to form a more natural hydrological boundary than the "official" CYPLUS boundary.

The study area has been classified into Hydrogeological Units based on potential groundwater availability. These are determined on geologically based features and represent areas of consistent hydraulic connection mechanisms. This data has been based on a reclassification of the 1:250 000 geology sheet data supplied by the CYPLUS Bedrock Digitising Program. A map of the principle hydrological units appears in Figure 3.2. These units have been determined according to their origin and distinguished as:

Consolidated Porous Sediments

- Regional sedimentary aquifers
- Potential local sedimentary aquifers
- Minor local sedimentary aquifers

Unconsolidated Surficial Deposits

- Alluvium
- Dune deposits
- Other deposits

Igneous and Metamorphic Rocks

- Potential fractured rock aquifers

The diverse geology in the study area has a strong influence on the nature and diversity of groundwater regimes. The clustered nature of detailed sub-surface geological information requires significant extrapolation to present an overview of the main features controlling groundwater processes. In some of the nominated hydrological areas these broad conclusions have necessarily incorporated knowledge gained from similar and more thoroughly understood areas in other parts of the world because of this sparseness of information.

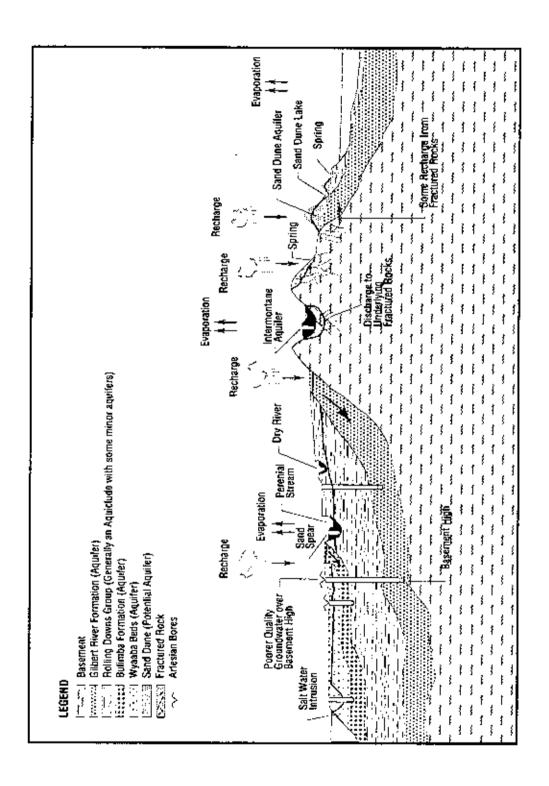
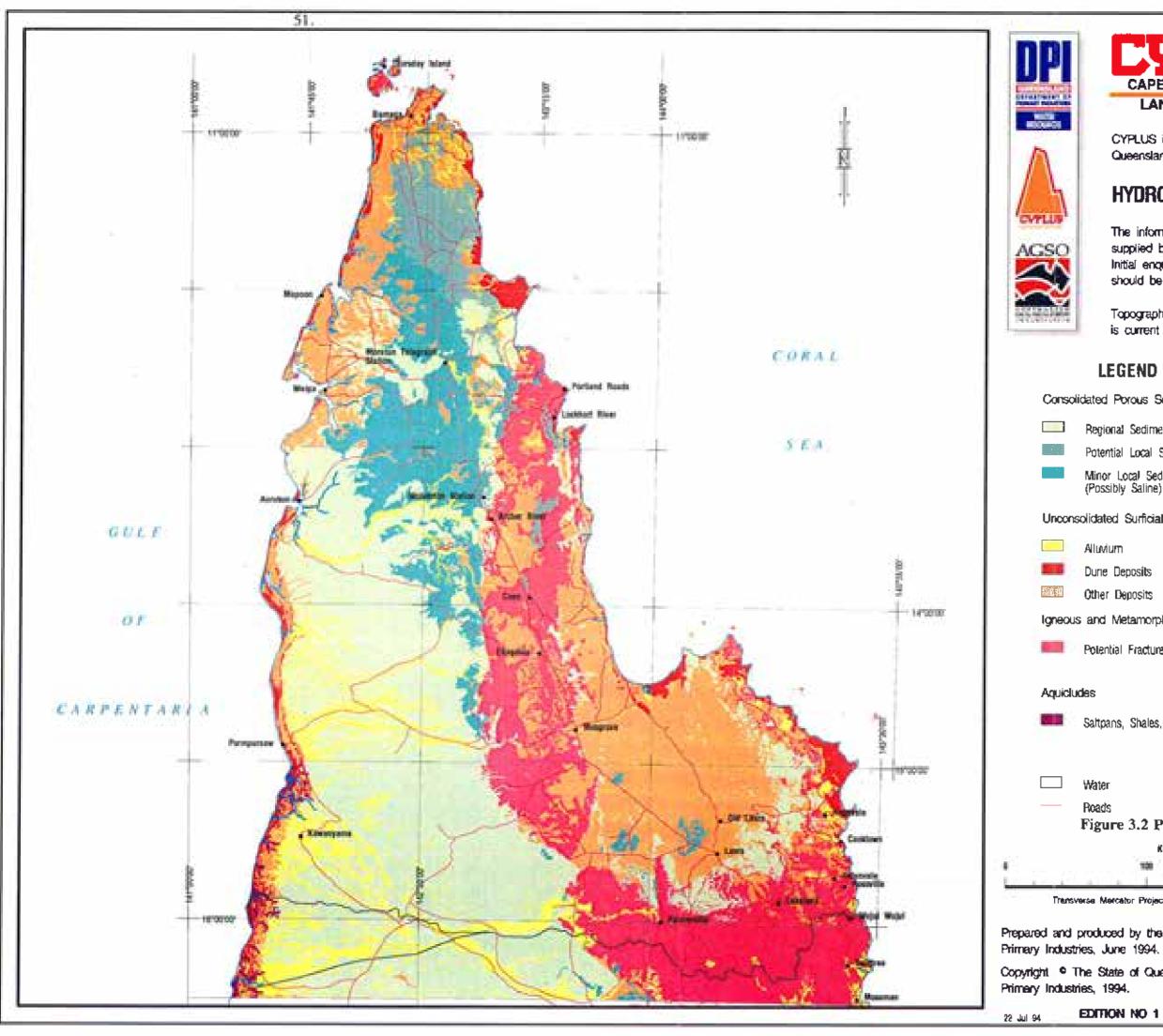


Figure 3.1 Schematic Hydrological Cycle - Cape York Peninsula







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HYDROGEOLOGICAL UNITS

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Topographic information shown on this map is current to 1989.

LEGEND

Consolidated Porous Sediments Regional Sedimentary Aquifers Potential Local Sedimentary Aquifers Minor Local Sedimentary Aquifers (Possibly Saline) Unconsolidated Surficial Deposits Alluvium Dune Deposits Other Deposits Igneous and Metamorphic Rocks Potential Fractured Rock Aquifers Aquicludes Saltpans, Shales, etc. Water

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Figure 3.2 Principal Hydrological Units

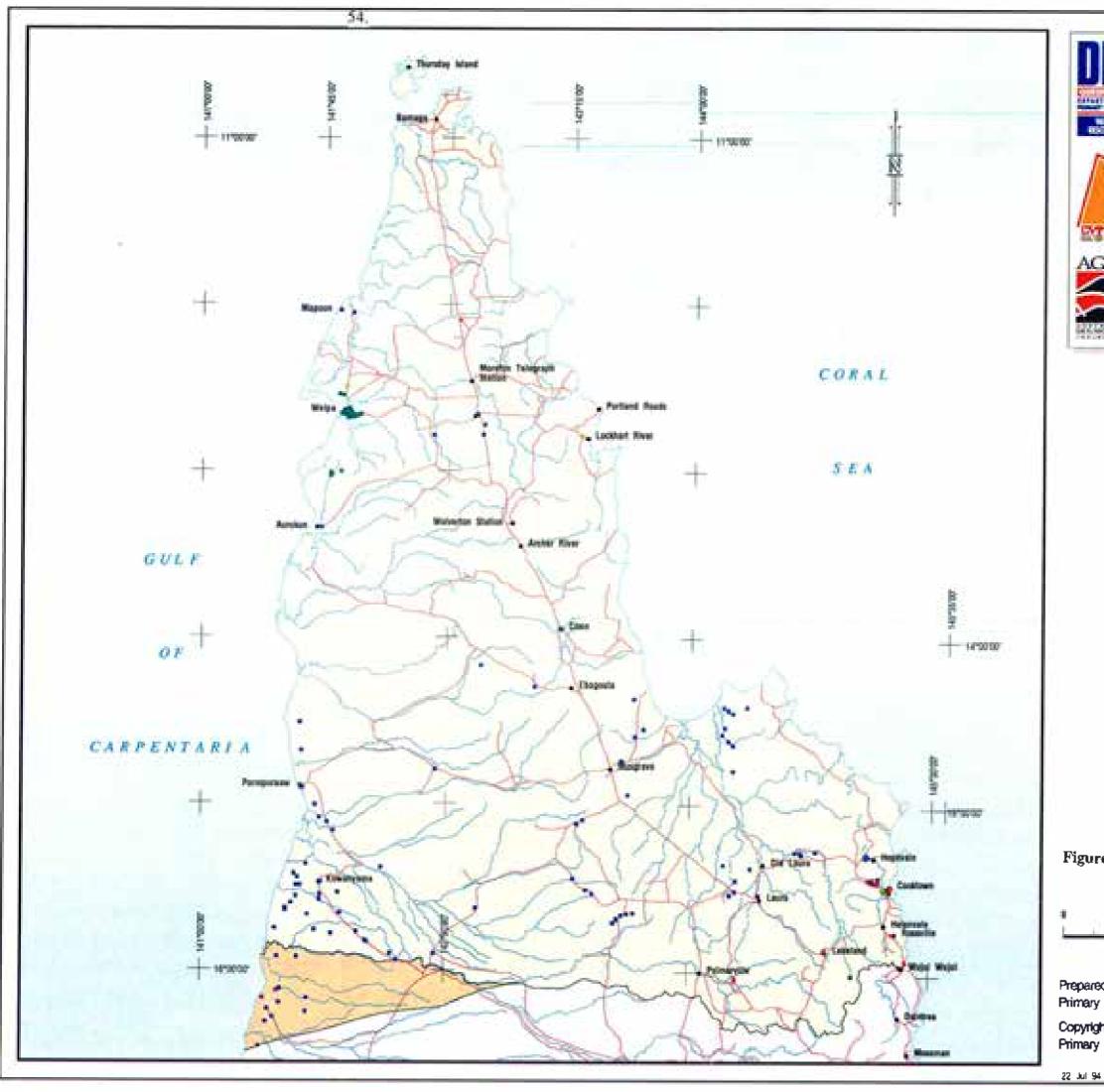
KILOMETRES

Transverse Mercator Projection Zone 54 : Australian Map Grid

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EDITION NO 1

FIGURE 3.2 A3-104417







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LICENSED BORES MAJOR WATER USAGE

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LEGEND

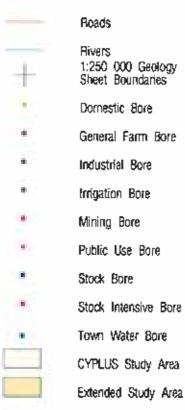
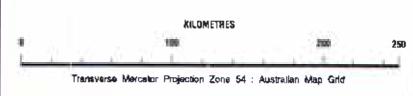


Figure 3.5 Licensed Bores - Major Water Usage

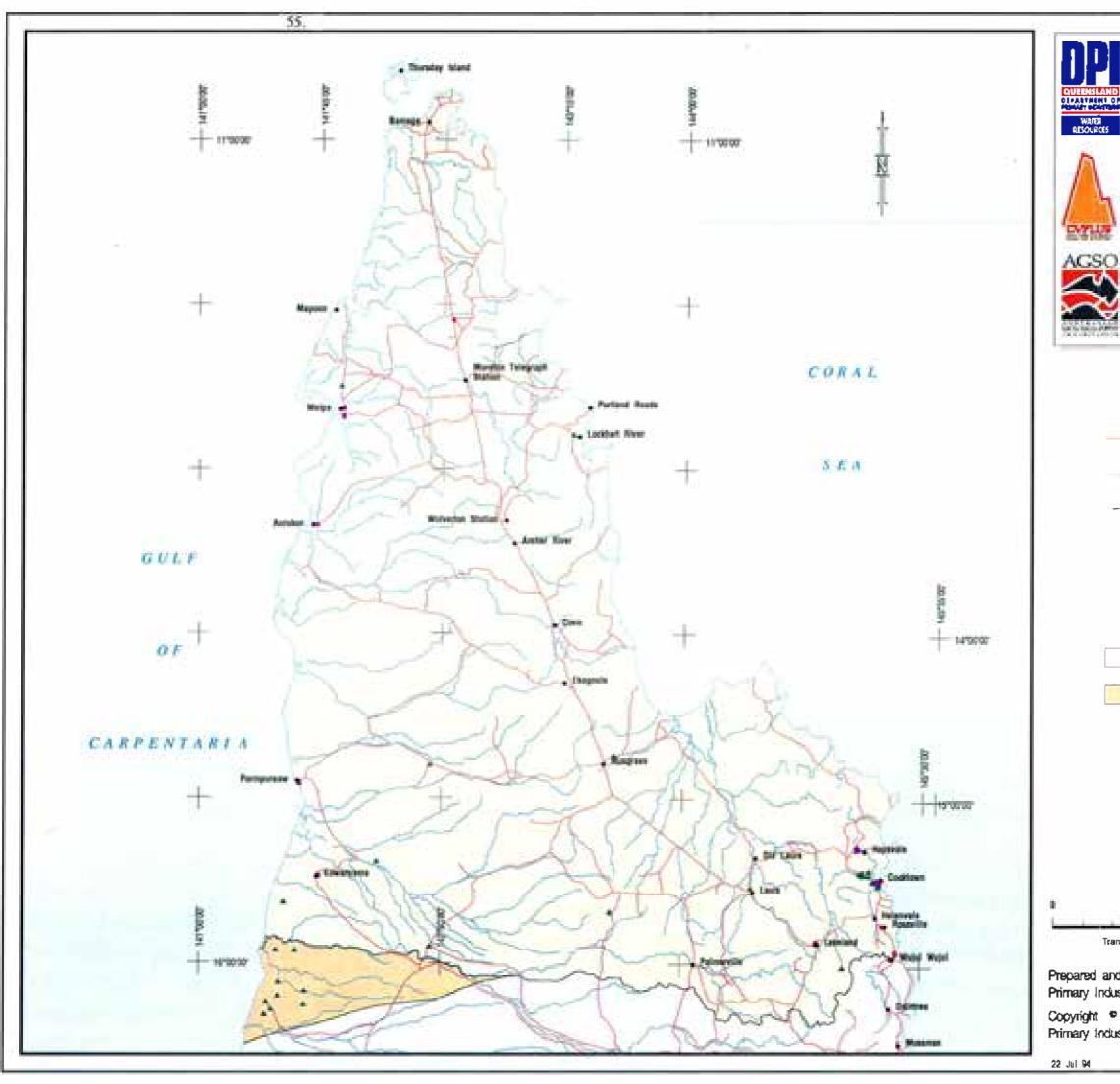


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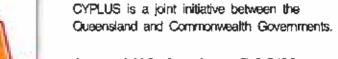
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EDITIÓN NO 1

FIGURE 3.3 A3-105519







DRINKING WATER BORES

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LEGEND

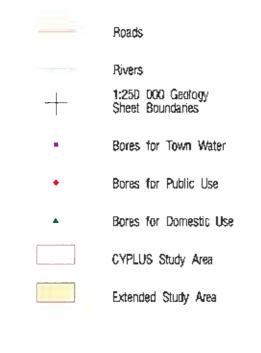
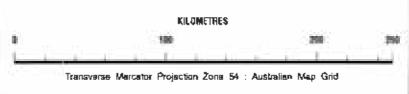


Figure 3.4 Drinking Water Bores

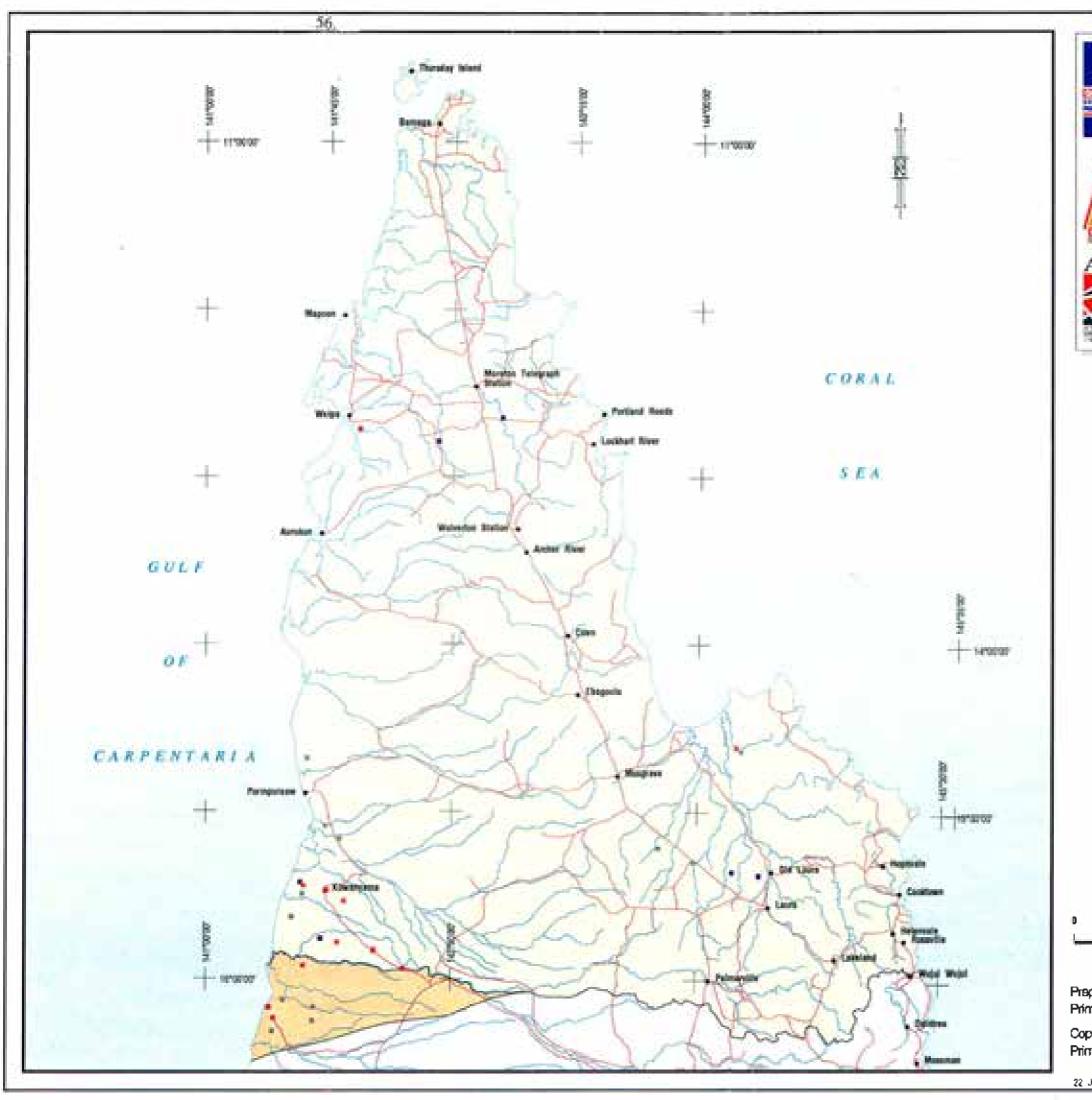


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EDITION NO 1

FIGURE 3.4 A3-105322







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ARTESIAN BORE DISCHARGE

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LEGEND

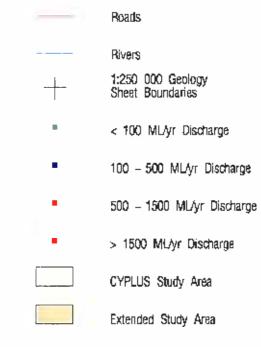
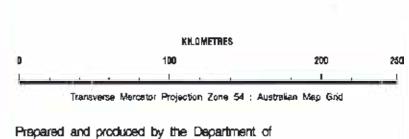


Figure 3.5 Artesian Bore Discharge Rates



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EDITION NO 1

FIGURE 3.5 A3-105520

Consolidated porous aquifers occur in the Carpentaria, Laura and Karumba basins.

The Carpentaria Basin is, along with the Surat and Eromanga Basins, one of three interconnected basins that comprise the Great Artesian Basin. They were formed by almost continuous sedimentary deposition during the Jurassic and Cretaceous periods. The depositional environment was dominantly continental (riverine) except for a major Lower Cretaceous marine transgression (GSA/TWSC, 1973). Sedimentary basins such as these supply approximately 30% of groundwater in Australia (Jacobson, 1983). The major porous aquifers which occur in the Carpentaria and Laura Basins are contained in the Dalrymple Sandstone, Gilbert River Formation and Helby Beds.

The Karumba Basin overlies the majority of the Carpentaria Basin in the study area. Within this basin the Bulimba Formation and the Wyaaba Beds contain major aquifers.

Unconsolidated surficial deposits incorporate unconfined aquifers, including those in alluvial, sand dune and other coastal deposits.

Fractured rock aquifers occur in the Palaeozoic metamorphics and granitoids of the Coen and Yambo Inliers, the Silurian/Devonian Hodgkinson Province, and the pyroclastic units of Cape York.

The DPI-WR has undertaken several minor hydrological investigations in the Peninsula area since the 1940s. This work has included formal reports published by the DPI and its predecessor organisations. Additional formal reports have been written on specific activities associated with this project including separate reports for each CYPLUS borehole drilled and an investigation into the Laura town water supply. Significant work has been documented in office memos and correspondence on the groundwater advisory work and smaller scale investigations conducted principally through the DPI's Mareeba office. This work is generally site specific.

Data on actual groundwater use in the study area is sparse, with only eight locations where water bores are metered. Use by the smaller communities, most mines, tourist locations and pastoral holdings can only be estimated.

Estimates of the major community water usages are based on administrative council reports and "local knowledge" and appear in Table 3.1. The major usage of bores licensed with the DPI is indicated in Figure 3.3 and those licensed bores used for drinking water supplies are shown in Figure 3.4. It should be noted that this information is taken from the registration details and other bores are also being used for these uses. Artesian bore discharge rates appear in Figure 3.5.

Town/Community	Usage/Annum in MI	Source	Accuracy
Kowanyama	250	G/W	Metered
Pormpuraaw	220	G/W	Metered
Aurukun	370	G/W	Metered
Weipa (including mine)	63 000	G/W	Metered
Napranum	200	G/W	Estimate
Bamaga *	900	Jardine River	Metered
Lockhart River	180	G/W	Estimate
Coen	54	G/W/Coen R/Lankelly Ck	Metered
Cooktown	318	G/W/Annan River	Metered
Lakeland	17	G/W	Metered
Laura	25	G/W	Estimate
Hopevale	300	G/W	Estimate
Wujal	150	Bloomfield River	Estimate

G/W = Groundwater

Table 3.1 Community Water Usage

^{(*} Includes Seisia, New Mapoon and Injinoo, Umagico)

Previous work undertaken to determine if the Carpentaria Basin sediments are mature for oil generation indicates the basin has a very high geothermal gradient compared to other sedimentary basins, including the Surat and Eromanga Basins. Leitch (1984, CR12877) identified the geothermal gradient as 108°C per km with a large variation (standard deviation of 18°C per km) on the Rutland Plains Sheet and a 60°C per km (standard deviation of 2°C per km) on the Weipa sheet (Table 3.2).

Leitch (1984) analysed twelve boreholes that had been logged by the BMR for their geothermal characteristics using the procedure outlined by Exon, (1976) in "The Geology of the Surat Basin". All holes were logged/tested during winter with assumed average near surface ground temperature of 20°C and an assumed average air temperature of 23°C. Some general isothermal contours localised around Weipa were presented.

Ogilvie (1954) considered that the generally accepted world geothermal gradient figure of 30°C per km of depth is about half the average generally experienced in the Great Artesian Basin, which is 60°C per km. Figure 3.6 indicates a general groundwater temperature trend in the study area.

: :	WEIPA				
RN	Depth of Hole (m)	Bettom Hole Temp (°C)	Geothermal Gradient (°C/km)		
13479	878	79	59		
35609	805	66.5	58		
35612	814	68.5	59		
35613	786	69	62		
	RUT	LAND PLAINS			
RN	Depth of Hole (m)	Bottom Hole Temp (°C)	Geothermal Gradient (°C/km)		
37234	137	35	109		
37235	152	35	99		
38304	101	34.5	143		
38475	90	28	89		
38821	144	36	112		
38822	102	32	119		
38922	101	31	109		
45020	201	36	82		

RN = Borehole Registered Number

Table 3.2 Geothermal Gradients - Weipa and Rutland Plains Areas (from Leitch 1984)

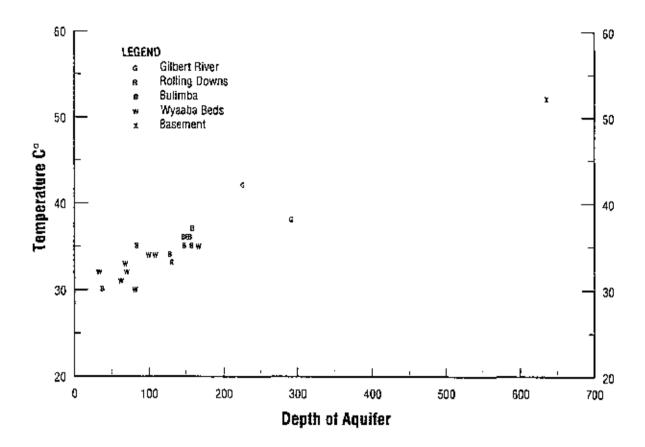


Figure 3.6 Groundwater Temperature Trend

A quantitative analysis of gases present in water sampled from flowing artesian bores was conducted in the Weipa area by Comaico. This work was documented by McConachie, (1987, CR23916) and encompassed the North Camp Bore (RN 37630) and five other bores in close proximity to Weipa (RN's 35609/10/11/12/13). The work concluded that the water in the deeper bores in the Carpentaria Basin is hotter and contains more gas than in the shallower bores. Relative weightings were applied to the laboratory results and indicated the North Camp Bore was an order of magnitude higher than the Weipa bores in methane and significantly higher in helium values.

The laboratory work determined concentrations of hydrogen, helium, oxygen, carbon dioxide, carbon monoxide and hydrocarbons (methane to octane). Methane isotope analysis was also carried out to determine the origin of the gas for some wells in the southern Carpentaria Basin.

McConachie, (1987) considered the presence of wide-spread high helium concentrations in the water bore gases may be a distinct characteristic of the Carpentaria Basin.

3.1 Fractured Rock Aquifers

Fractured rock aquifers are those that exhibit little intergranular porosity and derive their groundwater storage capability from secondary porosity features. These include joints, faults and voids and can occur as features derived from weathering action. Fractured rock aquifers supply about 10% of the groundwater abstracted in Australia (Jacobson, 1983).

Rocks in this category include Precambrian shield areas and sedimentary rocks commonly of Paleozoic age that have reduced primary permeability through post depositional crystallisation or cementation (GSA/TWSC 1973). In the study area, the Coen and Yambo Inliers and the Hodgkinson Province principally contain fractured rock aquifers. These tectonic units cover 33 700 km², being some 24% of the study area.

Fractured rock aquifers in the study area provide, through a large number of low yielding bores, important supplies for domestic and stock watering purposes. Behaviour of groundwater in fractured rocks is not well known and is sparsely documented (Kohut, 1983). However, it is considered that water supplies from such basement rocks will be small and by no means certain, with little scope for development of large scale resources (McEniery, 1980). In the study area generally, runoff rates are too high and the storativity too low for major accumulations to exist. There is comparatively little information available on transmissivities, specific yield and storage coefficient of these rocks.

Groundwater supplies in these terrains are recharged vertically and consequently are closely related to rainfall, soil cover and vegetation. This close dependence on rainfall increases the aquifer potential in the wetter parts of the study area. Supplies in such aquifers can be anticipated to deplete rapidly with intensive pumping (GSA/IWSC, 1973).

The aquifer yield and water quality is also closely dependent on structurally assisted permeability created by major structural features (Jones, 1985) or the occurrence of considerable thicknesses of weathered rocks or saprolites (GSA/IWSC, 1973).

Additionally, fractured rock terrains are usually topographically unsuitable for major aquifer occurrence because of their resistance to erosion (GSA/IWSC, 1973). The aquifers are generally unconfined, can exhibit considerable heterogeneity (Free, 1990) and their areal extent is limited by the topography of the stream basins.

Fractured rock terrains that have experienced tectonic stresses usually exhibit subvertical and extensive fracture systems (Ackworth, 1987). In the study area this includes almost all units in the Coen, Yambo and Hodgkinson Tectonic Provinces with the only possible exception being the Tertiary Piebald and McLean Basalts. Generally subhorizontal fractures are always present in crystalline basement aquifers that are close to the surface.

Generally fractured rock environments produce low yields of water and are characterised by variable transmissivities, low storativities, leakage and radical changes in permeability as shown in the Cape Bedford area of the Laura Basin (Martin, 1982). Flow characteristics can be complex and planar groundwater conduits, i.e. faults and joints that have been modelled as individual and isolated features that are seldom realised in nature (Snow, 1969). Consequently transmissivities of fracture systems cannot be extrapolated (Clark, 1985) because of this system heterogeneity. This is from pump tests usually showing barrier conditions (Free, 1990).

Deeply weathered profiles are termed saprolites when they occur as aquifers with the intergranular porosity developed in situ. They are exclusive to the regolith which also includes transported material. In the study area saprolites are uniform over large areas of the Coen and Yambo Inliers and the Hodgkinson Basin.

A requirement of such deep weathering to occur is a surplus of mean annual rainfall over recharge, conditions that are found in dry subhumid or wetter climates. If continuous high groundwater levels are not maintained, bauxite and other secondary minerals can form. These conditions are satisfied in the fractured rock provinces of the study area where there are extensive saprolites. Saprolites are commonly uniform over large areas and enhance the pre-existing mineralogical similarity that occurs in the basement complex rock types. Characteristically, saprolites are composed of leached soil horizons consisting largely of quartz sands, micas and pisolitic laterite. A duricrust commonly forms at the present water table (Jones, 1985).

Weathering zones represent a progressive chemical degradation from fresh rock to soil with a continuum through several zones (or soil horizons). These zones vary greatly in thickness and are illustrated in Figure 3.7.

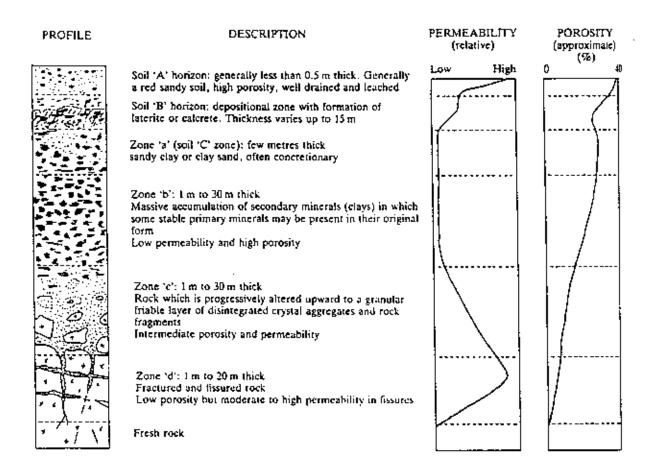


Figure 3.7 Typical Weathering Profile Developed on Crystalline Basement Rocks (from Ackworth, 1987)

Reasonable significant groundwater yields are possible in the deepest zone of weathered profiles. This is usually the main aquifer zone where fresh fractured rock is infilled by its weathered equivalents. This zone is usually of low to medium porosity but moderate to high permeability and can provide significant groundwater storage. The aquifers at the base of the saprolite may be semi-confined.

Yields from fractured rock aquifers tend to be comparitively low and often experience large seasonal variations because of their usually topographically elevated positions and low specific yield. This feature makes it difficult to predict long term bore behaviour and increases liklihood of failure.

Specific yields of fractured rock systems have been postulated by McEniery (1980) to be around 5%, although Clark (1985) estimated that such systems have an upper limit of 1%.

It is commonly considered that the largest and most pronounced fracture zones (those that can be located through topographic expression, air photo interpretation and satellite imagery) such as crush zones will yield the most water.

Groundwater resources in fractured rock terrains are principally arructurally controlled. Location of these resources needs to be aimed at identifying zones of either deep weathering or intense fracturing. This is most often achieved by using a combination of knowledge of local groundwater occurrences in conjunction with local geological characteristics, local vegetation patterns, geophysical and remote sensing techniques.

3.1.1 Coen Inlier

The Coen Inlier consists of two dominant rock types - acid intrusives (mainly granite) and relatively high grade metamorphics. Groundwater occurs in both rock types.

Metamorphics

Groundwater is extracted from 17 bores in metamorphic rocks in three main areas; Lockhart River, Coen and the southern tip of the Coen Inlier. In general, the most productive units are quartz-sericite schists with associated quartz veins.

There is very little consistency of depth of the bores in the metamorphics which range from 20 m to 70 m. Most productive bores occur in the Seston Metamorphics around the Lockhart River - Iron Range area. Here supplies of between 5 L/sec and 9 L/s are common. These bores are used for community water supply (mainly domestic) purches.

Three bores in the town of Coen extract water from the Coen Metamorphics. They have only meagre supplies (about 1 L/s) but are used for town water supply purposes from September to December in most years, after surface water supplies are exhausted.

Seven stockwatering bores which extract water from undifferentiated metamorphics are located in the southern tip of the Coen Inlier. The most common yields from these bores is 0.25 L/s. Most are less than 30 m deep and are equipped with windmills or small motor-driven pump jacks.

Acid Intrusives

Groundwater use from the acid intrusives follows the same geographical distribution as do the metamorphics. Seventeen bores are known to extract water from mainly granite sequence rocks.

The depth of the majority of these bores is less than 25 m. Below this depth the granite is usually referred to as "hard" or "massive" in drillers' logs. The primary source of groundwater from these bores is described as "soft granite" or "decomposed granite" i.e. the weathered zone.

Supplies from bores in this unit vary greatly. They are probably proportional to the rainfall received locally. For example, the supplies reported from the Lockhart River area range from 0.5 to 5 L/s while bores in acid intrusives at Coen, Ebagoola and the southern tip of the Coen Inlier rarely exceed 0.5 L/s.

3.1.2 Yambo Inlier

Only seven bores are known within the Yambo Inlier. All of these are shallow (about 20 m deep) and have been drilled into the weathered zone of acid intrusives. The supplies from these bores are between 0.25 and 0.5 L/s.

3.1.3 Hodgkinson Province

Aquifers in the Hodgkinson Province principally occur in secondary porosity features. These aquifers can yield substantial supplies of water for stock, and provide a significant component of the town water supply for Cooktown.

Hodgkinson Formation

Groundwater is known to occur throughout the entire Hodgkinson Formation. Secondary porosity is provide by bedding planes, jointing and disruption by quartz veins. As the formation is extensively deformed, isoclinal folding is common. As a result, the rocks commonly display secondary porosity in the form of schistosity and fracture cleavage. The rocks are essentially lutites in their original form and have little or no primary porosity. Yields are commonly of the order of 5 L/s but range from 0.5 L/s to 30 L/s.

Piebald Basalt

The basalt forms flat or gently sloping terrain. Drilling at Hopevale has shown that it ranges in thickness from less than 10 m adjacent to well incised streams to greater than 40 m. Groundwater is obtained primarily from blocky, jointed basalt rather than vesicular basalt. The Hopevale community extracts water from seven bores drilled into this unit. The supplies are about 5 L/s each.

The water level in the aquifer is very dynamic. It fully recharges by direct infiltration of rainfall in most wet seasons and commences draining towards surface water features almost immediately rainfall ceases. This has implications for the viability of a water supply based solely on groundwater as there is a real danger of failure of the bores in years with lower than average rainfall. No known groundwater extraction occurs from the northern occurrence of the Piebald Basalt.

McLean Basalt

Bores drilled into the McLean Basalt extract only very small supplies (usually less than 1 L/s). The thickness of the basalt is up to 30 m. Two of Lakeland Downs' town bores use groundwater from this unit.

The unit is recharged by direct infiltration of rainfall. Water levels in the unit are very dynamic. Groundwater levels in the town of Lakeland Downs approach the surface often in the wet season, but fall rapidly during the dry season. Seasonal variations of 15 m have been suggested by residents in the area.

3.2 Laura Basin

The first artesian bore, RN 10913, drilled in the Laura Basin was at Deighton, north of Laura in 1912. This was a coal exploration hole constructed by the then Queensland Department of Mines. 'Water of reportedly good quality is stated to have risen 4 inches over the casing' (Denmead, 1949). A.K. Denmead, the District Geologist, wrote in the Queensland Government Mining Journal in 1949 of drilling for water on Olive Vale Station. Since that time numerous bores have been constructed by mining companies and private landholders.

Groundwater now provides reliable supplies of water to most parts of the Laura Basin. Approximately 95% of the population depends upon groundwater for drinking and domestic purposes.

Spring flow maintains the region's only perennial stream, the Hann River, and provides nearly continuous supply to other rivers such as Little Laura, Kennedy, Normanby and Endeavour Rivers.

Stockwatering is at present the major water use, however domestic requirements are increasing as the population, particularly at Laura, increases. Laura is currently obtaining all its town water supply requirements from a shallow subartesian aquifer.

Aguifer Geometry of the Laura Basin

Three formations, the Dalrymple Sandstone, Gilbert River Formation and Rolling Downs Group comprise the entire basin from their outcrop areas in the south west, south and eastern margins to the northern onshore extremities at Port Stewart, Marina Plains and Bathurst Head. These are overlain by a veneer of Cainozoic sediments of widespread and variable nature. Total sediment thickness is over 1100 m (RN 22119, CBT Marina 1) in the central part of the basin.

Structural features have a significant impact on aquifer geometry in all Mesozoic sediments that occur in the Laura Basin.

The Palmerville Fault forms the boundary of the basin in the north western onshore area. In places vertical displacements of greater than 200 m have occurred resulting in aquifer truncations and conduits being formed along fractures.

Faulting of similar proportions has been measured in sections at Bathurst Range by Utah Development Co. geologists. Investigations by C D Mackie and Associates (1981) confirmed at least local dominance of secondary (fracture) porosity over primary porosity in the sandstones of this area.

Limited lithological and hydrochemical evidence from water bores drilled on Olive Vale Station in 1992 and 1993 indicates that faulting has occurred across the basin.

Basement topography indicates a somewhat irregular surface that influences the degree of dip in overlying sediments and thus has an influence over flow direction. Flow paths mapped by C D Mackie, (1982) indicated a south westerly trend from the Bathurst Range.

The Dalrymple Sandstone appears to maintain a relatively uniform lithology throughout the basin. It is in general conformably overlain by the Gilbert River formation which shares a similar lithology and fluviatile origin in its lower sections thus making the boundary difficult to distinguish.

The upper part of the Gilbert River Formation has, in contrast, a variable lithology ranging from clean quartzose sandstones to muddy sand interbedded with mudstones and siltstones especially where it grades into the Rolling Downs Group. This is important as the Gilbert River Formation contains the first artesian aquifers encountered in most water bores.

The Rolling Downs Group varies lithologically across the basin, particularly in the Bathurst Range area where a significant area is capped by the Normanton Sandstone. This is a clean quartzose sandstone that provides a highly transmissive aquifer not usually encountered in this formation elsewhere.

The general sequence of mudstone-siltstone sequences which are usually of low permeability, but contain isolated sandy layers that may act as aquifers. Cainozoic units of varied lithology overlie Laura Basin sediments.

In general, Tertiary formations such as the Lilyvale Beds and the undifferentiated unit beneath the Laura town area, consist of clayey sandstones and/or claystones of variable thickness (up to 130 m) that are often covered by a thin veneer of surficial deposits.

Surficial deposits which constitute colluvium, alluvium, ferricretes and gravels are rarely more than 10 m thick except at the base of scarps and associated with larger watercourses.

General Hydrology of the Laura Basin

Artesian flows occur from aquifers in the Gilbert River Formation and Dalrymple Sandstone within 20 kms of outcrop in the southern and south western parts of the Laura Basin. Artesian conditions persist across the basin up to the eastern onshore margin. These formations also provide artesian water in the north western onshore area at similar distances from the margins.

The Rolling Downs Group, where drilled, generally provides small quantities of water at depth but is not considered to be a regional groundwater target because of its limited permeability. Most bores either stop at the top of this Group or continue through it to better prospects in lower formations. Some older facilities (e.g. RN's 11223 and 11224) in the Fairview area obtained useful supplies, suitable for stockwater, from depths of 200 to 300 m.

The Normanton Sandstone contains a useful aquifer in the Bathurst Range area.

Tertiary sediments provide small supplies (less than 2.0 L/sec) to users in Laura township. The aquifer is located between 20 and 30 m below ground level. There appears to be no record of bores tapping water from Tertiary sediments elsewhere in the basin.

Surficial deposits contain useful, if somewhat seasonal supplies in various parts of the basin. Shallow holes, less than 15 m, drilled at Violetvale have struck freshwater. Alluvium associated with major watercourses may contain significant resources, but to the knowledge of the authors, these deposits have yet to be investigated or exploited.

Potentiometric heads are difficult to map as there is only limited data available across the basin. Generally it can be said that artesian bores possess water levels of between 1 m and 15 m above ground level. No history of water level fluctuations is available hence seasonal and long term variations cannot be determined.

Groundwater levels in the Rolling Downs Group appear to be fairly static at around 60 to 80 m below ground level in the rare facilities where measurement is possible. Field observations of spring flow derived from the Normanton Sandstone indicate that water levels fluctuate from several metres above ground level to perhaps 10 m below ground level dependent upon seasonal variations and local topography.

Water level behaviour in Tertiary formations has only been observed in the Laura town area. Here levels vary between 10 and 20 m below ground level, again dependent upon seasonal conditions and the degree of pumping from the aquifer.

Little is known of water table behaviour in surficial, alluvial and colluvial deposits. Comments made by local residents and drillers indicate large seasonal variations and often total failure in drought conditions.

Formation Hydrogeology

The Dalrymple Sandstone and Gilbert River Formation, in combination, contain the most significant aquifer systems in the Laura Basin. Aquifers are continuous across the basin and provide reliable supplies of fair to excellent quality water.

Large areas of grazing land depend on bores tapping these formations to provide stock water. Several stations obtain domestic supplies from this source and the new Laura town water supply is to be sourced from this formation.

Spring flow derived from both units maintains perennial or near continuous flow to several watercourses, most notably the Hann, Little Laura, Kennedy, Normanby and Endeavour Rivers.

The only constraints on availability and usage are the depth to intersection and deterioration of quality that increase towards the centre of the basin. These factors are not considered to be issues as this area is presently gazetted as national park and large supplies of water are unlikely to be developed.

The Dalrymple Sandstone and Gilbert River Formation underlie the entire Laura Basin.

Their outcrops delineate the basin margins except in the west and north west where basement inliers and the Palmerville Fault form the basin boundaries.

The thickness of the combined formations ranges up to over 700 m in the central part of the basin.

As discussed previously the boundary between the two formations is difficult to determine due to lithological similarities. Accordingly these two formations have been regarded as one hydrogeological unit for the purposes of this report. They will be referred to as the Mesozoic Sandstones from here on.

The Mesozoic Sandstones can provide water to all parts of the Laura Basin except elevated margin extremities where beds either lense out or drain soon after recharge events.

Total available water quantity from these sandstones has not been determined. Few bores penetrate the entire Mesozoic sequence and those that do were not tested. Geologists of the Utah Development Company recorded artesian flow rates ranging from 2.5 L/s to 12.6 L/s from exploration holes partially penetrating the Mesozoic Sandstones in the Bathurst Range and Kalpowar areas.

Mackie and Associates (1981) carried out flow and pumping tests on some of these wells but did not report flow rates.

DPI personnel have tested bores in the Bathurst Range area and three private facilities north west of Laura. Results at Bathurst Range indicated rates of 0.25 L/s to 6.9 L/s were available. These figures however are probably understated due to collapses in uncased sections of holes. Data from bores, RN's 11224, 78220, 78221, k nown to have intercepted only the uppermost section of the Gilbert River Formation, indicate flow or pumping rates of between 0.75 L/sec and 2.0 L/sec.

It is considered that substantially increased supplies would be available if greater percentages of the Mesozoic Sandstones were penetrated or larger diameter wells were installed with appropriate higher capacity pumping equipment.

The prospects of obtaining reasonable supplies from the Mesozoic Sandstones are good across the entire Laura Basin excepting outcrop margins where insufficient formation thickness exists.

Measurement of specific aquifer parameters has only been attempted in one small area of the Laura Basin, in the Bathurst Range coal prospect. General parameters for the Mesozoic Sandstones have been investigated by DPI personnel across the Basin. These, however, have been limited by the unsuitability for testing of many facilities.

Table 3.3 indicates aquifer parameter data for the Mesozoic Sandstones.

(1) Higher values generally indicate the influence of fracture porosity in tested bores.

Source of data (a) DPI-WR Groundwater Database (b) C. D. Mackie and Associates - Utah Development Company - Preliminary Groundwater Studies Bathurst Range, North Queensland, December 1981: Flow Tests (Artesian) (a.g.1 = above ground level, b.g.1 = below ground level)

Table 3.3 Laura Basin - Mesozoic Sandstone Aquifers

Rolling Downs Group

The Rolling Downs Group is not generally considered as an aquifer bearing unit due to its predominantly impermeable lithology. In the Laura Basin there are two factors that mitigate against this and result in this formation providing useful supplies of reasonable quality water.

The first is the presence of an unusually clean correlative of the Normanton Formation, informally called the Normanton Sandstone by Utah Development Company geologists. This sandstone occurs only in the Bathurst Range area, is of limited areal extent and a large portion of the stored water drains out by the end of each 'dry' season. Field observations and comment from local residents however indicate that it may significantly contribute to spring flow throughout the year, thus maintaining various wetland habitats.

The second consideration is fracturing which has occurred in the Rolling Downs Group, most noticeably in the southern part of the basin. These fracture zones were reported in mining companies' and private drillers' borehole logs. Reasonable supplies of fair quality water are available from fractures as indicated by observations made by the authors during the drilling of RN 78221 on Olive Vale Station.

Small lenses of sandier material are found throughout the Rolling Downs Formation. These lenses contain limited volumes of usually saline water and are only of consequence when considering their exclusion from a bore during construction.

The Rolling Downs Group overlies the Mesozoic Sandstones across most of the Laura Basin, lensing out towards the basin margins. Outcrop is relatively limited, occurring only as remnant hills (i.e. Jane Table Hill), exposures in Bathurst Range and in the sides of the Fairview Plateau.

Formation thickness varies from around 40 m near Kalpowar to over 200 m in the centre of the basin.

Little data is available regarding the potential supply of water from the Rolling Downs Group. In general the isolated lenses of sandier lithology encountered produce only limited subartesian supplies, less than 1 L/s.

An artesian flow, sourced from a fracture zone in RN 72881, was measured at 1.2 L/s with a positive head of 3.5 m. A subsequent water analysis revealed that this water is probably sourced from contact with a granitic basement.

There is no data concerning water availability in the Normanton Sandstone unit. Indications are that there would be worthwhile (greater than 2 L/s) supplies obtainable from this sandstone where sufficient thickness exists.

General aquifer parameters have only been investigated in two bores tapping Rolling Downs Group aquifers. No specific parameters have been measured.

Table 3.4 presents known parameters for the Rolling Downs Group in the Laura Basin. The lack of data requires that suitable caution be applied when considering these parameters.

Transmissivity	Storage	Unconfined Water	Confined (Artesian)
Range	Coefficient	Level Range	Water Level Range
m²/d	Range	metres b.g.l.	metres a.g.l.
up to 500 ⁽¹⁾	No Data	0-75.0 m	0-5.0 m

⁽¹⁾ Higher values indicate the influence of fracture porosity in the tested bore.

Table 3.4 - Laura Basin - Rolling Downs Group Hydrogeological Parameters

Cainozoic Sediments

The Cainozoic Sediments make a relatively minor contribution to the hydrology of the Laura Basin. Whilst these sediments cover large areas of the basin they are relatively thin and often consist of clayey and or silty materials that make poor aquifers. Localised areas assume some importance, particularly at Laura, where the entire town water supply is presently extracted from Tertiary sediments.

The Tertiary, Quaternary and Recent deposits have some potential to provide useful supplies but to date there has been little or no effort to locate or exploit resources.

Water is generally found in the basal layers of all the Cainozoic units but is often seasonal in nature. Bores in the Laura town area tap a silty, sandy aquifer about 30 m below ground level which provided reliable supplies at pumping rates of 0.1 to 1.0 L/sec.

Water quality is generally good with total dissolved solids ranging from 100 to 600 mg/L and averaging at 250 mg/L. Specific ions, (manganese and iron) can occur at levels high enough to be of concern.

Observations at Laura indicate that all shallow aquifers are at high risk from point source contamination. Effluent from septic systems in this town has rendered water from two shallow aquifers (at 5 m and 30 m below ground level) bacteriologically unsuitable for human consumption.

3.2.1 Fractured Sediments - Bathurst Heads

An analysis was undertaken by Martin, (1982) of a hard rock aquifer covering approximately 300 km² located just inside the Laura Basin in the Bathurst Ranges and Laura Plains south from Bathurst Head. The area is of variable Cretaceous sediments, Jurassic sandstones and Permian metasediments. The analysis was conducted using flow meter surveys, pressure testing and hydrochemical analyses including field testing for pH, redox potential, temperature and conductivity.

Two groundwater flow trends were identified with an older water flowing from the east and a more recent water flowing from the north. A mixing zone was identified near the Marrett River where an additional water unit may be influencing the hydrochemistry and where redox potential showed a reversal. Reducing conditions in the aquifer were identified by an almost complete lack of sulphate. Generally water characteristics changed from (younger) NaCl type to (older) NaHCO₃ along their migration paths with marginally anomalous samples being considered to be located close to more transmissive structural zones. Plots of TDS, pH contours and redox potential were presented.

3.3 Carpentaria Basin

The prospect of locating artesian water in the Carpentaria Basin was first discussed by Ogilvie in 1955. Few, if any deep boreholes existed in the Carpentaria Basin at that time. A deep petroleum exploratory bore - ZCL Weipa 1 (Power and Lindhe, 1958) was drilled in 1957. This bore reached a total depth of 989 m but encountered no hydrocarbons. It did however flow water at a rate of 33 L/s. In 1970 COMALCO drilled five artesian bores in the Weipa Peninsula vicinity. These bores ranged in depth from 820 m to 863 m and encountered flowing supplies between 25 L/s and 43 L/s.

Two deep bores were drilled in 1971 and 1972 as part of the Aurukun Joint Venture (Coffey and Hollingsworth, 1972). These bores were to investigate the water potential of the Gilbert River Formation and its hydrogeological equivalents for mining purposes. The depths of these bores were 1010 and 993 m. Coffey and Hollingsworth concluded that bores in the Aurukun area would flow if they were located at elevations of less than about 45 m and that no useful aquifers were available in the Rolling Downs Group sequence.

Several mineral exploration bores were drilled in the Wenlock River area to the east of Weipa and in the Olive River/Temple Bay area during the mid 1970s. Almost all of these bores were drilled to basement and some of these provided flowing groundwater. The majority were plugged and abandoned and no formal flow or pressure measurements were carried out. Water samples were obtained from the holes which flowed. Analyses of these samples have been incorporated into this report.

Only two other deep boreholes intersecting the Carpentaria Basin aquifers produce flows in the study area. These are GSQ Weipa 1 (now water bore RN 72262) and GSQ Rutland Plains 1 (now water bore RN 72275). GSQ Rutland Plains 1 is open to both Carpentaria Basin and Karumba Basin aquifers so its flow rate and water chemistry are composites of both basins. It does, however, provide valuable information on the depth of the Carpentaria Basin sediments towards the south western boundary of the study area.

Few bores produce water from the Rolling Downs Groups in the study area. Those that do are subartesian and usually have quite saline water and low discharges.

Stockwatering is the main use of Carpentaria Basin groundwater in the study area. The Weipa and Aurukun deep bores were intended for bauxite mining purposes but are no longer used for that purpose owing to the corrosive nature of their water and the ready availability of good quality groundwater from younger Karumba Basin aquifers.

Aquifer Geometry of the Carpentaria Basin

The main aquifer unit of the Carpentaria Basin is the Gilbert River Formation. In the northern part of Cape York Peninsula the Garraway Beds and Helby Beds also contain aquifers. Minor aquifers occur within the lower Rolling Downs Group but they are generally not hydraulically connected to each other or the underlying formations.

The Gilbert River Formation itself crops out along the western margins of the Coen Inlier in the study area. The east-west extent of outcrop of this formation rarely exceeds 20 kms.

The Rolling Downs Group is generally regarded as an aquitard and conformably overlies the Gilbert River Formation south of latitude 12°S and west of the Coen Inlier.

Tertiary Sediments of the Karumba Basin obscure most of the Carpentaria Basin on Western Cape York Peninsula. The Carpentaria Basin sediments reach a maximum thickness of 1200 m.

Two main depressions occur within the Carpentaria Basin in the study area. These are the Staaten Embayment and the Weipa Depression. Senapati, (1991) considers that the Weipa Depression should be assigned sub-basin status.

Basin topography beneath the Carpentaria Basin in the study area is considered to be subdued with a gentle westerly slope westwards away from the Coen Inlier.

Drilling during 1992 indicated that a graben-like structure may exist beneath the Strathmay-Holroyd areas. Bores RN 92000001 and RN 92100001 (drilled as part of this CYPLUS project) terminated in the middle of the Allam Mudstone at depths of 327 m and 331 m respectively. It has been assumed that approximately 300 m of Rolling Downs Group sediments would exist below these depths. It was expected that the top of the Gilbert River Formation would have been intersected at depths of less than 300 m in these bores.

For the purposes of this report the Gilbert River Formation, the Garraway Beds and the Helby Beds are considered to be the one hydrogeological unit. As previously indicated it is difficult to distinguish these conformable units in the subsurface. Too few bores have been drilled in the Garraway Beds and Helby Beds to allow proper definition of these units as hydrogeological units. Figure 2.7 is a structure contour map of the top of the Gilbert River Formation hydrogeological unit. It should be reiterated that few data points give accurate stratigraphic control between Weipa and GSQ Rutland Plains 1.

General Hydrology of the Carpentaria Basin

The Garraway Beds and Helby Beds, in their outcrop areas, generally contain subartesian aquifers. Few bores exploit these aquifers in these areas owing to the ready availability of surface water.

One of the CYPLUS test bores (RN 92600002) at Heathlands was drilled to ascertain the groundwater potential of the Helby Beds. The drilling results from this bore indicated that useful subartesian supplies of good quality groundwater are available from the Helby Beds.

Drilling undertaken by Utah Development Company in the Garrawa, Beds in the Temple Bay area indicated that this unit has the potential to supply useful quantities of good quality subartesian water. By contrast, the few bores which exploit subartesian aquifers of the Rolling Downs Group intersect meagre supplies of generally saline water.

Carpentaria Basin supplies of flowing groundwater are best understood in the Weipa area. In this area the Gilbert River Formation hydrogeological unit is completely confined. Bores tapping this formation flow if they are located approximately 50 kms west of the Coen Inlier. The exception to this hypothesis is RN 92500003 (Wenlock River) which flowed from a depth of only 120 m. This may indicate a local thinning of the Gilbert River Formation over a southerly extension of the Bramwell Arch.

Between Aurukun and Rutland Plains there is limited data as few bores intersect the Carpentaria Basin aquifers. The aquifers of this formation would be expected to produce flowing bores throughout the area.

As there are very few bores, either artesian or subartesian, which intersect Carpentaria Basin aquifers, no definitive potentiometric surface map has been produced. Most of the data for flowing bores are clustered around the Weipa Peninsula. It is considered that there is insufficient hydraulic connection between aquifers within the Rolling Downs Group to allow construction of a potentiometric surface map for this unit.

Formation Hydrology:

Mesozoic Sandstones

The Mesozoic Sandstones are considered to comprise the Gilbert River Formation, the Garraway Beds and the Helby Beds. Structure contours of the top of this unit indicate that it dips gently towards the west from its outcrop area. It is generally considered to be lithologically similar throughout its extent.

The Mesozoic sandstones are recharged by rainfall infiltration in their outcrop areas. Groundwater generally flows from east to west within the unit except in the very northern part of the Peninsula where a groundwater divide may exist over the Bramwell Arch.

The Mesozoic Sandstones should provide water to all parts of the Carpentaria Basin. No known bores which have intersected this unit have been regarded as failures.

An estimate of the total volume of water available from the Mesozoic Sandstones has not been made owing to the uncertainty of definition of the unit in the central western part of the study area.

Very few waterbores extract groundwater from the Gilbert River Formation when it is confined by younger fine-grained rocks within the study area. This is probably because of the availability of water from the younger Karumba Basin aquifers which overlie the Carpentaria Basin. It is simply uneconomical for pastoralists to drill to the Gilbert River Formation except in outcrop areas.

Few bores exploit the Garraway Beds in its confined state. It is, therefore, difficult to make any definitive assessment of the aquifer potential of the unit west of its outcrop area. Data from GSQ Weipa 1 (Derrington, 1988a) indicate that the Garraway Beds occur conformably beneath the Gilbert River Formation and rest unconformably on granitic basement. The cored sections of this hole show that the Garraway Beds are much finer-grained than the Gilbert River Formation with siltstone and mudstone evident.

As there was very little information available on the aquifer potential of the Garraway Beds one of the CYPLUS testholes (RN 92600002) was drilled within this unit at Heathlands. The results of this test hole indicated that the unit has the potential to deliver good quality water in sufficient quantity for stockwatering.

Flowing supplies of between 25 L/s and 43 L/s were recorded from the Mesozoic Sandstones in the deep Weipa Peninsula bores. Non-flowing supplies of up to 5 L/s are obtained from the Mesozoic Sandstones.

Specific aquifer parameters for the Mesozoic Sandstones have been measured in the Weipa Peninsula bores and in the Batavia Downs (RN 92500002) and Wenlock River (RN 92500003) bores. GSQ Rutland Plains 1 is open to both the Carpentaria Basin and overlying Karumba Basin sequences and measurements of transmissivity and head (water levels) are, consequently, a combination of these parameters from both basins. They are not used in this report.

Table 3.5 shows aquifer parameters for the Mesozoic Sandstones of the Carpentaria Basin. Data have been obtained from Department of Primary Industries testing and bore census during 1992.

Transmissivity Range m²/d	Storage Coefficient Range	Unconfined Water Level Range (metres b.g.l.)	Confined Water Level Range (metres a.g.l.)
4-570	No Data	2-76	8-31

Table 3.5 Carpentaria Basin - Mesozoic Sandstones Aquifer Parameters

Rolling Downs Group

The group is composed predominantly of argillaceous marine sediments (Vine et al., 1967 in Willmott and Powell, 1977) principally fine grained clastics and marine mudstones and some hydraulically unconnected sandstone lenses. Because of its finer grainsize compared with the underlying Gilbert River Formation and Garraway Sandstone, the Rolling Downs Group serves as a major confining unit for the regional aquifer systems throughout the Great Artesian Basin (GSA/IWSC 1973). The marine phase of the Rolling Downs Group contains sandstone interbeds formed in lacustrine conditions which support local aquifers. Minor aquifers are present in the lower part of the Wallumbilla Formation (Smart, 1980). These aquifers are usually hydraulically unconnected and are of relatively minor importance compared with the underlying Gilbert River Formation and overlying Karumba Basin aquifers.

Ten bores obtain water from relatively shallow subartesian bores in the Carpentaria Basin in the study area. Most of these obtain water from muddy sandstone beds located in thick sequences of dark grey shale and mudstone. None of these bores has been pump tested formally so aquifer parameter data are not available.

Supplies from these bores are generally low (<0.5 L/s). Groundwater from the Rolling Downs Group is generally saline except in its very lowest part where it grades into the underlying Gilbert River Formation. The known conductivity of water from the Rolling Downs Group ranges from approximately 200 μ scm⁻¹ to 11 200 μ scm⁻¹ in the study area.

The prospects of sustainable groundwater use from the Rolling Downs Group in the Carpentaria Basin are regarded as poor owing to the low discharge rates and poor water quality associated with this unit.

3.4 Karumba Basin

The water bearing potential of the Karumba Basin sediments was first mentioned by Derrington (1957). His final report on the drilling of the petroleum exploration well FBH No 1 (WYAABA) discusses a reversal in the SP (spontaneous potential) log that "probably represents a water bearing sandstone bed." This sandstone has since been correlated with the aquifers found in the Bulimba Formation.

In 1971 the Bureau of Mineral Resources and the Geological Survey of Queensland carried out a stratigraphic drilling program across the Carpentaria Basin in the south west of Cape York Peninsula (Smart et al., 1971). Grimes, (1972) reported on shallow artesian aquifers encountered in the Bulimba Formation in two of these holes, BMR Rutland Plains No 1 and BMR Walsh No 2.

Bedford, (1973) summarised data from the BMR-GSQ program and some of the subsequent private drilling on Rutland Plains, Dunbar and Koolatah Stations. He did not differentiate between bores tapping either the Bulimba Formation or Wyaaba Beds aquifers.

The first attempt to collate available data and delineate the two aquifers occurring in these units was made by Hillier, (1977). Comments made in his report regarding the limited areal extent of the Wyaaba limestone aquifer and the unpredictable nature of the Bulimba Formation have since been validated by further drilling.

McEniery, (1979) updated the preceding reports, expanded upon the known aquifer parameters, estimated storage coefficients and focussed a little more closely upon water quality aspects.

Since 1971 over 150 bores have been drilled to tap both artesian and subartesian aquifers in the Bulimba Formation and the Wyaaba Beds.

The Karumba Basin aquifers are considered the most significant water resource in Cape York. These aquifers provide the domestic supplies for some 6200 people in five centres, the entire water supply requirement for the regions largest mining and industrial complex at Weipa and stockwater over approximately one third of the Cape.

The hydrogeology of the Karumba Basin is still poorly understood. It is considered that the assessment and management of the groundwater resources of the Karumba Basin is essential to any strategy developed for Cape York Peninsula.

Aquifer Geometry of the Karumba Basin

The Karumba Basin consists of two units, the Bulimba Formation and the Wyaaba Beds, both of which contain important aquifers. The Bulimba Formation is more significant in terms of areal extent and capacity.

The Bulimba Formation has an extremely variable lithology but can be recognised in outcrop from its northern extremities near the Dulhunty River, eastern limits approximately following the Great Dividing Range and southern areas well outside the CYPLUS study boundary. Aquifers of variable capacity occur throughout its extent.

The Wyaaba Beds by contrast are somewhat monotonous in lithology excepting the near basal marine sequence that occurs in coastal areas centred around the Edward River delta. This marine bed, consisting of sandy, calcareous sediments (described by drillers as 'greyrock' or 'limestone'), offers the only aquifer of real importance in the Wyaaba Beds. Hence further discussion regarding the hydrology of this unit will refer only to that area in which these marine sediments occur.

Aquifer thicknesses vary in both formations. Sandy intervals in the Bulimba Formation range from less than 1 m to greater than 15 m thickness and can occur at any depth, from the surface at Weipa, to over 200 m below groundlevel in the Kowanyama-Rutland Plains area. The aquifer in the Wyaaba Beds is always found near the base of the formation onshore and thickness varies from 25 m to over 30 m at Kowanyama. Observation of water levels in bores at Pormpuraaw shows tidal influences that imply this aquifer outcrops on the seabed to the west.

Structural features have little effect on the Bulimba Formation aquifers as their occurrence is primarily related to localised conditions of deposition.

The Wyaaba Beds aquifer is limited to the near present day coastline where a shelf structure allowed a marine transgression to occur thus providing the necessary depositional environment.

Stratigraphic Interrelationships

The Bulimba Formation lithology ranges from virtually impermeable claystone, often kaolinitic, to a coarse grained unconsolidated sand, or cemented cobble conglomerate. This reflects a wide range of depositional environments and impacts heavily upon its predicability when drilling for water. The formation rests unconformably on blue-grey mudstones of the Rolling Downs Group sediments thus making the lower boundary very distinctive.

The Wyaaba Beds consist primarily of coarse to fine grained sandy claystones with a basal marine bed occurring in near coastal areas. This unit appears to be remarkably consistent in lithology across its mapped extent.

Cainozoic sediments overlie most of the Karumba Basin except the Bulimba Formation outcrop in the eastern and northern extremities of the study area. These units are frequently sourced from parent material in common with the Bulimba Formation and Wyaaba Beds which makes the upper boundary of the Wyaaba Beds difficult to determine. They are predominately fine grained sands, silts and clays. Coarser grades of sand and gravel are associated with alluvial deposits along rivers in the more elevated areas or where harder material forms a stream bed such as Shelfa Crossing near Kowanyama. Fine grained dune sands and coquinas occur near the Gulf shorelines.

General Hydrology

Artesian aquifers are found in both units of the Karumba Basin.

Sandy layers within the Bulimba Formation provide flowing supplies in the area approximately bounded by the Staaten River to the south, the northern arm of the Mitchell River Delta and the confluence of the Mitchell and Palmer Rivers to the east.

The marine section of the Wyaaba Beds supplies artesian water to an area extending from near Rutland Plains Station north to Christmas Creek and approximately 50 kms inland from Pormpuraaw.

The Bulimba Formation contains variable quantities of subartesian water across its entire extent in the study area.

The Wyaaba Beds are not considered to be an aquifer bearing unit outside the area of artesian supplies. Limited supplies may be encountered elsewhere but existing data suggests that these are of small volume and often poor quality.

Overlying Cainozoic sediments provide small but useful sources of water particularly along the western coastal fringe.

The overall contribution of these sediments is not significant in a basin wide context but several community outstations and commercial fishing camps rely on shallow bores and wells for domestic and drinking water.

Potentiometric Surface Levels

Artesian water levels in the Bulimba Formation range from 1 m to 35 m above ground level dependant upon site elevation, depth of interception and variations in aquifer characteristics.

The variation in potentiometric head is difficult to quantify because of a lack of long term data. However, scattered measurements of the water head at RN 45019 (the Kowanyama Town bore), indicate a decline in pressure head from +22.5 m in 1974 to +8.25 m in 1992. This decline is considered to be either due to a succession of poor recharge events and near continuous discharge at high volume over this time or possibly to mining of this resource.

Subartesian water levels in the Bulimba Formation vary from 1 m to 6 m below ground level across most of the basin. Bores located on this formation in outcrop areas of relatively high elevation, such as RN 92500004 drilled on the Embley Range as part of the CYPLUS drilling program, may be completely dry as any waters collected during the wet season drain completely once rain ceases.

Artesian water levels rarely rise more than 2 m above ground level in the Wyaaba Beds. Water levels appear to vary seasonally by 2 to 3 m and as a consequence some bores may cease to flow. This has been the case on Rutland Plains and at Kowanyama since 1991.

Subartesian water levels recorded by data loggers installed at Pormpuraaw range between 1 m and 3 m below ground level. It is likely that there is some influence from pumping in this area. It is of interest, and long term importance, to note the daily variation of 0.5 m that reflects the influence of tides and barometric pressure changes on water levels this close to the coast.

There is little data available to assess potentiometric levels in the Cainozoic sediments.

Some general comments can be made about shallow sand aquifers that occur along the coastline. These aquifers are usually perched on impermeable marine muds (i.e. saltpans) or are in hydraulic connection with seawater and can thus only have a water level that varies between ground level and sea level. There are few coastal areas that rise more than 10 m above sea level and it is known that some bores decrease in yield or suffer quality decreases at the end of the dry season. It is also known that most of these areas are inundated by fresh water for long periods during the wet season, therefore water levels can range from groundlevel to around 10 m below ground dependant upon seasonal factors.

Formation Hydrology

Bulimba Formation

The Bulimba Formation contains the most extensive and productive aquifer systems in the Karumba Basin. Water supplies for Kowanyama, Aurukun, Napranum and Weipa (domestic and mining/industrial) are drawn from these aquifers. Numerous cattle properties also use water from this formation for domestic and stockwatering purposes.

Springflows from the Bulimba Formation contribute to base flows in several rivers and maintain wetland environments near Weipa and Aurukun.

The major constraint on availability of supplies from the Bulimba Formation is the variability of lithology than can make location of successful bores a difficult exercise.

The Bulimba Formation underlies the entire Karumba Basin. Formation thickness varies from less than 30 m at Weipa to over 150 m in the central onshore part of the basin. Structure contours are shown in Figure 2.9.

Aquifers in this formation are not continuous and are not always in hydraulic connection with each other.

The Bulimba Formation aquifers can be loosely divided into two distinct systems; the shallow (less than 20 m deep) unconfined beds that occur in the Weipa-Aurukun area and the deeper (40 m⁺) confined aquifers found from Strathmay and Holroyd Stations in the east to Kowanyama and Inkerman on the west coast.

The shallow aquifers consist mostly of coarse grained sand beds closely associated with east-west trending paleochannels that occur in approximately the same plane of elevation. Thickness of these aquifers ranges from 1 m to 10 m. Recharge is via direct infiltration and is relatively fast; within two weeks of significant (greater than 100 mm) rainfall events.

The deeper, confined, aquifers have a similar structure and geometry to those just discussed but were buried under varied thicknesses of sandy clay material. These aquifers are found at depths from 40 m to over 200 m below ground level and range in thickness from 1 m to greater than 15 m.

Subartesian water is available over most, if not all the northern extent of the Bulimba Formation. Several test holes may be required to locate suitable volumes of water, dependent upon the intended usage.

The eastern section of the Bulimba Formation has had few holes drilled in it, hence there is a lack of data available. Drilling at Strathmay, Holroyd and Strathgordon during the CYPLUS program located supplies ranging from 1 L/s to over 5 L/s at depths of less than 70 m.

Artesian water can only be considered as a reliable prospect in the western onshore area bounded by the Mitchell and Staaten Rivers. Supplies may be encountered at varying depths dependent upon a sites location.

Volumes of water available range from 5 L/s to over 30 L/s again dependent upon depth, aquifer lithology and aquifer thickness.

Aquifer parameters for the Bulimba Formation can be reasonably well defined as there is a substantial amount of data available particularly for the shallow aquifer systems.

Data quoted in Table 3.6 has been collated from the following sources:

- (a) Department of Primary Industries Water Resources
 Groundwater Data Base : Water Levels, Pumping Test, Artesian Tests,
 Unpublished Reports
- (b) Coffey and Hollingsworth (1971) Comalco Ltd Shallow Groundwater Investigation, Weipa North Queensland, Volume 1: Report

Aquifer Type	Transmissivity Range m³/d	Coefficient	Subartesian Water Level Range metres b.g.L	Arlesian Water Level Range metres a.g.t.
Unconfined	10-1000 (ь)	2x10°2-1x10°1 (b)	0.0-10.0 (ъ)	N/A
Confined	5-1100 (a)	No Data	4.0-10.0 (a)	0-35.0 (a)

Table 3.6 Karumba Basin - Bulimba Formation - Aquifer Data

Wyaaba Beds

The Wyaaba Beds, as previously discussed, only contain a viable aquifer within a limited part of their areal extent. This aquifer is, however, important as it provides the town water supply to Pormpuraaw and access to relatively shallow sources of artesian and subartesian water for stockwatering purposes.

The aquifer is hydraulically connected to seawater under the Gulf of Carpentaria and thus is at risk of saltwater intrusion should total discharge of water exceed the available recharge.

With this in mind two observation bores were drilled in July 1992 at Pormpuraaw, as an adjunct to the CYPLUS drilling program, and equipped with automatic water level recorders. Data from these recorders and information collected by Council Officers will be used to redefine and institute a water management plan for the town.

The aquifer within the Wyaaba Beds consists of a calcareous, muddy sandstone of marine origin. It has no known onshore outcrop. It is probable that the Wyaaba Beds are recharged by deep drainage from the overlying younger sediments. It has been intercepted in bores located from Christmas Creek, near the Holroyd River mouth, south to the area around Rutland Plains Station and east to a point about 50 kilometres from Pormpuraaw.

The thickness of the Wyaaba Beds is often over 140 metres across its onshore extent. The basal marine unit averages at around 20 metres thick was but can vary from 10 metres to over 30 metres.

Within its limits of occurrence the Wyaaba aquifer is a reliable producer of fair quality water at rates of 0.5 L/s to 6.0 L/s from either flowing or pumped bores.

There should be no constraint on usage of water for stockwatering provided artesian bores are properly controlled. The careful management of town water supply facilities at Pormpuraaw is essential if the risk of salt water intrusion is to be negated. Any proposed increase in water abstraction from this area will require the investigation and construction of a well field over a wide area to prevent a depression forming in the water table that would encourage an easterly movement of seawater through the aquifer.

Parameters for the Wyaaba aquifer have only been measured in the Pormpuraaw town area. It is considered that these parameters will apply to the aquifer in its entirety due to the relative uniformity of lithology across its extent.

Transmissivity	Storage		Confined (Artesian)
Range	Coefficient		Water Level Range
m³/day/m	Range		metres a.g.l.
300-700	lx10 ⁻³ -1x10 ⁻⁴	0.0-6.0	0.0-2.0

Table 3.7 Karumba Basin - Wyaaba Beds - Aquifer Data

3.5 Surficial Deposits

3.5.1 Alluvial Aquifers

Water supplies from Quaterary alluvium are probably limited and of variable quality. In the more highly transmissive aquifers the sands and gravels predominate with lenses of silt and clay.

In other aquifers the clays and silts predominate with lenses of sand and gravel (Rushton, 1986). Hydraulic conductivities of sands and gravels lie between 1 and 100 m/d and for sandy clays and silts between 0.001 and 0.1 m/d (Todd, 1980). Little specific data on water quality and yields is available. McEniery, (1980) considered that there may be prospects for groundwater in the more extensive flood plain deposits in the eastern rivers such as the Stewart River.

Most of the larger rivers in the study area have sandy beds which can provide small supplies though in a few localities there is some prospects of obtaining high yielding bores (McEniery, 1980). Supplies have been obtained from sandy river channels in the Weipa 1:250000 sheet, Jardine River 1:250000 sheet Aurukun area and from the thick alluvium in the east of the Cape Weymouth 1:250000 sheet.

The alluvial deposits of the Endeavour River Basin near the coast are up to 20 metres thick and could contain high yielding aquifers. The alluvium at Hopevale south west of Cooktown is approximately 9 metres thick and saturated for 1.5 to 2 metres. The composition is of clay and sporadic lenses of clayey gravel (McEniery, 1980).

Good water supplies were found in shallow alluvial sand and gravel deposits that probably represent old channels of the Mitchell River in BMR Walsh Numbers 1 and 2. (Grimes and Whittaker, 1977). Similar lenses are likely to occur over the length of the Mitchell River and others.

Groundwater occurs in some areas of residual sand in the Coen 1:250,000 sheet and Ebagoola 1:250,000 sheet area, that is evident in Ebagoola Nos 8 and 9. Groundwater also occurs from shallow depths (less than 60 metres) from porous surficial deposits in the Cape Melville 1:250,000 sheet area.

Freshwater was also obtained in the Coen 1:250,000 sheet area from TQS (Tertiary/Quaternary Sands) in BMR Coen No.3 from colluvial sand that was originally considered to be a fossil dune set (Whittaker and Gibson, 1977a). In the eastern uplands groundwater is only of minor abundance. On the broad plains alluvial water quality is generally poor.

With the low gradient of many of the eastern rivers close to the coastline the possibility of saltwater intrusion is high.

3.5.2 Coastal Sand Dune Aquifers

Beach ridge and coastal dunes are extensive around most of the coastline of the study area. These contain groundwater resources of variable quality, but can be suitable for stockwatering and domestic use, though little detailed work on these resources has been done. McEniery, (1980) considered that large groundwater resources may be present in these terrains, particularly in the large eastern peninsula dunefields. These aquifers with the possible exception of the Cape Flattery and other large dunefields, are of a site specific nature requiring detailed investigations to evaluate their resource potential.

These groundwater resources often occur in isolated locations and would require significant infrastructure to be of use at the present demand locations. In the current tourism trend,

these aquifers may become significant for recreational developments. This is significant for the beach ridge aquifers, which already express significant potential for seasonal variation because of their vertically recharging nature and generally smaller aquifer dimensions. This feature, combined with the high drainage potential of these aquifers results in small, unreliable and often "empty" aquifers.

The barrier island type ridges occur as thick sand bodies and tend to be much larger than chenier style ridges, commonly tens of kms in length with a depth up to three times as great (Leblanc, 1972 in Smart, 1976).

The essential difference for their potential aquifer characteristics is the barrier island type rest directly on basement with their seaward margins abutting/lying on marine sand and muds, whereas the chenier style lies almost exclusively on marine sands and muds (Whitehouse, 1963, Smart, 1976). The Chenier aquifers are most likely to be small and hydraulically isolated whereas the barrier type are most likely in hydraulic connection with basement aquifers, and depending on their location more susceptible to saltwater intrusion.

The small size of some of these ridges is indicated by an auger hole drilled near the coast at Edward River that found 1.3 m of sandy shell grit, 1 m of medium sand, 1 m of coarse sand and 0.3 m of medium sand overlying at least 4 m of blue marine mud. One kilometre further inland a hole drilled in a medium sand ridge encountered 2 m of medium sand, 1.5 m of sandy shell grit overlying blue marine muds (Whitehouse, 1963).

Saltwater periodically inundates the topographically lower swales of the Holocene beach ridge terrain and the lower border rivers and creeks, with saltpans containing up to 2 mm of fibrous salt crystals (Doutch et al, 1973).

The extensive Olive River Dunefield has a greater potential as a groundwater resource. It is composed of large NW trending longitudinal sand dunes with an average height of 30 m though some dunes are up to 90 m high. Some of the dunes are actively advancing while others have been stabilised by thick low brush. Many of the dunes in the study area carry heath, scrub or vine forrest and have been consequently stabilised, enhancing their probability of containing a groundwater resource. The Cape Flattery Dunefield is composed of approximately 15% active dunes and 10% swamps and lakes (Coventry et al, 1980). The dunefields are composed largely of white, sharp featured, transgressive, elongate parabolic dunes, with heights up to 100 m and lengths up to 7 kms, but usually only 0.5 km wide, as well as rounded degraded dunes stabilised by vegetation (Coventry et al, 1980, Cooper, 1993). The deposits are extensive with the Cape Flattery Dunefield covering 700 km² and Cape Grenville Dunefield covering 400 km².

Groundwater supplies from the beach ridge and dunes have had little quantitative documentation. General interpretations consider that they are important sources of water for domestic use. Hillier, (1977) noted that dune and beach deposits have been previously used by the Edward River community. Their use was abandoned because of problems of fine sands, seasonal variations and discovery of deeper aquifers.

Minor supplies of good quality groundwater have been indicated in the Aurukun 1:250 000 Sheet area, Jardine River 1:250 000 Sheet area, and the Rutland Plains 1:250 000 Sheet area.

These aquifers are of further significance as they can contribute good quality water to freshwater springs and lagoons in areas that usually have brackish supplies. The aquifers in beach ridges are considered to be uniform and extensive though thin but with less brackish water than the underlying Cainozoic deposits (Quaternary sediments).

The major sand dune aquifers are considered to contain large quantities of potable water. No specific testing of the aquifer potentials have been undertaken but the broad characteristics are probably similar to those of the southern Queensland dunes.

Specific yield has been estimated to be around 20%. However the yield may be restricted in smaller dunes by the consideration that the total of rainfall minus evaporation may be equal to the natural aquifer losses and little abstractable water may be retained. The large dunes, though, probably contain large reserves of potable water, similar to such deposits in southern Oueensland.

Extensive surface and underground freshwater supplies (undefined quantities), were located in the sand dune swamps of the lower Jardine River. Additionally, in this sand dune country, several lakes up to 1 km in diameter were located south-west of Somerset behind Newcastle Bay.

3.6 Torres Strait Islands

Drilling undertaken on Thursday Island has shown that no useable groundwater is available to the local community. Drilling in 1988 by Gold Copper Exploration established some relatively low-yielding (~ 2 L/s) water bores in the Endeavour Straits Ignimbrite on Horn Island. One bore, on Vidgen Creek, yielded a supply of 5 L/s but was subsequently abandoned because of saltwater intrusion. These bores were used mainly for domestic purposes.

The Irrigation and Water Supply Commission (now DPI) conducted a field analysis of the available water resources of the Torres Strait Islands and adjacent mainland Peninsula (Ogilvie and Weller, 1949). The work was undertaken in the area from latitudes 9 to 11°S and Longitudes 142° to 144°E. A reconnaissance of the local geology and hydrology was made with an assessment of existing supply sources and current and perceived future usages.

The water supply for the islands was principally sourced from sand dune aquifers located adjacent to and behind the coastal beaches.

In general, supplies are sourced from dune sands, coral sand and beach rock on the coral cay islands (McEniery, 1980). These include Coconut, Sue, Yorke, Boigu, and Saibai. Surficial alluvial deposits yield minor groundwater supplies on Darnley, Stephens, Maer, Yam and Dauan Islands. In some cases, they are connected with the underlying igneous rocks, which can be vesicular or fractured.

Saltwater intrusion of these aquifers was not identified as a problem by Ogilvie and Weller, (1949), principally because of the low (hand bailing) abstraction rates. Water quality was considered good but slightly acidic. However McEniery, (1980) considered the supplies for those islands would be subject to saltwater intrusion. The thick alluvial and deltaic deposits of Baigu and Saibu islands have been completely intruded by saline groundwater.

Sand Cays (coral sand islands), depending on their size and geological base (coral, coralline mud or rock), often yield useable community supplies. Coral mud based cays and rock based cays (depending on the nature of the rock base) usually provide excellent quality groundwater. Coral reef based cays of a diameter of at least 1 km can be assumed to provide permanent freshwater. McEniery, (1980) considered smaller coral based cays may contain freshwater but this would need to be specifically assessed. Occurrences of "beach rock" (calcium carbonate cemented sand grains that form under tidal water level fluctuations) can indicate sources of freshwater on these islands.

All islands in the area were characterised by low supplies around 0.5 L/s, with Maer, Yorke and Dauan having the only assured water supply. All other islands had severe water restrictions. Because of the very pronounced wet season, supplies need to last six to eight months.

Further work on improving the water supplies of the Torres Strait Islands is being undertaken.

4 HYDROCHEMISTRY

4.1 Introduction

Groundwater chemistry in the study area is comparatively poorly understood. In this study all of the available groundwater chemistry data has been analysed. This information has been presented as an overview of the groundwater quality of Cape York Peninsula from which more detailed site specific studies can be drawn.

Previously, resources have not permitted a large scale systematic regional groundwater analysis and sampling program, with only sparse and variable sampling having occurred. This led to the situation where there was insufficient reliable data over a sufficient period for some statistical, particularly time series, analysis.

The bore census program undertaken as part of this project is the first systematic collection and analysis of data on the region's groundwater quality. The census provided 253 water quality samples. These samples represent the majority of the 465 samples used for detailed analysis. The bore census program is the only survey that has provided regional background information using most of the bores in the Peninsula that are currently in use.

In providing this information in one field season, more realistic comparisons between locations can now be made. Analyses which were previously available have been taken in differing areas over differing times during the past 30 years.

This work is timely as expanding agricultural, mining, tourism and other ventures will require detailed environmental and water resource availability studies. These studies will be able to draw on the results of this work.

4.1.2 Data Constraints

The regional nature of this project has necessitated the combination of certain aquifers and the omission of some other less important aquifers for the analysis. This is principally because of a lack of sufficiently precise data with which to pinpoint the exact formation from which groundwater is being sourced. This has resulted in general conclusions on aquifer characteristics being presented.

This lack of precise data is particularly relevant to the Karumba/Carpentaria Basin and the Laura Basin where deep bores often penetrate several potential aquifers and there is often no definitive guide to the actual water source. Interpretations based on available information were made on groundwater sources. In some cases groundwater samples may have been sourced from more than one aquifer.

This discussion only includes data collected by DPI. Groundwater data collected by AGSO were not supplied in time for inclusion in this report.

Generally the information used for determining the aquifer source of groundwater is taken from indications in the sampler's report, depth of casing slots and deepest likely aquifer. Where this information appears to give misleading interpretations, either an interpretation based on other sources of information was used, or the sample was not included in the analysis.

Table 4.1 indicates those aquifers that have sufficient data available to be reported on and those aquifers that have necessarily been combined into composite aquifers.

Tectonic Unit	Formations Used	Aquifer Code	
Carpentaria Basin	Garraway Beds Gilbert River Formation	ga gr	
Coen Inlier	Acid Intrusives Metamorphics	i m	
Hodgkinson Province	Acid Intrusives Basalts Metamorphics	a b m	
Karumba Basin	Bulimba Formation/Wyaaba Beds	b/w	
Laura Basin	Basalts Gilbert River Formation/Dalrymple Sandstone	b gr/d	
Yambo Inlier	All Units	у	

Table 4.1 CYPLUS Area Aquifers

In the Karumba Basin there is considerable ambiguity in distinguishing between the aquifers of the Bulimba Formation and Wyaaba Beds using the available data even considering that the Wyaaba Bed's aquifers are generally more saline. For this reason these two formations have been treated as one aquifer in this report.

Mixing of water types is highly probable in the Bathurst Range area of the Laura Basin. Additionally, the aquifers of the Gilbert River Formation and the Dalrymple Sandstone in the Laura Basin were treated as one aquifer because of the general similarity of the groundwater from these two formations and the ambiguity of information on the source formation. In the Carpentaria Basin where the Gilbert River Formation and Garraway Beds are probably in hydraulic continuity a similar approach was taken and these aquifers were combined.

In the Coen Inlier and Hodgkinson Province, insufficient data necessitated combining groundwater information into broad rock types. Similarly, as only a very small number of samples were available for the Yambo Inlier, these samples were combined into one category. No groundwater information was available in the DPI groundwater database on the mainland Cape York Pyroclastics. Additionally, because of ambiguity in defining Rolling Downs sourced water only a brief summary of groundwater ionic concentrations for this formation has been included.

4.1.3 Interpretation Methodology

In the extended CYPLUS study area used in this project, data was obtained from 1025 boreholes. These include production and monitoring bores, decommissioned bores and specific exploration company drillholes that provide detailed information on either the groundwater or geology of the study area. This includes 281 bores that have had water samples taken, with approximately half of these sampled through the CYPLUS program. In total 693 water samples were taken from these bores.

Hydrochemistry statistical analyses were performed in SYSTAT computer software program on the following water quality parameters: alkalinity, conductivity, hardness, Sodium Adsorption Ratio (SAR), Total Dissolved Ions (TDI) and the major ions, sodium, potassium, calcium, magnesium, chloride, bicarbonate, and sulphate.

Parameters such as pH (except field pH readings)and trace metals e.g. iron and manganese have not been statistically analysed because of their susceptibility to changed values during the long lag time between collection and analysis. However some general comments on these parameters have been provided. Nitrate data was not analysed because of the low number of reliable analyses available.

Several checks on chemical validity were applied to the data to delete inappropriate samples and ensure data reliability. Firstly the total dissolved ions were compared with the sum of the major ions (Na⁺, Ca⁺⁺, Mg⁺⁺, SO4⁻, CO3⁻, HCO₃⁻, NO3⁻, PO4⁻). If the ratio of these two figures lay outside the range of 0.98 - 1.01 the sample was rejected. In this test 20 samples were rejected of which 18 had a lower concentration of the summed major ions than the total dissolved ions. This is probably due to another or several ions other than the major ions listed being significantly high and the sample probably being unrepresentative. Secondly the electrochemical "balance" of the ions (i.e. the ratio of the equivalent weights of cations/anions) was also tested after conversion of concentrations to milli-equivalents/litre. All samples outside of the ± 4.5% balance range were rejected.

Samples that had passed the mass balance test but failed the cation/anion ratio test though satisfied the conditions of: conductivity less than 200 µscm⁻¹, a ratio of conductivity/ total dissolved ions of less than 20 and were within a standard grouping on a cluster analysis were used. These samples were included as the previous tests have a tendency to discard valid information that has a low conductivity. In all 507 samples satisfied the mass balance and ionic ratio criteria and were considered suitable for use in the chemical analysis of the study area's groundwater. Table 4.2 indicates the division of these samples by aquifer type.

Summary	Number	%	
Carpentaria Basin	Garraway Beds	10	2.0
	Gilbert River Formation	26	5.1
	Helby Beds	7	1.4
Karumba Basin	Bulimba Formation/Wyaaba Beds	216	42.6
Laura Basin	Gilbert River Formation/Dalrymple Sandstone	81	16.0
Study Area	Acid Intrusives	24	4.7
	Basalts	21	4.1
	Metamorphics	69	13.6
Other		53	10.5
	507	100	

Table 4.2 Sample Availability by Aquifer

Additional conductivity values were added to the valid tested samples that were used in the analysis. These included those that had conductivity and pH information only (these are standard field tests that are taken more regularly and do not require laboratory analysis). Using these criteria 693 samples were considered to have valid conductivity information.

A multivariate analysis of the relationship of water types was undertaken using cluster analysis of the independent major components. Cluster analysis techniques were used to arrange the water samples into a number of discrete water types and to determine chemical relations between the samples.

A simplified dendrogram using the results of this cluster analysis shows the relationship or closeness of the water types and appears in Figure 4.1. In this analysis the two closest water types or clusters were determined and the mean of these two clusters was then used in determining the next two closest clusters in an ongoing process ending when all the clusters had been included. Relative distances between groups were calculated using a simple Euclidean technique.

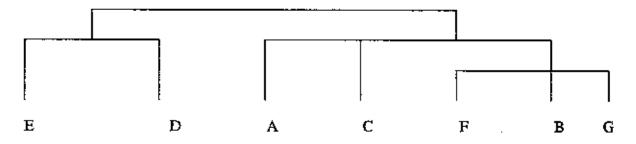


Figure 4.1 Simplified Dendrogram of Water Types

Box and Whisker plots for all water types have been used to show the complete range of data for the major cations and anions in each basin or formation. These plots indicate the variation of the major ions between water types (e.g. Figure 4.5 Water Quality Variation Among Water Types) and the relationship of major ions between each other for all water types (e.g. Figure 4.6 Major Ions Water Type A). The centre line of the box indicates the median value of the sample and the ends of the box represent the 25th and 75th percentile figures. More distant values within the whisker section of the diagram and outlying values are represented as symbols. All relevant samples for Box and Whisker plots have been used to show the complete range of data in the basin or formation.

Trilinear diagrams have been constructed from water sample data for each of the major aquifers in the study area. This technique displays the composition of the water with respects to the component cations and anions as points on two separate equilateral triangles. Each point on the cation triangle indicates the percentage of Mg²⁺, Ca²⁺, and K⁺ and Na⁺ ions. Likewise each point on the anion triangle indicates the percentage of Cl⁻, SO₄²⁻, and CO₃²⁻ and HCO₃⁻ ions. The data points from these two triangles can be projected into an adjacent diamond field. This projected point (on the diamond field) represents the composition of the water with respect to the combination of all of the major ions. Trilinear diagrams can demonstrate certain relationships among individual samples, often allowing determination of hydrochemical facies.

Maps are presented showing hydrochemical data. It should be noted that these maps show data for the latest appropriate (i.e. chemically balanced) samples at each location irrespective of the aquifer unit from which the groundwater is sourced. Similarly because of poor sample density, information has been presented as point data and could not be contoured effectively. The data presented is aimed at giving a regional overview. More detailed advice is available from the Department of Primary Industries (Water Resources) Mareeba Office.

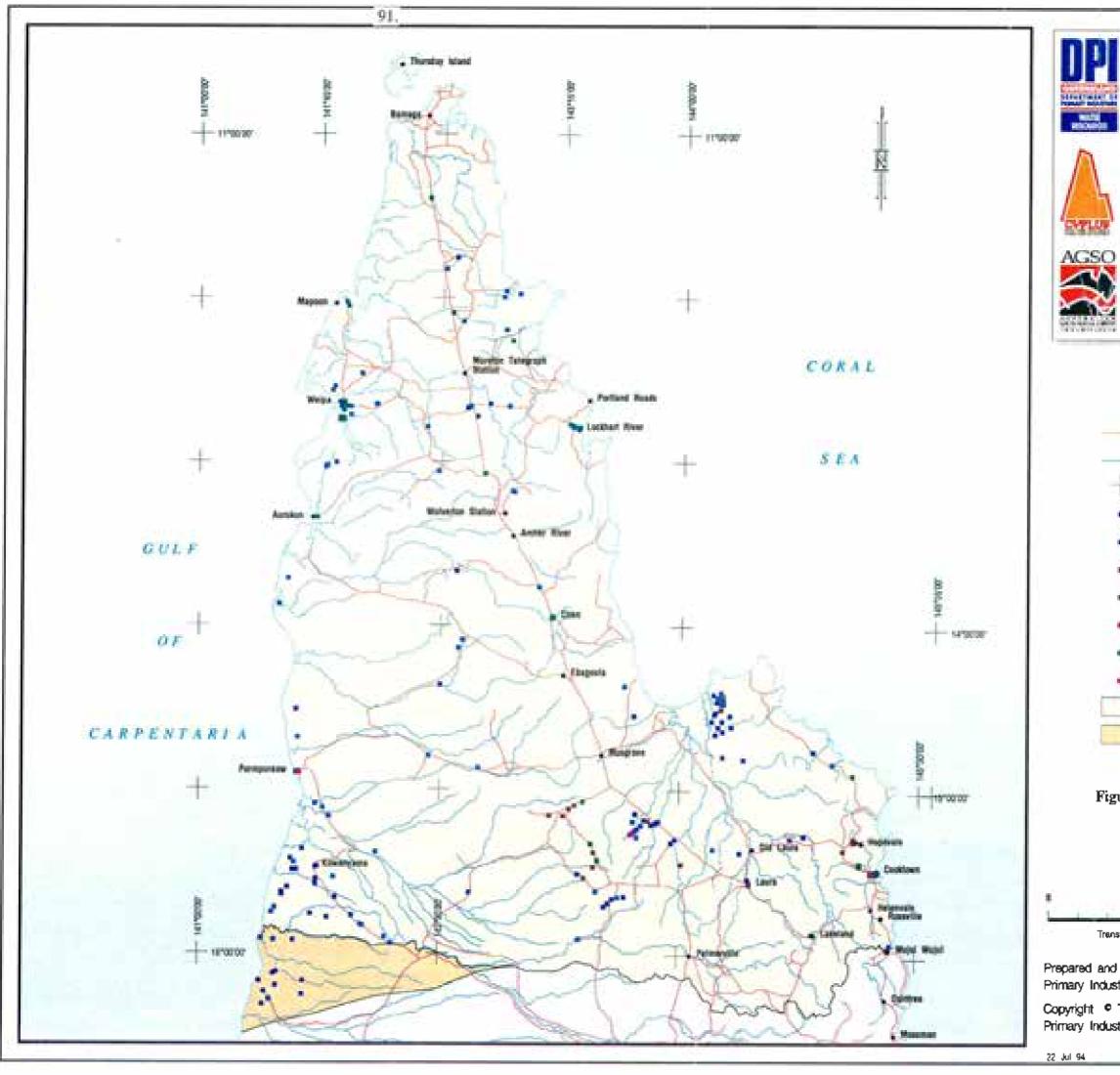
4.2 General Groundwater Chemistry

All of the available groundwater chemistry data has been analysed and this information has been presented as an overview of the groundwater quality of Cape York Peninsula. Generally the groundwater of the study area is of good quality and suitable for most purposes though some specific water quality problems occur.

More specific water analyses are detailed by tectonic basin with Table 4.4 outlining those formations that have sufficient water quality data for inclusion. In the study area most water types are sodium bicarbonate and sodium chloride type or minor variations of these. This general category accounts for 90% of all samples used in this analysis. One of the most significant constraints on groundwater usage is high fluoride values in some locations which can affect use for human consumption particularly in waters sourced from the Carpentaria Basin and for some waters sourced from the Karumba Basin such as those at Pormpuraaw. Saltwater intrusion into aquifers in some of the southern coastal areas is a significant problem. Saltwater intrusion in the Hodgkinson Province around Cooktown is presently a problem. This threat to the Cooktown water supply is being currently monitored at a minimum of weekly intervals.

Groundwater chemistry in the study area is variable with seven water types (supergroups) having been determined by a cluster method using major ionic concentrations although three of these types contain less than five samples each.

Data on general groundwater chemistry is presented as a series of figures and tables: Figure 4.2 indicates the locations at which each of these water types occurs and Table 4.3 provides a summary of water types by geographical location. Table 4.4 provides a summary of the tectonic basins and aquifers in which these water types occur as well as chemical characteristics. It also provides some of the potential limitations on usage. A summary of average analyses figures for each major water type appears in Table 4.5. A scatter plot of the water types in relation to conductivity and depth for each tectonic unit is provided in Figure 4.3 and for some key aquifers figure 4.4. A box and whisker plot showing ionic variation between water types is provided in Figure 4.5. Additionally the concentration of major ions for each water type is displayed as a box and whisker plot in Figures 4.6 to 4.12. Appendix 2 contains a table indicating Borehole Number (RN), Latitude, Longitude, Tectonic Basin, Aquifer and Water Type for the samples used.





GROUNDWATER TYPES

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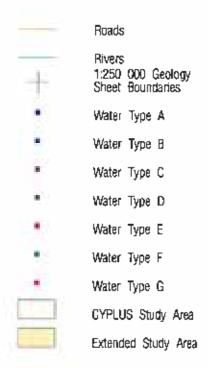
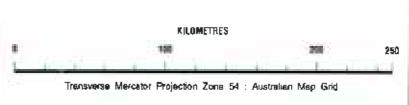


Figure 4.2 - Groundwater Types



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FIGURE 4.2 A3-105521

	No. al. of Physical as IValue of Physics
Carpentaria/Karumba Basin	North of Ebagoela to Holroyd Track
Dasin	A mixture of Groundwater Types A and B predominate. Isolated samples of Groundwater Type F occur at; Weipa (where Groundwater Types F and B predominate), Mapoon, adjacent to the Peninsula Development Road north of Bramwell and near the southern junction to the Northern Bypass Road and adjacent to the Olive River. South of Ebagoola to Holroyd Track Groundwater is almost exclusively of Type B. An exception occurs in a sub-area to the west and south of Kowanyama where Groundwater Type A dominates.
	However, within this sub-area, a pocket of Groundwater Type B occurs adjacent to the coast at 16°S. Groundwater Type E exists exclusively at Pormpuraaw where it is associated with Groundwater Type B.
Laura Basin	Groundwater Types A and B predominate. Isolated samples of Groundwater Type D occur near Laura, Hann River, north of Fairlight and in the Bathurst Head area.
Coen Inlier	South of Musgrave, Groundwater Type F predominates with isolated Groundwater Type D occurrences. The Coen Township and Lockhart River areas have isolated occurrences of Groundwater Types F and B.
Yambo Inlier	In the northern Inlier, Groundwater Type A is dominant, with an isolated sample of Groundwater Type B occurring. No information is available for the southern Inlier.
Hodgkinson Province	The Cooktown area contains Groundwater Types F and B and the only occurrence of Groundwater Type G in the study area. At Wujul Wujul, Groundwater Type B is present and at Lakeland, Groundwater Type F. The north-eastern arm contains isolated individual samples of Groundwater Types A, B and F.

Table 4.3 Summary of Water Types by Geographical Location

Water	Domins	int Ions				Potential Usage Limitations
Туре	Cations	Amons	Tectonic Basin	Occurrence by Aquifer 9 Samples	e of	(specific bores may be unsuitable for other uses)
A .	Na	нсо, сı	Carpentaria Karumba Laura Yambo (4 samples)	Besalts Gilbert River Formation Gilbert River Formation/ Delrymple Sandstone Bulimba Formation/ Wyasha Beds Other	2% 3.5% 26.2% 56.9% 11.4%	Specific samples contain high F and Mn values
Б	Na Mg, Ca	CI HCO ₃	All Tectonic Basins (N.B. Yambo - 1 sample)	Basalts Garraway Beds Gilbert River Gilbert River Formation/ Dairymple Sandstone Helby Beds Acid Intrusives Bulimba Formation/ Wysaba Beds Metamorphics Other	2% 5.3% 9.4% 6.5% 2.4% 4.1% 48.8% 8.8% 13.5%	Average SAR higher than is solerable by most tree crops, e.g. deciduous fruits Specific samples contain high F and Mn values
С	Na	ZO*	Laura	Gilbert River Formation/ Dalrymple Sandstone	100 %	Specific samples contain high Mn values
D	Na Mg, Ça	нсо,	Coen, Laura	Basalts Gilbert River Formation/ Dalrymple Sandstone Acid Intrusives Metamorphics Other	29.3 % 36.6 % 7.3 % 12.2 % 25 %	Specific samples contain high F and Mn values
E	Ca	нсо,	Karumba	Bulimbs Formation/ Wysaba Beds Other	75% 3%	Specific samples contain high F
F	Na Mg, Ca	нсо, сі	Carpentaria Coen Hodgkinson Karumba	Basalts Gilbert River Acid Intrusives Bulimbs Formation/ Wyasha Beds Metamorphics Other	3.5% 3.5% 12.9% 17.6% 54.1% 8.2%	Specific samples contain high F
G	Na, Ca	Ci	Hodgkinson	Acid Intrusives/Metamorphics	100%	

Table 4.4 Summary of Occurrences and Potential Limitations of Water Types

Water Type	Cond	Hard	SAR	Allx	Na	Ca	Mg	cı	HCO3	SO4	NO ₃	F	Sample Size
A	705	162*	7.1	229	126	22*	11	103	276	7.1*	0.4*	0.8	202
В	1012*	396*	11	123*	187#	60*	63*	247*	146#	142*	1.09*	0.95	170
c	138	14	1.7	6.5	15	0.8	3.05	7,6	7.9	34.9	0.0	0.1	2
D	318	118*	1.5	139	40*	19	17*	23*	169*	3.8*	1.1*	0.3*	41
E	633	319	0.6	327	26	122	3	33	398	4.3	0.0	0.1	4
F	611	166*	2.1	143	60	30*	22*	101*	173	15*	2.4*	0.6*	85
G.	3240	675	5.6	72	365	232	23•	915	73*	158	0.1*	0.5	3

^{*} indicates data forms a skewed distribution and significant variations from mean values occur

Table 4.5 Water Types - Average Analyses

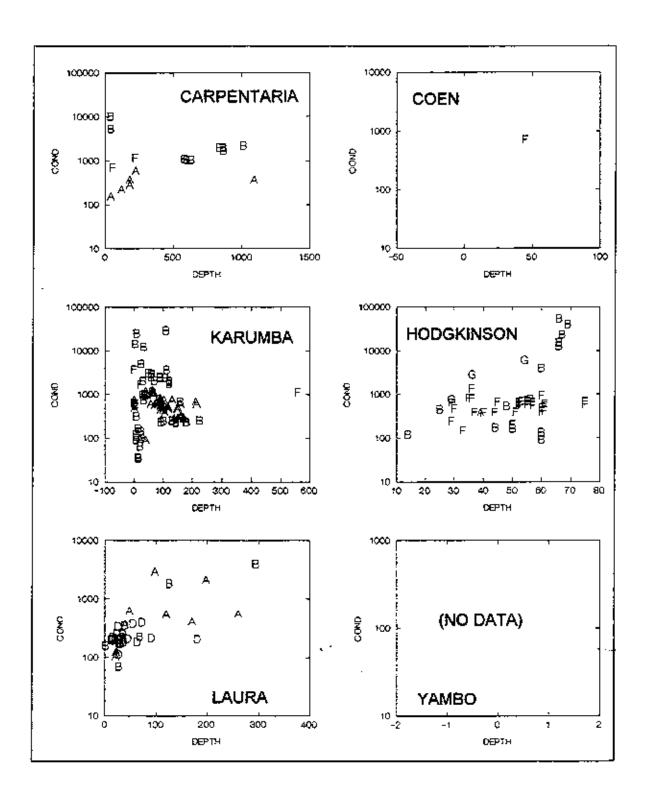


Figure 4.3 Water Type by Tectonic Unit

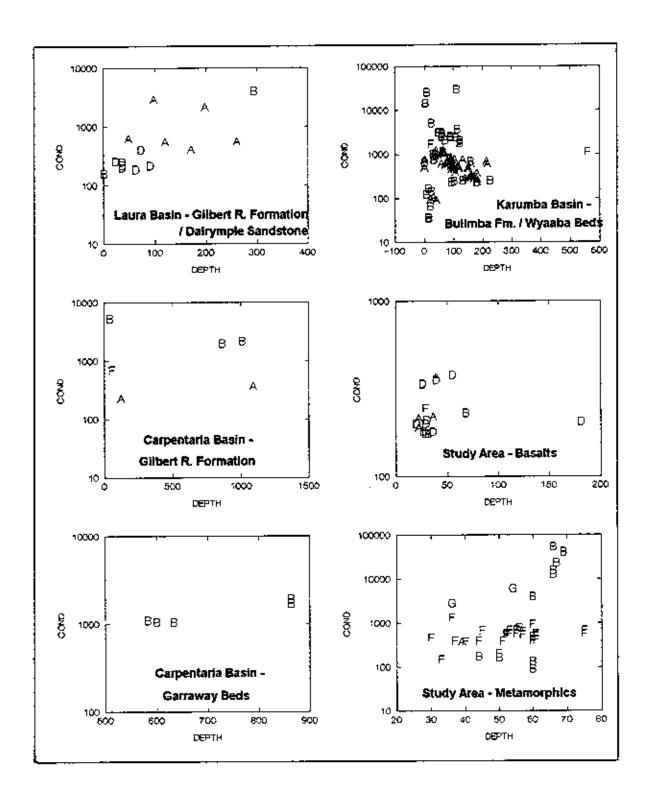


Figure 4.4 Water Type by Aquifer

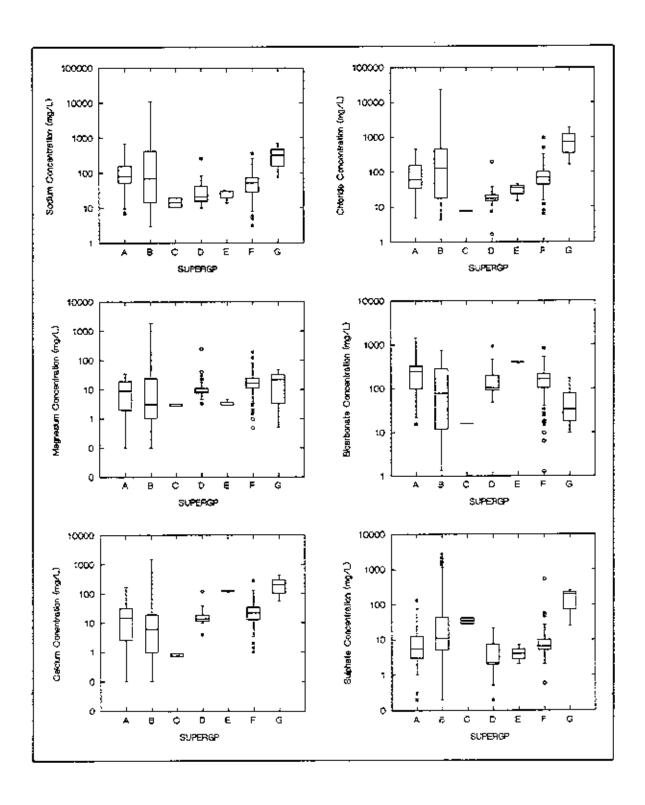


Figure 4.5 Ionic Variation Between Water Types

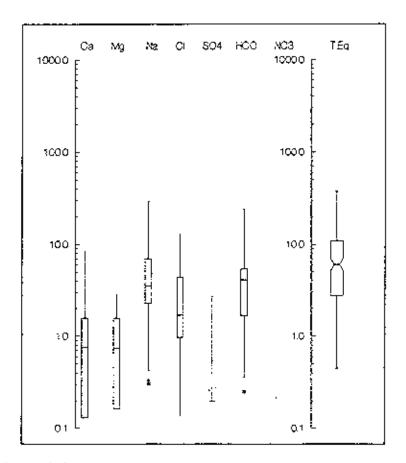


Figure 4.6 Concentrations of Major Ions - Water Type A

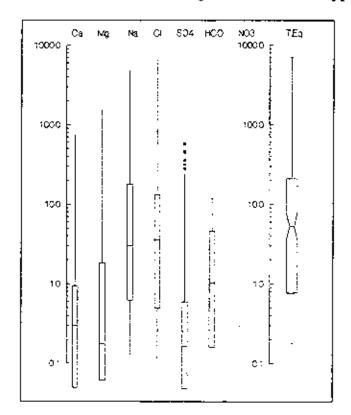


Figure 4.7 Concentrations of Major Ions - Water Type B

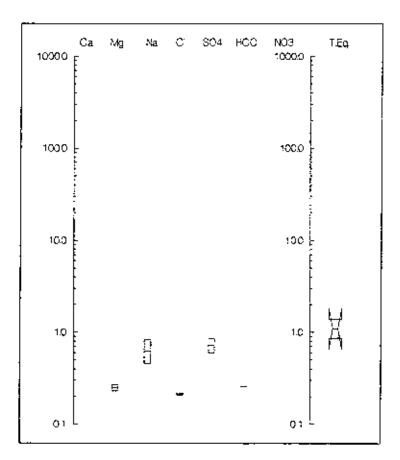


Figure 4.8 Concentrations of Major Ions - Water Type C

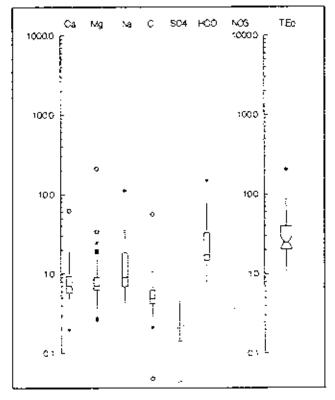


Figure 4.9 Concentrations of Major Ions - Water Type D

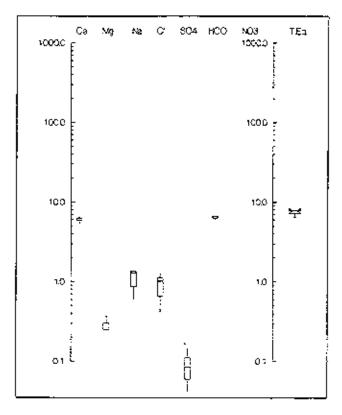


Figure 4.10 Concentrations of Major Ions - Water Type E

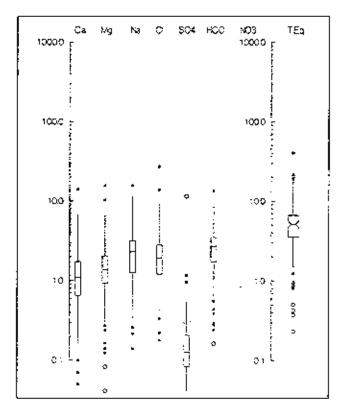


Figure 4.11 Concentrations of Major Ions - Water Type F

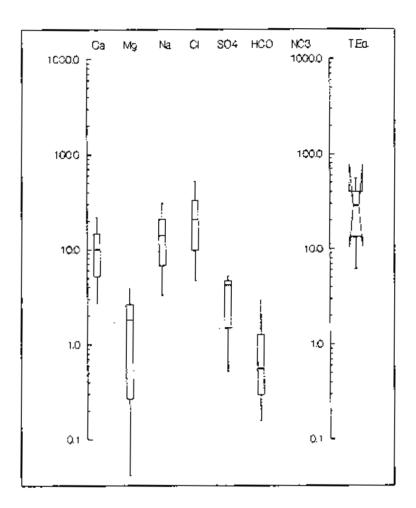


Figure 4.12 Concentrations of Major Ions - Water Type G

Groundwater conductivity levels in the study area usually indicate good quality water with most samples having a sufficiently low conductivity value to allow for most purposes. Conductivity values for water types have been outlined in Table 4.5. Groundwater conductivity ranges are presented in Figure 4.13 (on Salinity and Hardness Variation) and are discussed for the major aquifers in sections 4.3 to 4.6. Figure 4.14 displays a groundwater conductivity map. Generally groundwater is suitable for human consumption if it is less than $1600 \, \mu \text{scm}^{-1}$ (ANZECC 1992), and suitable for medium salt tolerant crops if it is less than $3000 \, \mu \text{scm}^{-1}$ (Gill 1986) (these crops include cauliflower, pumpkin, olives and rockmelons). Water with conductivity values of $3000 \, \text{to} 5000 \, \mu \text{scm}^{-1}$ are suitable for high salt tolerant crops only which include date palm, beetroot, asparagus, spinach. Most stock will tolerate conductivity values up to $8000 \, \mu \text{scm}^{-1}$.

i

The groundwater of the study area is predominantly acidic. Widespread alkaline groundwater occurs only in the Bulimba Formation/Wyaaba Beds aquifers in the Karumba Basin. Minor alkaline groundwater occurs in the Gilbert River Formation/Dalrymple Sandstone aquifer of the Laura Basin. pH values were determined using field measurements only as pH results from laboratory analyses can be greatly affected by the time lag between sample collection and the date of analysis. Table 4.6 provides pH data for those hydrogeological units from which sufficient field samples have been taken to determine reasonably indicative values. The NHMRC (National Health and Medical Research Council) (1993) guidelines for pH for drinking water is 6.5 - 8.5. Some drinking water sourced from groundwater at Weipa requires treatment for low pH.

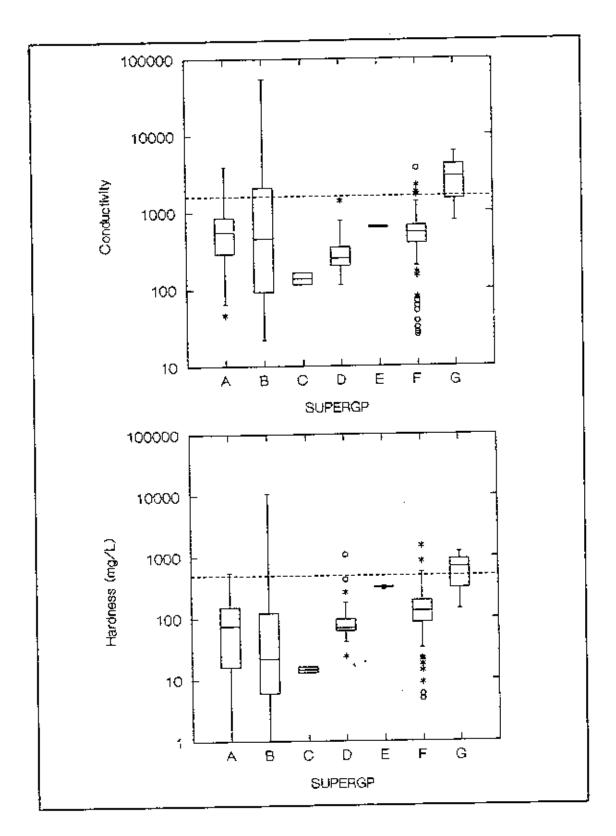
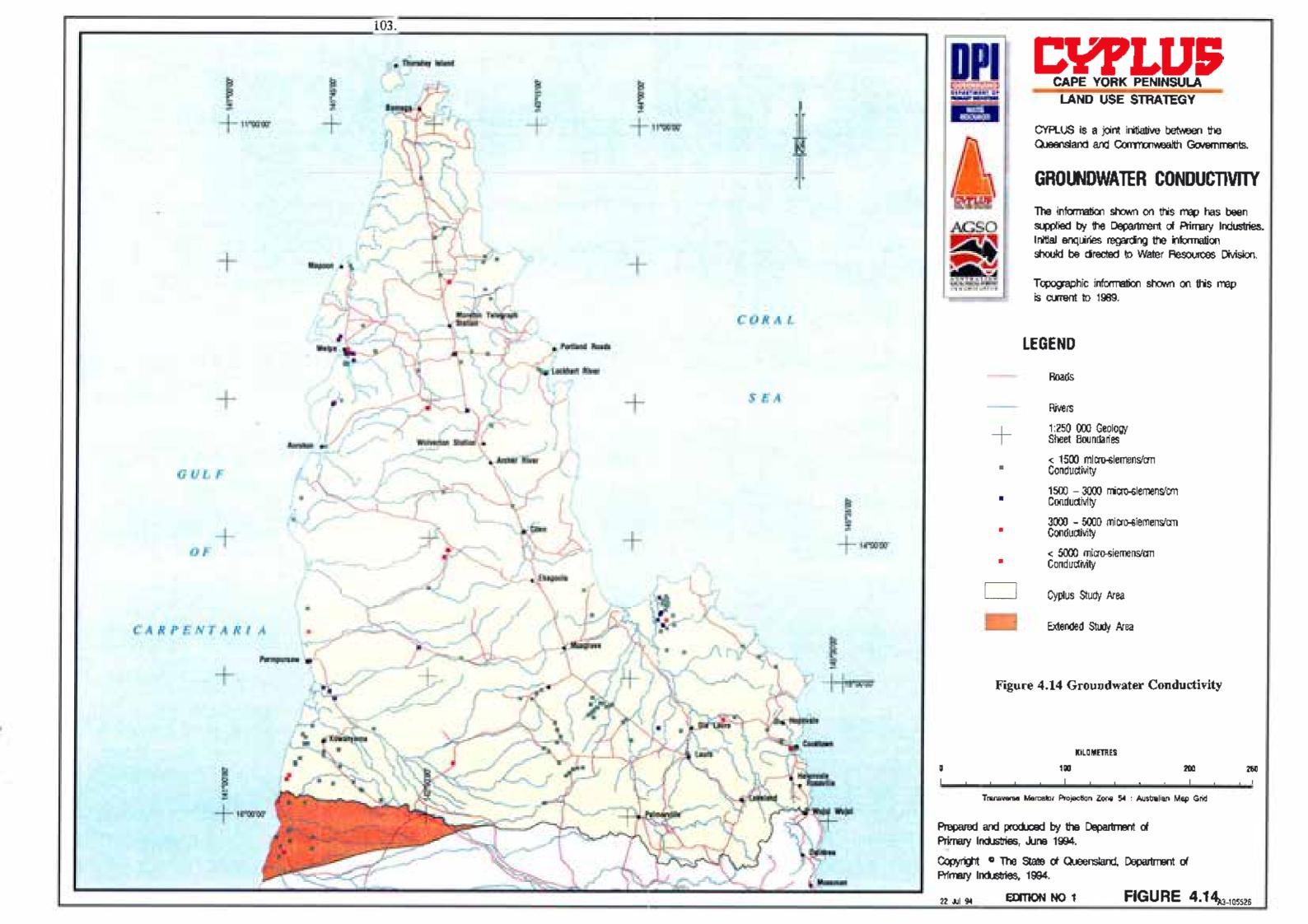


Figure 4.13 Conductivity and Hardness Variations Between Water Types



Hydrogeological Unit	рН
Carpentaria Basin - Gilbert River Formation	6.4
Coen Inlier - Acid Intrusives	6.6
Coen Inlier - Metamorphics	6.6
Karumba Basin - Bulimba Formation/Wyaaba Beds	6.7
Laura Basin - Gilbert River Formation/Dalrymple Sandstone	6.4
Yambo Inlier	6.2

Table 4.6 Average pH values

(It should be noted that there is significant variation in pH between approximately 5.0 and 8.0 in the Karumba Basin - Bulimba Formation/Wyaaba Beds.)

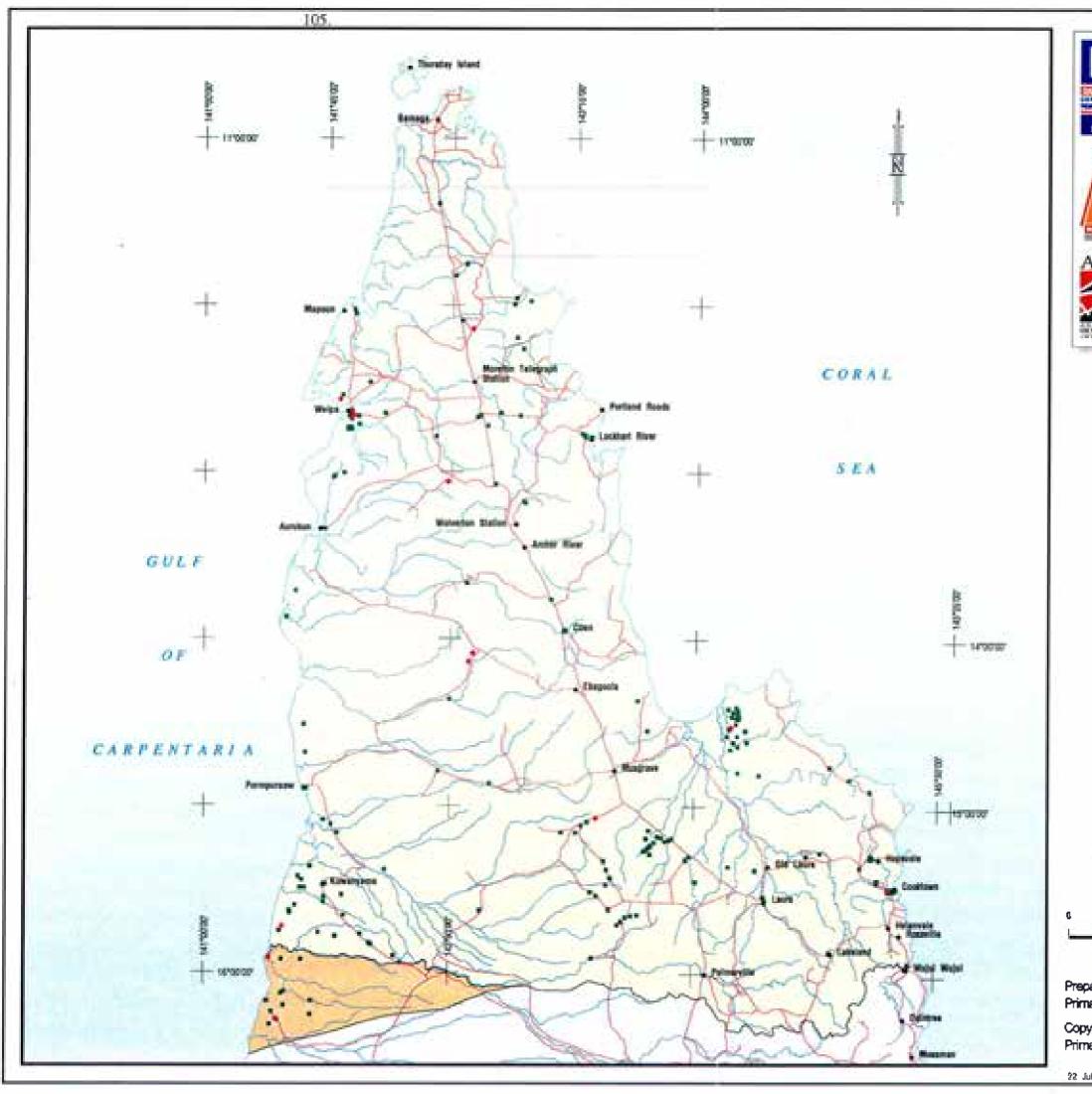
Water hardness is an expression of the concentrations of calcium and magnesium salts and is expressed as calcium carbonate. The ANZECC (1992) guidelines suggested maximum hardness for potable water is 500 mg/L. The hardness range for each water type is displayed in Figure 4.13 and the variation throughout the study area in Figure 4.15 - Groundwater Hardness Levels.

Alkalinity levels of between 30 - 500 mg/L are recommended for human consumption (Hart, 1974). Groundwater alkalinity variation in the study area is displayed in Figure 4.16.

Fluoride is a major constraint on groundwater use for human consumption in the study area. Significant groundwater sourced from the Carpentaria Basin and some of the Karumba Basin water high levels of fluoride. The NHMRC (1993) recommends a maximum level of 1.5 mg/L fluoride for human consumption under normal conditions. However in the tropical conditions experienced in the study area a more realistic safe maximum value is 1.0 mg/L due to higher water consumption rates. ANZECC (1992) recommends a maximum fluoride concentration of 2.0 mg/L for stock. Figure 4.17 shows fluoride concentrations in the study area.

The Sodium Adsorption Ratio (SAR) expresses the sodium hazard of a water in relation to its likely effect on soils and plants. The sodium adsorption ratio is calculated from

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$$







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GROUNDWATER HARDNESS LEVELS

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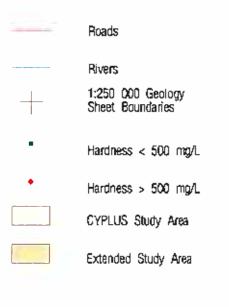
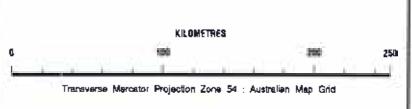


Figure 4.15 Groundwater Hardness Levels

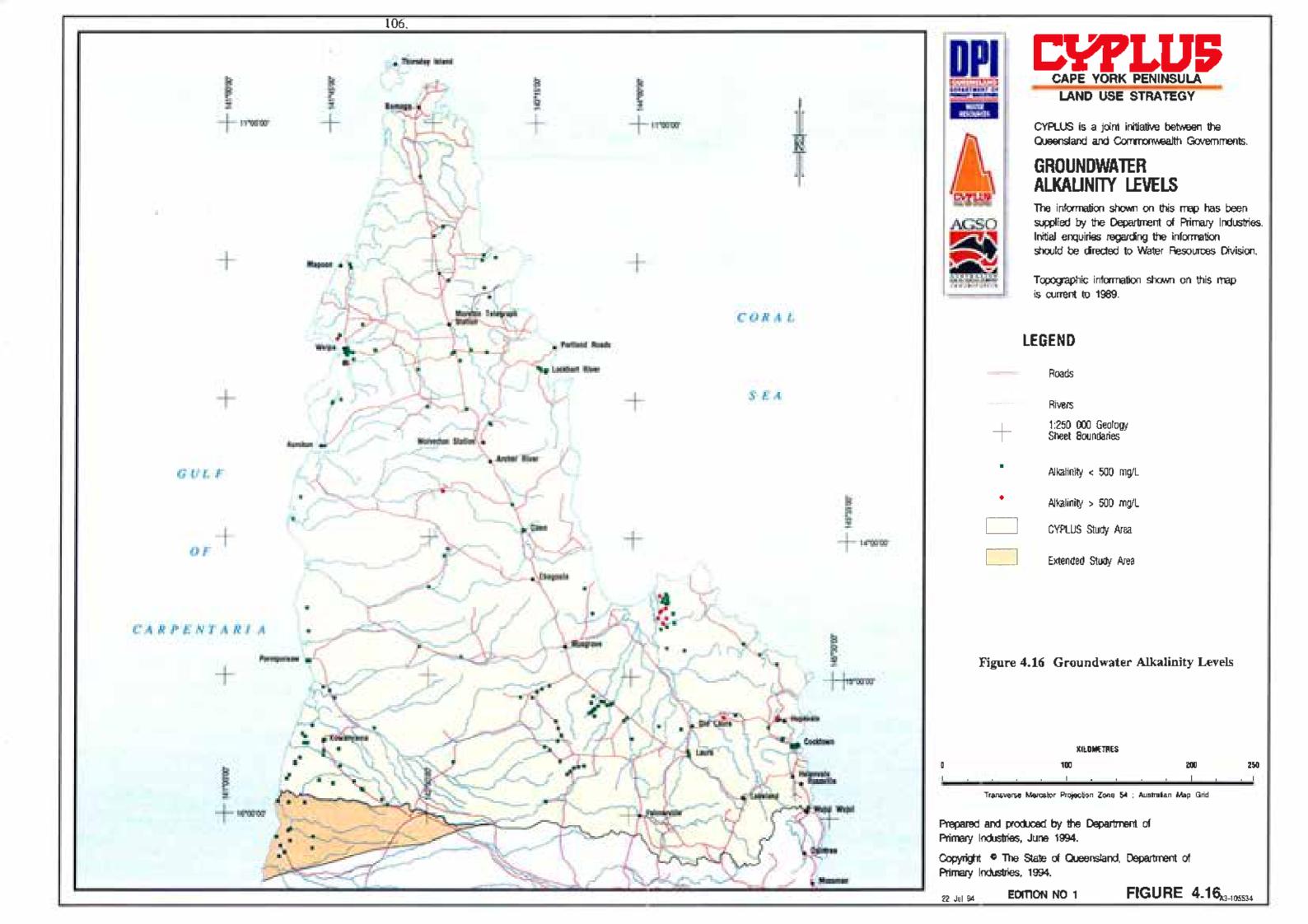


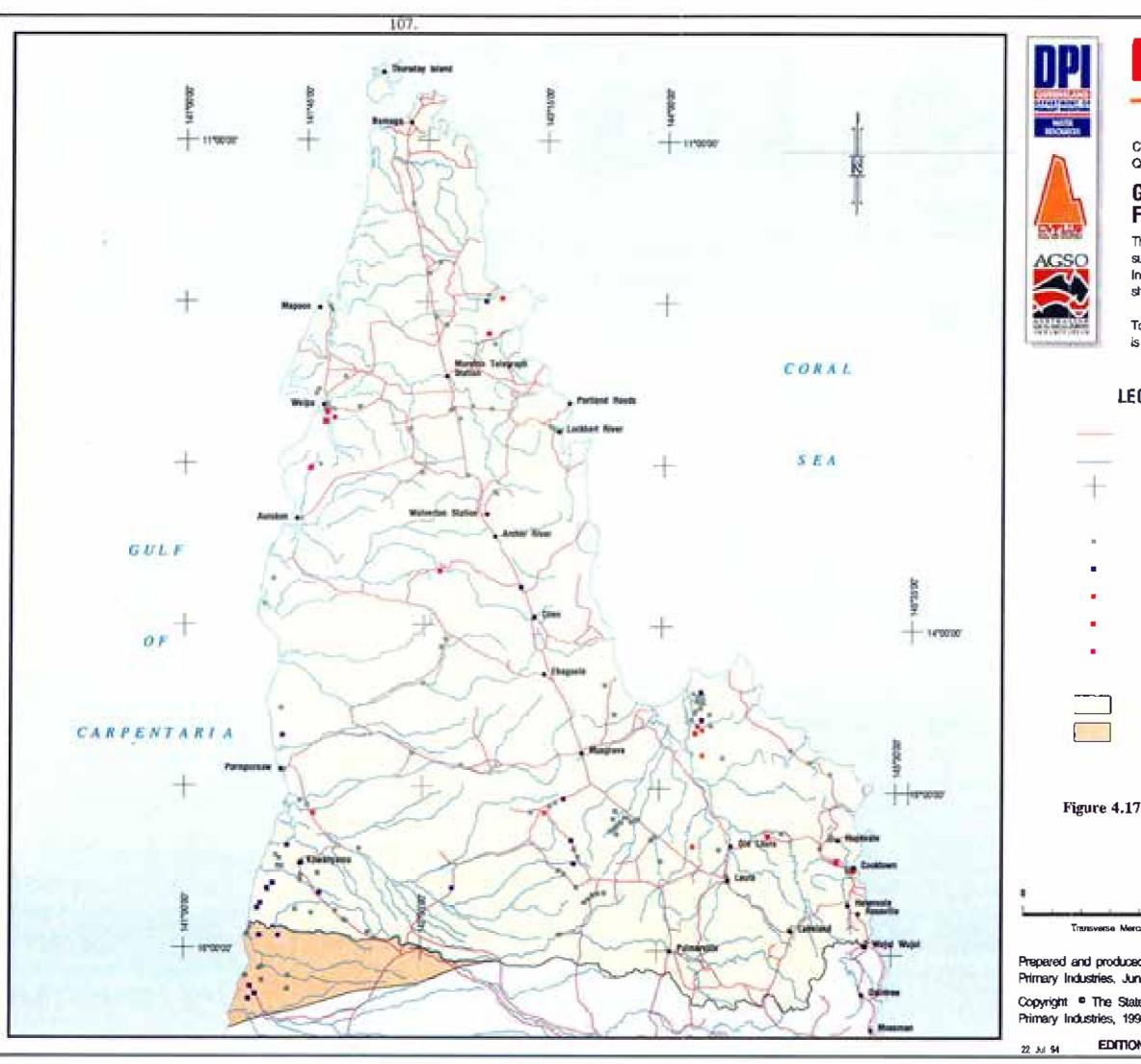
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FIGURE 4.15_{A5-105533}







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GROUNDWATER **FLUORIDE CONCENTRATIONS**

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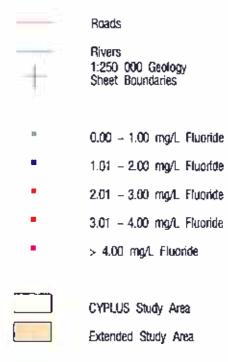
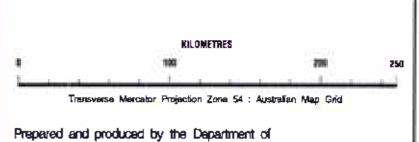


Figure 4.17 Groundwater Fluoride Levels



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FIGURE 4.17_{A3-405524}

Table 4.7 summarised from ANZECC (1992) indicates specific SAR toxic effect levels on plants.

Crop Tolerance	SAR	Suitability
very sensitive sensitive moderately tolerant tolerant	2 - 8 8 - 18 18 - 46 46 - 102	horticultural tree crops beans clover, oats, rice wheat, lettuce, barley, tomatoes, beets, cotton

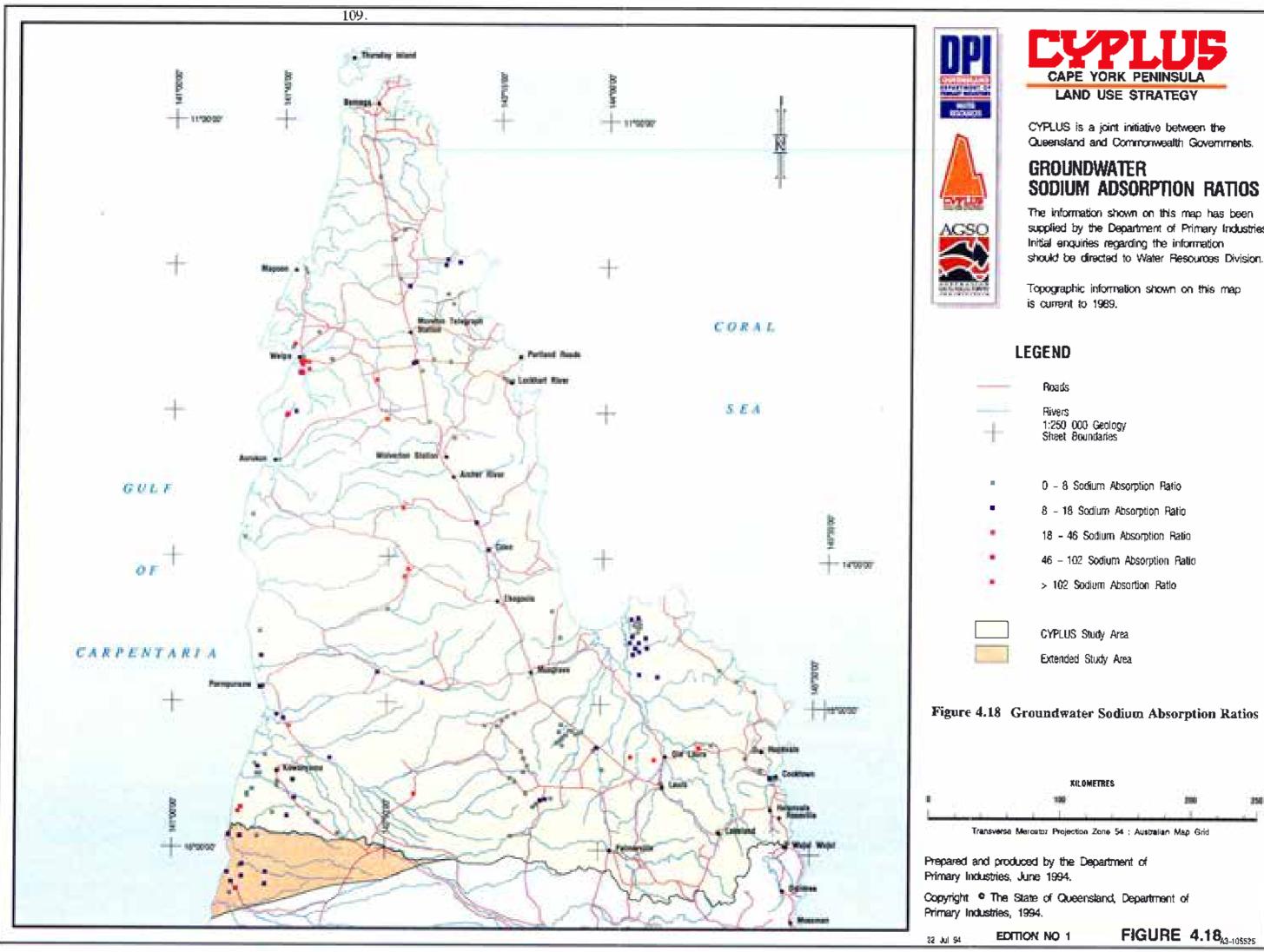
Table 4.7 Sodium Adsorption Ratio Toxicity Levels

For irrigation, SAR figures need to be considered in conjunction with physical soil constraints. It should be noted that irrigation applications of water with a SAR value of 8 or greater is likely to cause substantial soil physical degradation especially on soils with a heavy clay content. Irrigation on some deep draining sandy soil types may be able to tolerate a higher SAR value than indicated above. SAR values for the study area are indicated in Figure 4.18.

4.3 Fractured Rock Aquifers

Generally fractured rock aquifers in the study area contain good quality groundwater. However because of a lack of data the results presented are only an indication and should be considered in conjunction with the constraint of the small sample sizes.

Trilinear diagrams are presented in Figure 4.19 for the latest samples for basalt aquifers in Figure 4.20 and for acid intrusive aquifers. The basalt aquifer trilinear plot includes samples from the Hodgkinson Province, Laura Basin and Coen Inlier. It indicates the waters are of sodium or mixed cation (i.e magnesium, calcium, sodium) bicarbonate waters. Even with consideration of the small sample size, samples from the different tectonic areas do not cluster into identifiable groups on the trilinear diagrams. Groundwater from acid intrusive aquifers are of predominantly sodium with (some mixed cation) bicarbonate or chloride water.



CAPE YORK PENINSULA LAND USE STRATEGY

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GROUNDWATER SODIUM ADSORPTION RATIOS

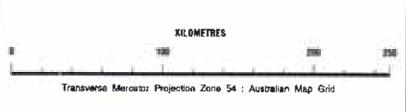
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1:250 000 Geology Sheet Boundaries

- 0 8 Sodium Absorption Patio
- 8 18 Sodium Absorption Ratio
- 18 46 Sodium Absorption Ratio
- 46 102 Sodium Absorption Ratio
 - > 102 Sedium Absortion Ratio

CYPLUS Study Area



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FIGURE 4.18_{A3-105525}

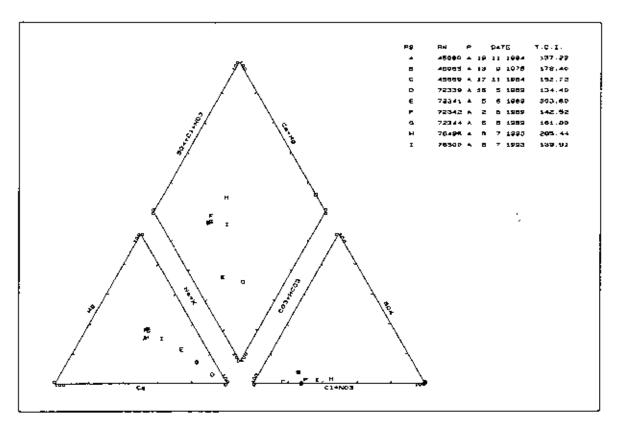


Figure 4.19 Trilinear Diagram - Basaltic Aquifers

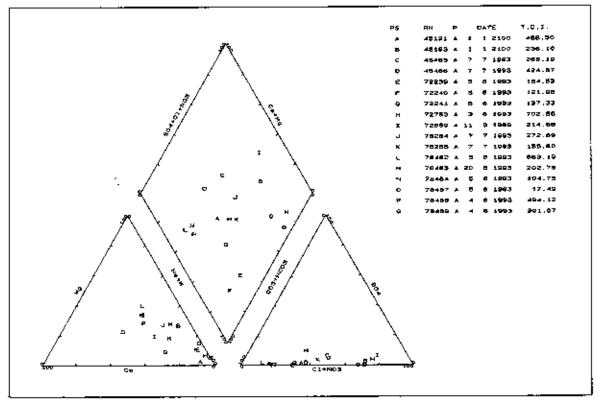


Figure 4.20 Trilinear Diagram - Acid Intrusive Aquifers

4.3.1 Coen Inlier

The Coen Inlier has been analysed under the broad categories of acid intrusive aquifers and metamorphic aquifers. The groundwater quality is generally good with average analyses shown in Table 4.8. Figure 4.21 indicates the salinity and hardness variations. A trilinear diagram showing metamorphic aquifer samples for this unit (Figure 4.22) indicates the groundwater ranges from sodium to mixed cation, bicarbonate to chloride type waters.

The quality of the water from the metamorphics at Lockhart River, Coen and the southern tip of the Coen Inlier is good. Salinity ranges from $70 \mu \text{scm}^{-1}$ to $280 \mu \text{scm}^{-1}$ in the Lockhart River area to $700 \mu \text{scm}^{-1}$ at the southern tip of the Coen Inlier. Generally the water is suitable for all purposes.

The salinity of the water from the acid intrusives in the Coen Inlier is generally higher than that of water from the metamorphics. It ranges from 280 to 1550 μ scm⁻¹ and averages 850 μ scm⁻¹. This is generally regarded as the salinity limit for high quality drinking water.

The fluoride concentration of water from the acid intrusives is in the Coen Inlier is generally much higher than water from the metamorphics. In the northern Coen Inlier, fluoride content ranges from 0.2 to 0.88 mg/L. In the southern Coen Inlier it ranges from 0.1 to 2.8 mg/L and averages 0.9 mg/L. The NHMRC suggests an upper limit of 1.5 mg/L for drinking water for humans and 2 mg/L for young stock. Water from five bores in the southern Coen Inlier exceeds the limit for potable water.

		Çſ	DEN IN	LIER -	avej	RAGE	GRO	UNDW.	ATER AN	ALYS	es	٠.	
	indica	es data j	lomu α	skewed .	distrib	ution o	ınd sig	ngicant	variations	from n	nech val	ues occu	· · ·
	Cond	Hard	ŞAR	Alk	Na	Ca	Mg	Cl	нсоз	SO4	NO3	· F ·	Sample Size
Acid Intrusives Metamorphics	660 490	122 147*	4 2	160 144	86* 46	24 28*	15 19	101* 67*	194 175	10 5*	3.5° 7.3*	0.8 0.7*	12 11

Table 4.8 Coen Inlier - Average Groundwater Analyses

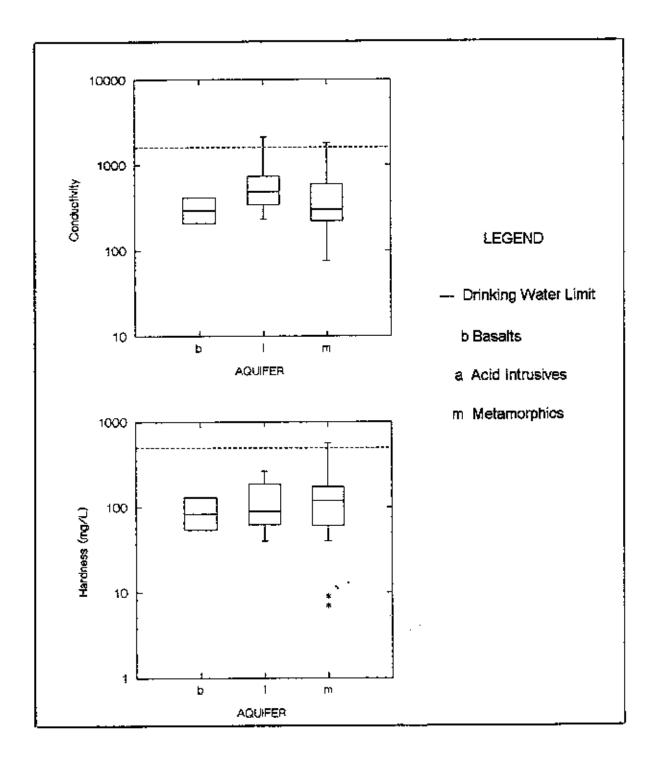


Figure 4.21 Coen Inlier - Conductivity and Hardness Variations

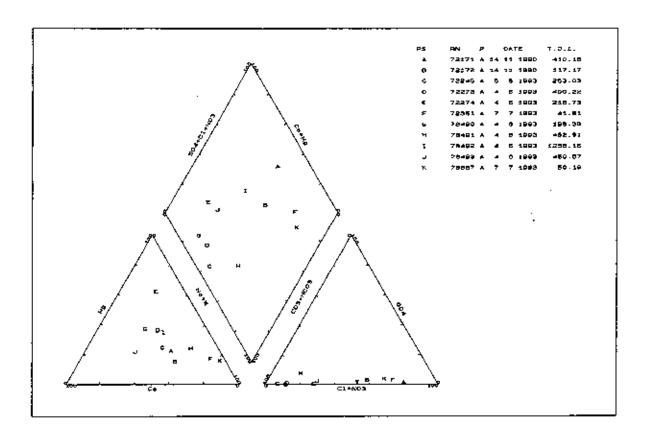


Figure 4.22 Coen Inlier - Trilinear Diagram - Metamorphic Aquifers

4.3.2 Yambo Inlier

Only two groundwater samples from the Yambo Inlier were suitable for analysis. Averages have been tabulated (Table 4.9) and indicate the groundwater may be of good quality from this tectonic province. It is expected that the groundwater from the Yambo Inlier would, in a more regional evaluation, be similar to groundwater from the Coen Inlier.

Water quality from the seven Yambo Inlier bores is good, with conductivity ranging from 200 to 320 μ scm⁻¹. In contrast to the groundwater from the southern part of the Coen Inlier, which has elevated fluoride concentrations, no such values have been observed in water from the Yambo Inlier.

The water from the acid intrusives of the Yambo Inlier is suitable for all purposes.

	•	Υ	AMBO I	NLIER	- AVE	RAGE	GROUI	IDWA	TER ANA	LYS€S			
	Cond	Hard	SAR	Alk	Na	ű	Mg	Ci	нсоз	S04	NO3	F.	Sample Size
Acid Intrusives	200	9	6	46	38	0.9	1.7	31	56	0.15	0.0	0.2	2

Table 4.9 Yambo Inlier - Average Groundwater Analyses

4.3.3 Hodgkinson Province

The Hodgkinson Province is similar to the other fractured rock areas in providing good quality water. However in some coastal areas aquifers in the metamorphic rocks in the province has been intruded by saltwater. Average analyses appear in Table 4.10 and salinity and hardness variation are shown in Figure 4.23. Also, similarly to the other fractured rock aquifers, the trilinear diagram indicates the groundwater ranges from sodium to mixed cation, bicarbonate to chloride type water.

Groundwater from the Piebald Basalt and McLean Basalt is of low salinity and is suitable for all purposes.

		HOL	GKINS	ON P	ROVI	NCE -/	VERA(GE GRO	DUNDWA	TER AN	ALYSI	es ·	
	± in	diças e s a	lata forn	25 0 5 K	ewed .	distribut	ion and .	significa	nt variation	ns from 1	nean va	dues occ	ur ·
	Cond	Hard	SAR	Alk	Na	Ca	Mg	CI	исоз	SO4	NO3	F	Sample Size
Metamorphics	719*	725*	4*	127	74*	109*	110*	142*	153	138*	0.8*	0.51*	58

Table 4.10 Hodgkinson Province - Average Groundwater Analyses

4.4 Laura Basin

Water quality is generally good with the only concerns being elevated iron and manganese levels in shallow aquifers. Point source contamination, from settlements and future developments, will be a potential threat to the integrity of water quality if suitable management practices are not adopted.

The quality of water from the Mesozoic sandstones is usually acceptable for most purposes. The conductivity content varies from between $50 \mu \text{scm}^{-1}$ and $3200 \mu \text{scm}^{-1}$ with an average figure being only $900 \mu \text{scm}^{-1}$. A box and whisker plot displaying conductivity and hardness ranges for the basalt and Gilbert River Formation/Dalrymple Sandstone aquifers is shown in Figure 4.25.

The major ions found in these waters are Na⁺, Cl⁻ and HCO₃. The majority of water samples from the Gilbert River Formation/Dalrymple Sandstone aquifer fall in the sodium bicarbonate field as indicated by the trilinear plot in Figure 4.26. Isolated bores in outcrop areas near the sea (i.e. at Bathurst Head) supply water of the Na-Cl type probably as a result of higher NaCl content of rainwater from seaspray.

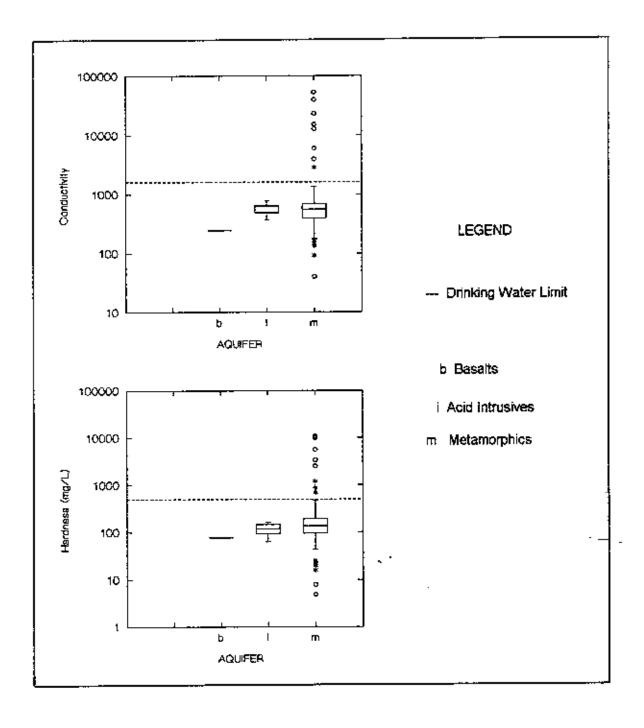


Figure 4.23 Hodgkinson Province - Conductivity and Hardness Variations

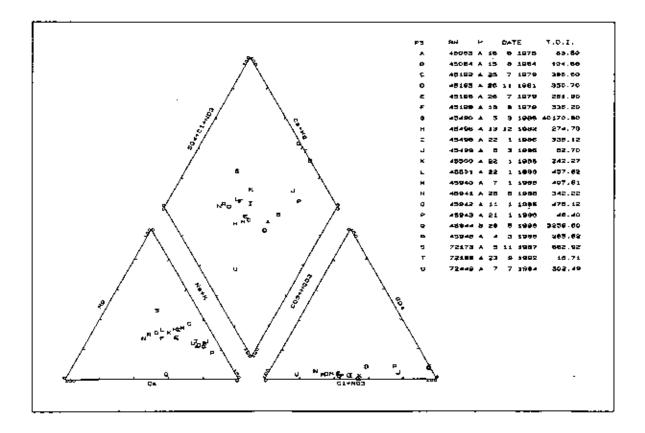


Figure 4.24 Hodgkinson Province - Trilinear Diagram - Metamorphic Aquifers

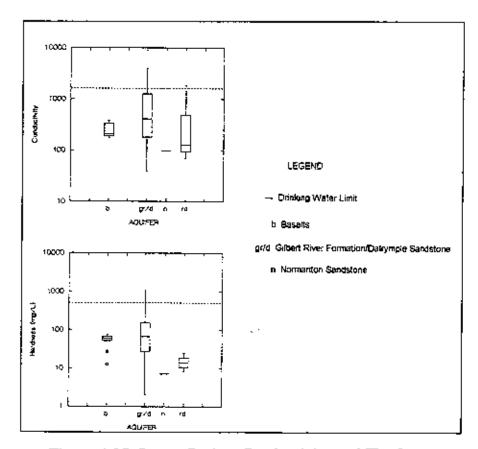


Figure 4.25 Laura Basin - Conductivity and Hardness

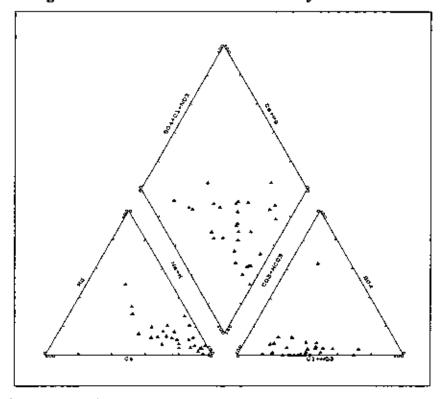


Figure 4.26 Laura Basin - Trilinear Diagram - Gilbert River Formation/Dalrymple Sandstone

Average water analyses for the Gilbert River Formation/Dalrymple Sandstone aquifer are shown in Table 4.11. An analysis of water quality records indicates that there is a slow increase in total dissolved solids as water migrates away from intake areas towards the basin axis i.e. T.D.S. 40 mg/L to T.D.S > 350 mg/L over a distance of approximately 50 kms. Bores that supply water with a T.D.S. of greater than 1000 mg/L are, it is proposed, probably subject to influences external to the aquifer. These may include structural features that allow interformational water mixing, the proximity of the aquifer to basement rocks or lithostratigraphic interrelationships.

The quality of water sourced from Rolling Downs Group aquifers is generally poor, though it is usually suitable for stockwatering. Conductivity ranges from 1400 μ scm⁻¹ to over 7000 μ scm⁻¹. The water is predominantly of the Na-Cl type.

Water from fracture zones in this group is probably not characteristic to the formation as the source may be quite remote. Samples from the fracture zone previously discussed in RN 78821 revealed concentrations of fluoride and boron normally associated with granitic rocks rather than mudstones and siltstones.

The Normanton Sandstone provides water of varying quality dependent upon the degree of 'flushing' that is possible. Spring flow appears to be of excellent quality with a T.D.S. of 50 mg/L. A deeper bore sample (100 m) had a T.D.S. of 900 mg/L. It would appear that once the Normanton Sandstone dips under overlying sediments it rapidly lenses out with groundwater tending to "stagnate".

The water quality of the Cainozoic sediments overlying the Laura Basin is generally good with conductivity ranging from $140 \,\mu\text{scm}^{-1}$ to $840 \,\mu\text{scm}^{-1}$ and averaging at $350 \,\mu\text{scm}^{-1}$. Manganese and iron can occur at levels high enough to be of concern for human use.

Observations at Laura indicate that all shallow aquifers are at high risk from point source contamination. Effluent from septic systems in this town has rendered water from two shallow aquifers (at 5 and 30 m below ground level) bacteriologically unsuitable for human consumption.

RN 78220 located on Olivevale Station in the Laura Basin illustrates the importance of lithostratigraphy on water quality. Four aquifers were encountered whilst drilling this bore. The first two, at depths of 115 and 140 m respectively, supplied water from the Rolling Downs Group and had conductivities of 2700 μ scm⁻¹ and 4300 μ scm⁻¹ respectively. The third aquifer had a conductivity of 2200 μ scm⁻¹ at a depth of 220 metres, only one metre below the top of the Gilbert River Formation. The last aquifer, at 260 metres had a conductivity of 530 μ scm⁻¹. The first three aquifers consisted of thin layers of muddy sand laminated between mudstone and siltstone layers that act as effective aquicludes. The bottom aquifer occurred at the top of a progressively sandier sequence of lithology and was not effectively separated from the main aquifer below.

	J	LAURA	BASEN	- AVER	AGE G	ROUN	DWA	TER AN	NALYSES				•		
* indic	* indicates data forms a skewed distribution and significant variations from mean values occur														
	Cond Hard SAR Alk Na Ca Mg Cl HCO3 SO4 NO3 F Sampl Size														
Gilbert River Formation/ Dalrymple Sandstone	900=	137*	7	288*	170*	32*	14*	142*	348*	5*	0.7*	0.6*	80		

Table 4.11 Laura Basin - Average Groundwater Analyses

4.5 Carpentaria Basin

The quality of groundwater from the major Carpentaria Basin aquifers, the Gilbert River Formation and the Garraway Beds, when they are unconfined, is generally good and suitable for most purposes. When these aquifers become confined, the water quality deteriorates. This deterioration is probably due to mixing with saline groundwater from the overlying Rolling Downs Group. Generally water from the Rolling Downs Group is quite saline and, therefore, unsuitable for purposes other than stockwatering. A box and whisker plot displays the conductivity and hardness ranges for Carpentaria Basin groundwater in Figure 4.27.

The groundwater from the Mesozoic sandstones is generally suitable for stockwatering purposes. However the elevated levels of sodium and bicarbonate in the groundwater generally make it unsuitable for irrigation of clayey soils derived from the Rolling Downs Group. Fluoride levels in water from the Mesozoic sandstones can often exceed the recommended limits for drinking water for humans and young stock. Generally the conductivity content varies from around 400 μ scm⁻¹ in outcrop areas to 1400 μ scm⁻¹ in deep artesian bores. Average groundwater analyses appear in Table 4.12.

The predominant ionic type of the groundwater from the Mesozoic sandstones is sodium-bicarbonate-chloride. A trilinear diagram of Mesozoic sandstone aquifers (Figure 4.28) indicates the Garraway Beds aquifers contain a more sodium-chloride type water, while water from the Gilbert River Formation and Helby Beds are of sodium bicarbonate and sodium chloride type.

·	CAR	PENTA	RLA: BA	SIN -	AVERA	GE G	ROUNE	WATE	R ANAL	YŠES				
* indi	cates dat	a forms e	a skewee	l distri	bution a	nd sign	ficant v	ariation	s from nu	an valu	ės occur			
Cond Hard SAR ABk Na Ca Mg Cl HCO3 SO4 NO3 F Sam Siz														
Garraway Beds	1170	43	17	204	247	14	2.1*	227	245	*16	0.3	1.5*	10	
Gilbert River Formation	1340	87*	17	223	258	23*	7.6*	276*	267	36*	1.0*	2.6*	26	
Helby Beds	94	27	6	81	80*	7	42.2	82*	99	2	0.1*	0.7*	7	
Rolling Downs Group	3800*	566*	20	277	667*	119*	65*	975*	335	336*	0.07*	2.6*	8	

Table 4.12 Carpentaria Basin - Average Groundwater Analyses

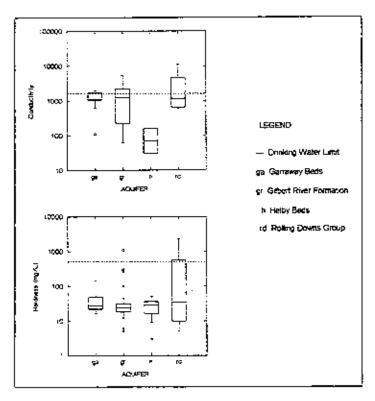


Figure 4.27 Carpentaria Basin - Conductivity and Hardness

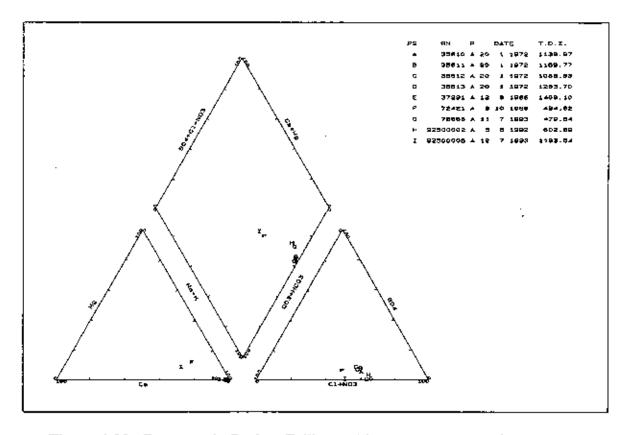


Figure 4.28 Carpentaria Basin - Trilinear Diagram - Mesozoic Sandstones

4.6 Karumba Basin

Groundwater quality in the Karumba Basin is good although some highly saline water occurs. Groundwater conductivity values are usually low though the Wyaaba Beds generally have higher conductivity values than the Bulimba Formation.

Bulimba Formation

The quality of water from all Bulimba Formation aquifers is in general excellent being suitable for all purposes.

Low pH levels may be of concern in the shallow aquifers (<5.0 at Aurukun) however this can be corrected easily. Bore construction using corrosion resistant materials (PVC/ABS casing, stainless steel headworks etc.) is recommended in all areas due to the presence of aggressive CO₂ gas.

The conductivity values vary between 210 μ scm⁻¹ and 700 μ scm⁻¹ with an average figure of around 420 μ scm⁻¹.

Wyaaba Beds

The quality of water sourced from the Wyaaba aquifer reflects the marine origins of its sediments. Conductivity ranges from 700 μ scm⁻¹ to 2500 μ scm⁻¹. The pH of waters varies between 7.5 and 8.5.

On average the water is found to be at the lower end of the above margins. The highest values occur in a bore located adjacent to a tidal inlet and may therefore reflect some influence from the local marine environment.

Figure 4.29 presents the conductivity and hardness variation in the Karumba Basin and Table 4.13 indicates average groundwater analyses. A trilinear diagram (Figure 4.30) indicates the groundwater from the combined Bulimba Formation/Wyaaba Beds principally is of sodium chloride type with significant sodium bicarbonate water.

[KARU	JMBA E	ASEN	- AVE	RAGE	GRO	UNDW.	ATER AN	ALYSE	:S .				
I	indicase.	s dava fo	rms a sk	ewed e	กัรชายแบ	ion an	d sign	ficant v	wintions fi	rom med	in value	s occur			
	Cond Hard SAR Alk Na Ca Mg Ci HCO3 SO4 NO3 F Sample Size														
Bulimba Formation/ Wysaba Beds	801*	154+	7.41	158	128*	26	22	158*	190	38*	0.8	0.7	214		

Table 4.13 Karumba Basin - Average Groundwater Analyses

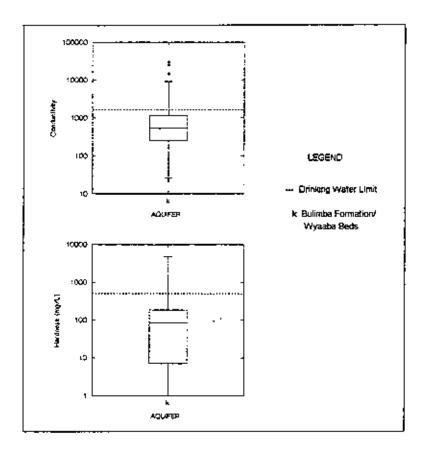


Figure 4.29 Karumba Basin - Conductivity and Hardness Variation

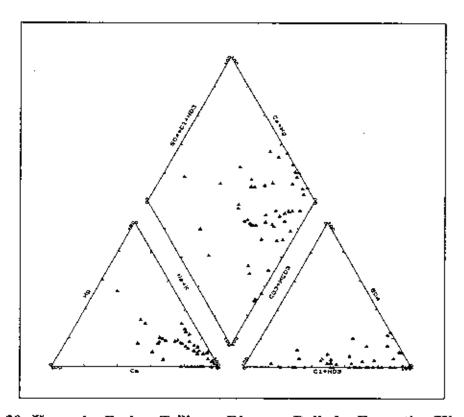


Figure 4.30 Karumba Basin - Trilinear Diagram Bulimba Formation/Wyaaba Beds

4.7 Coastal Sand Dunes

Generally the quality of groundwater from sand dune aquifers is good. However only one reliable sample from beach ridge aquifers is available and it is difficult to extrapolate broad aquifer type characteristics from this one sample. A summary of the results from this sample appears in Table 4.14.

RN 45011	Total Depth: 76.2	m	s	am	ple	D	ept	h:	4 :n	<u> </u>	5	320	ap)	le]	Da	te:	2	9/9	9/73
Description of	Sample Site:	Но 141				eac	h I	Rid	ge	. (L	at -	- 14	1 °5	41	.0*	, <u>'</u>]	Lio	og ~
Stratigraphic (Classification:	0 -	10	.4	m l	Rec	en	ŧ ((Cos	ısta	11	Dep	208	its)				
		Ge	olo	gic	al l	log	,												•
3.05 - 4.88 4.88 - 9.14		• •	• •		• •	• •	C (ar 	se .	san	d.	an Ga	d g ey	ra m	vel an	a gr	nc '01	l si e :	hells mud
		We	uter	· Aı	ralj	vsis						·		_					
рН			• •							٠.			٠.	•				•	.7.5
Ratios																			
Alkalinity Sodium Absor	ption Ratio	 	• •		• •	• •	•		• •	• •	•			•					4 . 3.8
Concentrations	s (mg/L)																		
Total Dissolve Na ⁺ Ca ⁺⁺ Mg HCO3 CO3	d Ions (mg/L) d Solids (mg/L)		• • • • • • • •					• •				· · · · · · · · · · · · · · · · · · ·			· ·			1	6.56 . 9.3 . 0.3 . 0.1 . 5.2
F				٠.															0.00

Table 4.14 Beach Ridge - Groundwater Quality

5.0 GROUNDWATER RECHARGE AND GROUNDWATER DISCHARGE

Recharge is a critical component of the hydrological cycle. This feature, permeability and hydraulic gradient are the principle factors controlling the quantity of groundwater flow (Acworth, 1987). In homogenous rock types the water types and chemical nature of the water is determined by recharge infiltration and the early stages of flow (Martin, 1982) with subsequent modifying processes being physically controlled.

The quantity of groundwater recharge is influenced by climate, vegetative cover, extent of evapotranspiration and the soil depth and composition. Potential recharge areas are displayed in Figure 5.1 and have been determined using a combination of fractured rock outcrop areas, dunefield locations, soil and regolith data, and datalogger records. This map is a general guide of potential recharge locations and gives a very broad indication of areas vulnerable to groundwater pollution. Detailed assessment of groundwater vulnerability for a particular location would require further site-specific study.

Fractured rock and unconsolidated sedimentary rock aquifers principally recharge vertically. Recharge occurs at the ground surface of these units, and response to sufficient rainfall is usually a rapid rise in local water table levels.

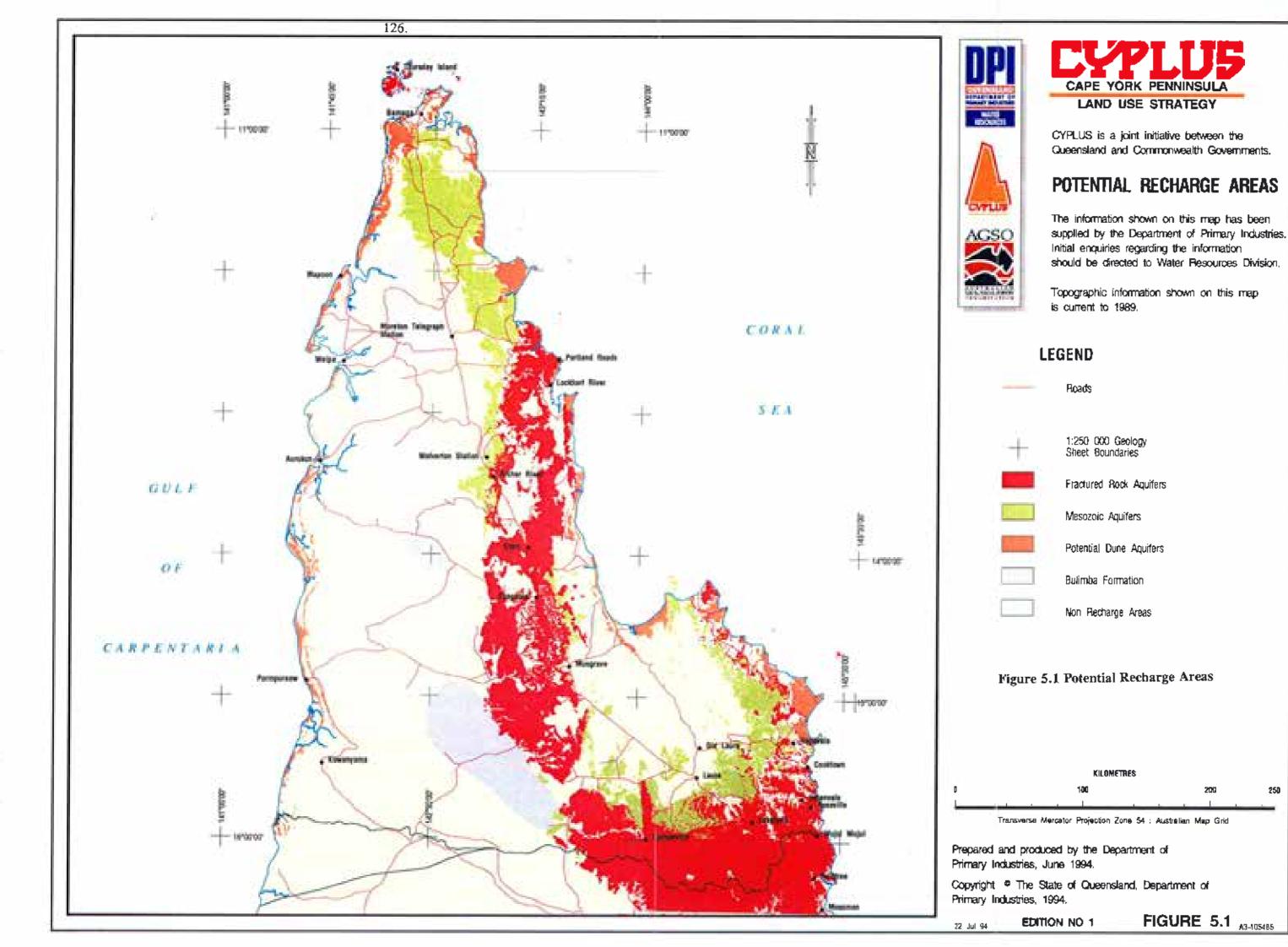
The recharge of the sedimentary basin aquifers is more limited, because of predominantly low rainfall conditions in the recharge areas and low transmissitivity rates. In Australia, much of the groundwater in storage is fossil water derived from recharge during wetter periods in the Quaternary (Jacobson, 1983).

The main recharge areas for the Carpentaria Basin lie along the western margins of the Great Dividing Range. Similarly, for the Laura Basin recharge areas are present in the ring of Mesozoic outcrop areas that occur west of the eastern uplands between Cooktown and Cape Melville, as well as north of the Hodgkinson Basin and east of the Great Dividing Range (between approximately Hann River Roadhouse and Cape Sidmouth). Recharge areas are present in the Karumba Basin along the Weipa Peninsula and in sections of the Central Western Cape York Peninsula.

The lateritic Weipa Plateau, containing loose friable bauxite, is unique (Chapman, 1963) and its open structure is conducive to vertical recharge. The Kimba Plateau also has an absence of surface drainage features and exhibits springs around the plateau margins (Whittaker and Grimes, 1977). These features on a plateau suggest vertical recharge. BMR Hann River No. 1 which yielded little water was drilled into the Kimba Plateau, but the drilling mud used may have prevented the recognition of sub-artesian supplies.

The interrelationships between beach ridges and alluvial deposits indicate there is a high potential for hydraulic continuity between these units. The possibility exists for some of the recharge of the alluvials occurring though the beach ridges and conversely, leakage of the beach ridge aquifers through the alluvials.

In the more arid zones, which include much of the Peninsula, low recharge means that future groundwater development will depend on abstraction from historical groundwater storage, rather than replenishable supplies.



Dataloggers were installed as part of this project at six locations in the study area to monitor groundwater level behaviour and recharge mechanisms. Datalogger records are shown in Figures 5.2 to 5.7. It should be noted that the Water Level (m) axis on these records refer to the depth below ground level.

The Strathmay (RN 92000001) and Holroyd (RN 92100001) data loggers were installed primarily to investigate if the Bulimba Formation recharges vertically in the central western peninsula. Pluviometers were also installed at these locations. The data logger displays for these two bores (Figures 5.2 and 5.3)show a good correlation between significant rainfall and a rising water table. The water table rise shows a lag behind the rainfall events and is probably attributable to soil saturation and hydraulic conductivity processes.

The dataloggers for the Batavia Downs and Wolverton (Figures 5.4 and 5.5) bores were installed to monitor the water level behaviour of the Gilbert River Formation. No rainfall pluviometer was installed at these sites though significant rainfall events occurred. The data logger records indicate no significant changes in water levels over the monitoring period. The two data loggers installed at Pormpuraaw (Edward River, Figures 5.6 an 5.7) were installed principally to monitor water levels for resource management purposes. These data loggers show a general rise in water levels following rainfall periods and a short term oscillation attributable to the datalogger's responses to temperature variations.

All of the groundwater is derived from rainfall on areas of the aquifer which outcrop at the surface with many factors influencing the actual water available for recharge. The following equation summarises these processes.

$$Q = Q_R - Q_S - Q_P - P - S_S$$

where:

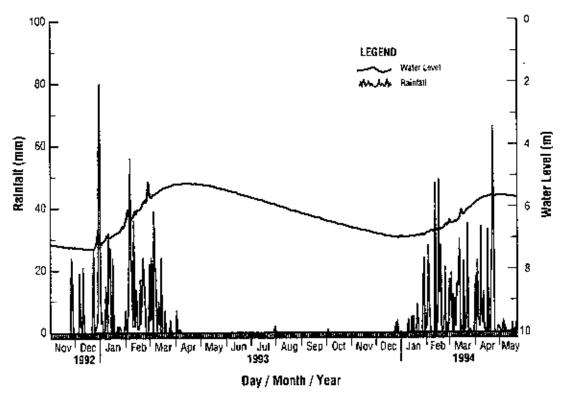
O = Water Available for Recharge

 $Q_R = Rainfall$

 Q_S = Surface Runoff Q_P = Pan Evaporation P = Plant Uptake

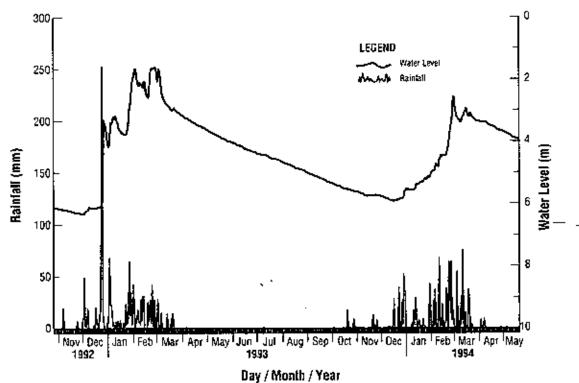
 S_s = Soil Storage Retention

The water balance equation is further complicated when considering the temporal effects of rainfall and evaporation. Peak evaporation rates may not coincide with peak rainfall events. Less rainfall is available for recharge while evaporation rates are high. If high evaporation rates occur when there is no actual rainfall, this will have a small influence on recharge rates. Similarly, intense rainfall may cause little recharge, as the majority of this rainfall quickly runs off.



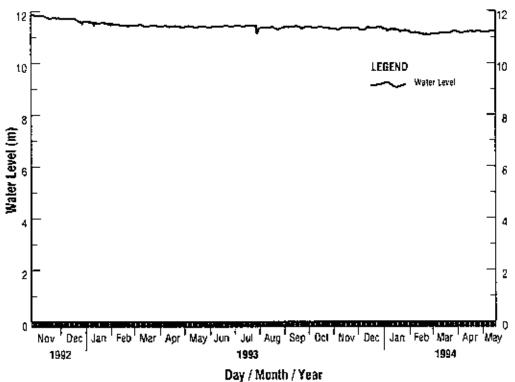
STRATHMAY RN 92900001

Figure 5.2 Data Logger Record - Strathmay



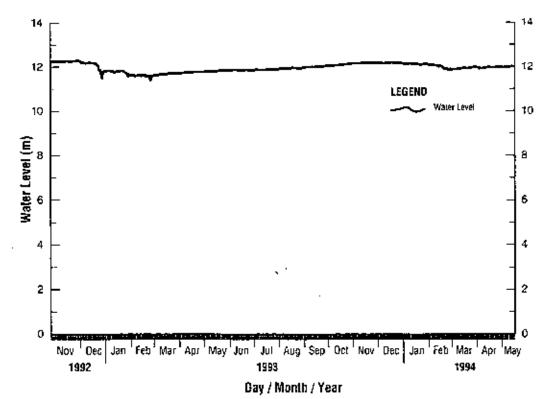
HOLROYD RN 92100001

Figure 5.3 Data Logger Record - Holroyd



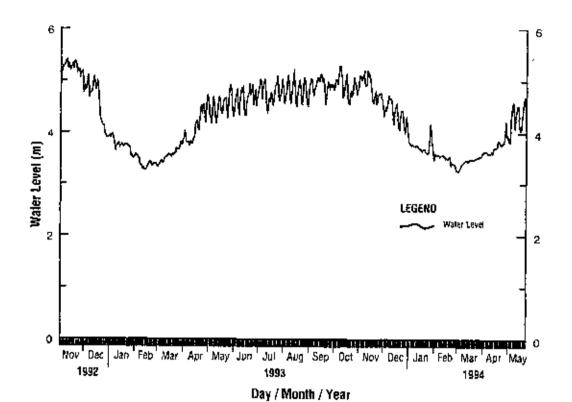
BATAVIA DOWNS RN 92500002

Figure 5.4 Data Logger Record - Batavia Downs



WOLVERTON RN 92300003

Figure 5.5 Data Logger Record - Wolverton



EDWARD RIVER 1 RN 92010001 Figure 5.6 Data Logger Record - Edward River I

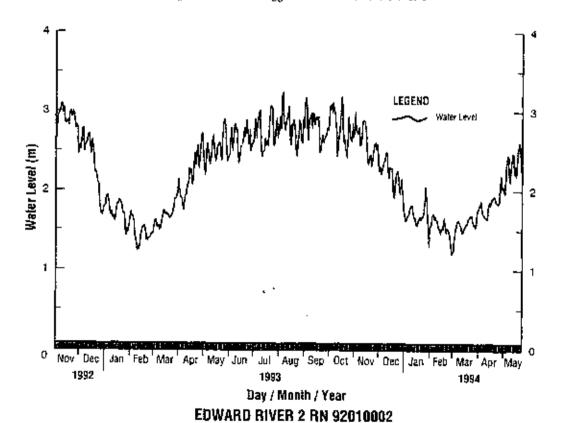


Figure 5.7 Data Logger Record - Edward River 2

General water balances for Weipa, Cooktown and Coen appear in Table 5.1 and show the limited water available for recharge.

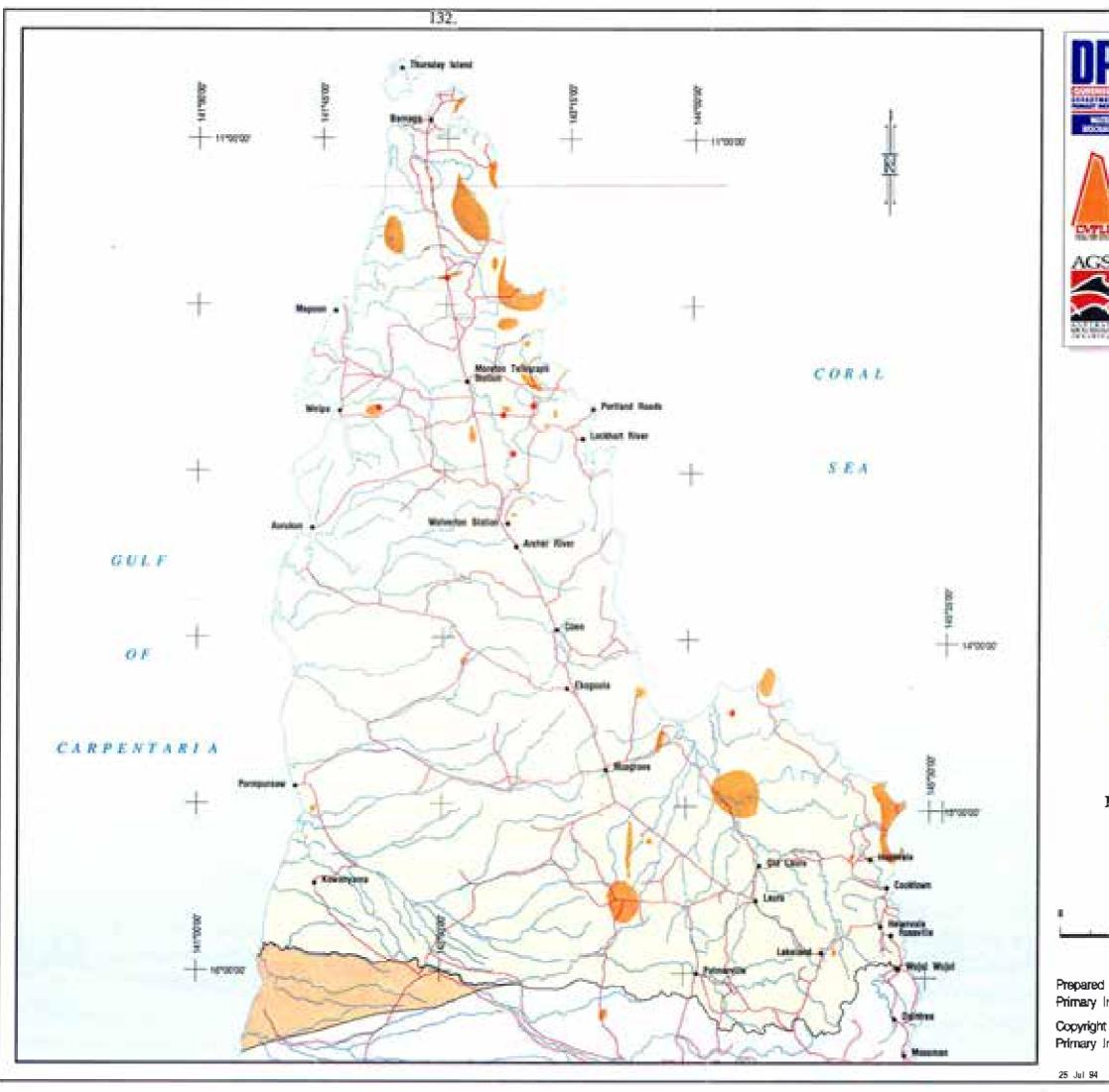
This table was compiled using data calculated using PERFECT (Productivity Erosion Factors) (Littleboy et al, 1993). Daily rainfall data for the period 1914-1988 were used for all simulations. Soils descriptions and Plant Available Water Capacity values were supplied by the CYPLUS Land Resource Inventory Project and the profile drainage was inferred from this project. The partitioning of runoff and infiltration is the most doubtful output as profile drainage parameters were inferred from the soil descriptions. In summary, the soil descriptions used for this simulation are Weipa-Red Earth, Coen-Yellow Earth. Around Cooktown, several relevant soils exist and no one soil was considered representative, three soils were selected as giving, in combination an adequate summary of the area. These are Jennie-Yellow Earth/Yellow Podzolic, Gibson-Soloth or Solodic, and Kingjack-Yellow Podzolic.

Location	Rainfall mm	Runoff mm	Evapotranspiration	Infiltration
(Soil Type)	(%)	(%)	mm (%)	mm (%)
Weipa	1708	447	933	328
	(100)	(26)	(55)	(19)
Coen	1153	496	586	71
	(100)	(43)	(51)	(6)
Cooktown			-	
(Jennie)	1089	369	695	25
	(100)	(34)	(64)	(2)
(Gibson)	1089	398	687	4
	(100)	(37)	(63)	(≅.004)
(Kingjack)	1089	399	688	2
	(100)	(37)	(63)	(≅.002)

Table 5.1 Average Annual Water Balances (Courtesy - M. Littleboy)

Groundwater Discharge Areas (Springs)

The Figure 5.8 shows groundwater discharge or spring locations, was compiled from a survey of Cape York Peninsula landholders and researchers from most associated CYPLUS projects.







CYPLUS is a joint initiative between the Queensland and Commonwealth Governments,

GROUNDWATER DISCHARGE (SPRING) AREAS

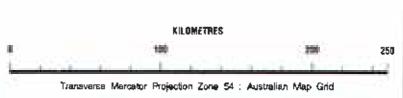
The information shown on this map has been supplied by the Department of Primary Industries Initial enquiries regarding the information should be directed to Water Resources Division.

Topographic information shown on this map is current to 1989.

LEGEND



Figure 5.8 Groundwater Discharge Areas



Prepared and produced by the Department of Primary Industries, June 1994.

Copyright . The State of Queensland, Department of Primary Industries, 1994.

EDMON NO 1

FIGURE 5.8 A3-105058

In northern Cape York Peninsula (north of Coen) many springs are associated with outcrops of the Gilbert River Formation, the Helby Beds and the Garraway Beds. These springs are often major contributors to the baseflow of streams (e.g. the Archer, Wenlock and Jardine Rivers).

Significant springs also occur in the Lakeland area other isolated locations and in various coastal dunefields. Minor and somewhat rare freshwater beach springs occur along the eastern coastline.

6.0 MANAGEMENT ISSUES

Groundwater resources provide 90% of the study area's water supplies. Principal aquifers exist within the Cainozoic Bulimba Formation and Wyaaba Beds, the Mesozoic Gilbert River Formation and Dalrymple Sandstone, with additional significant supplies obtained from fractured rock aquifers. Coastal dunes and beach ridge deposits may prove a significant resource if groundwater demands increase.

Adequate regional groundwater resources appear to meet current demand. However many of these resources are often isolated from areas of demand, and some are not available or "dry" at the times when most needed. Over-exploitation of aquifers can result in a decrease of resources, and a deterioration of quality.

A significant concern is the paucity of groundwater data away from the population centres of the Peninsula. This point was highlighted during the CYPLUS drilling program during which artesian water was discovered at Frenchman's Road, an area previously unknown to contain artesian supplies. Because of a lack of data, groundwater hydrological mechanisms in this area are not sufficiently well understood to precisely explain this occurrence.

Similar concerns regarding limited data apply to the Karumba Basin. This basin is the major water resource of the study area providing water supplies to 60% of the study area's population. This resource provides domestic supplies for Weipa, three Aboriginal communities and for the Weipa mine.

The Karumba Basin is the water source for the two Kowanyama town water supply bores where the pressure heads have decreased from approximately 22 metres in 1974 to approximately 8 metres in 1992. It is still unclear if this results from an extended period of poor recharge or from actual mining of the resource.

Presently there is no management plan for the water resources of the Karumba Basin.

Pollution has not been identified as a major problem. However, few areas at present support intensive agricultural crops or other industries that have high nutrient, pesticide and other chemical uses. The Weipa area (with its mining activities and township) poses significant potential pollution risks to groundwater. This situation requires careful management as it is located on the recharge area of the Bulimba Formation which is a major source of potable water for the region.

Public awareness of groundwater management issues needs to be raised to facilitate greater public decision making and co-operative resource management between government departments, the shire council, aboriginal councils and the local Peninsula residents.

Issues affecting the management of the groundwater resources fall into several related areas. Most of these are influenced by or are likely to be exacerbated by extraction rates greater than those the groundwater system can safely bear. This may occur with expanding industrial, agricultural and population trends putting an increasing burden on limited natural water resources

These issues have been identified as:

1. Over Exploitation of Aquifers Reducing Availability

This has not been identified as a major problem at present as the abstraction rates of the resource in the study area are generally low. For the sedimentary aquifers this may become an issue in the long term as pressures in the artesian areas begin to fall as a result of usage and a steady state equilibrium occurs. Because of the isolation of nany of these bores few have had pressure measurements taken more than a few times. There does not exist a sufficient length of record on which to base any conclusions on the pressure trends for the artesian aquifers. This point is being addressed with the ongoing collection of data. However it will be five to ten years before sufficient data has been accumulated to determine long term trends.

At present over exploitation of small fractured rock resources appears to be of concern to local users. These aquifers are usually small and isolated having little influence except on adjacent bores. Often these aquifers are vertically recharged and replenish fairly quickly with good rainfall. With these aquifers, reductions in groundwater availability tends to be seasonal.

Consideration also needs to be given to the relationship between groundwater abstraction and natural discharge. This may be of particular concern to the tourist industry if there is a significant reduction in size and quality of natural discharge sites (i.e. springs). It should be noted that in many areas any use of this resource will reduce the outflow from springs.

Groundwater contribution to stream flows and wetlands is important in some areas. Protection of environmental values and ecological integrity in these areas is a major management issue.

2. Deteriorating Groundwater Quality

Groundwater quality has been observed to deteriorate in various locations (e.g. Kowanyama) in relation to falling groundwater levels. This may be related to either a lowering of potentiometric heads in the area allowing poorer quality water to enter the local aquifer system from adjoining strata, or to changes in aquifer transmissivity decreasing discharge and increasing residence time and absorption of ions. This feature appears to be most pronounced over basement highs and other areas where there is a local constriction of groundwater flow. Generally changes in groundwater chemistry composition are not expected to change significantly except in those areas where there is a potential for saltwater intrusion.

3. Saltwater Intrusion

Saltwater intrusion into near coastal aquifers has been identified at Pormpuraaw. This process has occurred where groundwater levels have been reduced by extraction, to a level low enough to permit the entry of seawater.

It is of particular concern in aquifers that contain significant clay material where, because of cation exchange processes permeability can be reduced and the process becomes virtually irreversible and the aquifer remains salty indefinitely.

Saltwater intrusion may also need to be monitored carefully in coastal dune aquifers if significant exploitation of these aquifers commences. However, in vertically recharging sandy aquifer environments, with appropriate management, such intrusion in bad seasons should reverse quickly in good seasons.

The Bulimba Formation aquifers are considered vulnerable from saltwater intrusion (Smart, 1977), with overpumping having the potential to draw seawater into the aquifer system (Smart et al, 1980). Chapman, (1963) calculated that to just avoid the reversal of the flow of fresh groundwater into the saltwater zone on the Weipa Peninsula, 0.19 metres of the average 0.406 metres of recharge must be permitted to remain as throughflow. This assumed that drawdown was uniform over the Weipa Peninsula.

4. Groundwater Pollution

Pollution usually affects shallow aquifers and can affect groundwater in various ways. It can effectively sterilise the resource, excluding it from use for any purpose, or it can have a range of influences down to giving potable water an unpleasant taste, colour or odour. More commonly, pollution tends to reduce water from potable to a lower quality category such as suitability for stock or irrigation only. This process may either be through inorganic or organic contamination.

There are two principal origins of groundwater pollution. Point source pollution may originate from, for example, industrial mining or feedlot sites, sewerage or septic systems and waste disposal sites. Diffuse pollution, which is usually associated with broad scale agricultural activities particular widespread continuous fertiliser application.

At Laura point source pollution has occurred from septic systems. The Laura septic system pollution was sufficient to warrant DPI-WR using research from the CYPLUS project to provide an alternative safe water supply for the township. Some local changes to the groundwater may have occurred at Weipa South and at Edward River where an initial analysis of water quality indicates there is a distinct water type at these two locations.

Potential mining development for base and precious metals appears most likely to occur in groundwater intake areas of the fractured rock aquifer systems or, in areas where minesite runoff water can flow to the intake areas of the major sedimentary basins. The likely proximity of such development to critical intake areas will warrant detailed evaluation and management of potential mining activities.

Potential Threats from Unidentified Sources

The vertically recharging nature of many groundwater regimes in the study area indicates these resources are particularly vulnerable to pollution. Because of the short term travel times, potential for chemical buffering of the system is reduced. This is well illustrated by the data logger responses showing rapid infiltration at Strathmay and Holroyd and would be similar for the fractured rock aquifer areas and coastal sand dune areas. In essence the Cape York Peninsula groundwater regime in many areas shows the potential to respond rapidly to human influences.

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APPENDIX 1 DRILLING PROGRAM

The drilling program constituted a substantial component of this project. The program was designed to effectively address a number of significant knowledge shortfalls regarding stratigraphy and hydrological processes of the Peninsula.

Boreholes were drilled at Batavia Downs, Strathmay Station, Holroyd River Station, Heathlands Ranger Base and Wolverton Station. Nine bores were drilled (totalling 1542 metres) with CYPLUS funding. All but one of these bores encountered useful water supplies, the exception being a shallow hole drilled on top of the Emberly Range near Batavia Downs. In conjunction with the CYPLUS drilling program three private bores were completed. These included one for Strathgordon homestead and two water level observation bores on behalf of the Department of Family Services and Aboriginal and Islander Affairs at Pormpuraaw.

Five of the boreholes were pumptested and six were equipped with dataloggers. The CYPLUS bores were located principally where there was no stratigraphic information. These bores provided detail on the geology of the central Peninsula area and identified the principle aquifer bearing Mesozoic sandstones as lying much deeper than was previously thought in several of these locations. Additionally the overlying and generally groundwater deficient Rolling Downs Group proved a much thicker sequence than expected. This information is of significant value to landholders in determining the practicality and costs of establishing productive water bores.

The pumptesting and datalogger recording of these boreholes has provided significant hydrological information including aquifer transmissivities rates, potential groundwater pumping rates and recharge mechanisms. The following tables provide a summary of these borehole locations, prognosed stratigraphy, interpreted stratigraphy, aquifer depths and field water measurements.

SITE	R.N.	LAT/ LONG	TD (m)	S.W.L. (m)	W/Q CONDUCTIVITY µscm ⁻¹	FORMATIONS ENCOUNTERED (* DENOTES AQUIFER)
Strathmay	9200 0001	14°52'04" 142°44'43"	327.2	- 5.80	950	Wyaaba/Bulimba Fm* Rolling Downs Group
Holroyd	9210 0001	14°21'46' 142°29'57	331.5	- 4.21	80	Wyaaba/Bulimba Fm* Rolling Downs Group
Batavia	9250 9002	12°39'48' 142°40'08'	291.2	- 10.47	847	Bulimba Fm Rolling Downs Group Gilbert River Fm* Garraway Beds
Heathlands	9260 0002	11°45'10' 142°34'54'	101.0	- 30.45	158	Helby Beds*
Weipa x Road	9250 0005	13°04'25' 142°45'57'	212.0	- 42.50	3940	Rolling Downs Group Gilbert River Fm* Granite Basement
Wolverton 1 (Homestead)	9230 0002	13°11'05" 142°56'58"	68.0	- 13,00	710	Colluvium Gilbert River Fm* Setton Metamorphics
Welverton 2 (Fox Creek)	9230 0003	13°10'31' 142°56'18'	56.0			Colluvium Gilbert River Fm* Metamorphics?
Wenlock River	9250 0003	12°38'46" 142°47'38"	120.6	+ 14.00	213	Bulimba Fm Gilbert River Fm
Embley Range	9250 0004	12°42'17' 142°35'12'	33.0	Dry		Bulimba Fm Rolling Downs Group

TD = Total Depth RN = Registered Number

Table A - Initial Field Tests - CYPLUS Funded Boreholes

SITE	RM	LAT/ LONG	T/D (m)	S.W.L. (m)	W/Q CONDUCTIVITY pscm ²	FORMATIONS ENCOUNTERED (* DENOTES AQUIFER)
Edward River 1	9201 0001	14°54°14° 141°36′43°	70.0	- 1.00	1560	Wyaaba Bods *
Edward River 2	9201 0002	14°53'43" 141°37'39"	70.1	- 1.00	1400	Wyaaba Beds*
Strathgordon	78 390	14°47`45` 142°25`57`	71.5	- 4.00	1600	Bulimba Fm*

Table B - Initial Field Tests - Other Bores Constructed During CYPLUS Program

BORE NAME RN NUMBER LAT/LNG	STRATIGRAPHIC SUB-DIVISION	FORMATION TEMPERATURE	AQUIFERS (m)	CASING DETAILS
Strathmay 9200 0001	0 - 0.3 Losm 0.3 m - 88 m Bulimba Formation 88 m 327.2 m Rolling Downs Group		64 - 71	125 mm 75.5 m 127 mm Slots;
14°52'04′ 142°44'43′				63-75 m
Holroyd 9210 0001 14°21'46' 142°29'57'	0 - 1 m soil/loam 1 - 5 m Ferruginized Bulimba Formation 5 - 49 m Bulimba Formation 49 - 331.5 m Rolling Downs Group		6 - 12, 25 - 26, 27 - 33, 41 - 42, 43 - 47	125 mm 48.5 m 125 mm Slots, 28 - 34 m, 42 - 48 m
Batavia Downs Homestead 9250 0002 12°39°48' 142°40'08'	+ R.L. 0 - 2 m Ferruginous soil/ Ferricrete 2 - 7 m Leached zone 7 - 153 m Rolling Downs Group 153 - 183 m Transitional Gilbert River Fm 183 - 274 m Fluvistile Gilbert River Fm 274 - 291 m Garraway Bods	4)°C	183 - 192, 196 - 198, 205 - 209, 224 - 231, 248 - 261, 276 - 286, 286 - 288	125 mm 185.2 m
Embley Range 92500 0004 12'42'17' 142'35'12'	0 - 4 m Ferruginized Lateritic Profile 4 - 25 m Bulimba Formation 25 - 33 m Rolling Downs Group			
Wenlook River 9250 0003 12*38'46' 142*47'38'	0 - 1 m soil/loam 1 - 17 m Bulimba Formation 17 - 120.6 m Fluviatic Gilbert River Fm	32°C	8 - 9, 9 - 17, 39 - 40, 111 - 112, 116 - 117, 117 - 120-6	125 mm Surface - 117
Heathlands 9260 0002 11°45°10° 142°34'54°	0 - 5 m Ferricrete, Ferruginous soil and Ferruginous sandstone 5 - 23 m Mottled weathering zone: - mottled clays, sandstone leached in part, ferruginized in part. 23 - 101 m Helby Beds	29°C	48 - 50, 64 - 66, 90 - 92	51 mm Surface - . 44.5 m
Weipa Cross Roads 9250 0005 13°04'25' 142°45'57'	0 - 1 Ferricrete, Ferruginized soil 1 - 6 m Alluvium 6 - 141 Rolling Downs Group 141 - 209 m Gilbert River Fm 209 - 212 m Transitional 212 - 213 m Quertize		161 - 164, 167 - 174, 192 - 193 194 - 195	51 mm Surface - T.D. (180 m)
Wolverton i (Homestead) 9230 0002 13°11'05' 142°56'58'	0 - 2 m Ferricrete & Ferruginous soil 2 - 7 m Weathered, ferruginous zone 7 - 15 m Leached zone 15 - 49 m Colluvium 49 - 56 m Gilbert River Fm 56 - 64 m Transitional Githert River Fm/ Sefton Metamorphics 64 - 69 m Sefton Metamorphics (Chlorite - muscovite schist)	30°C	54 - 55	125 mm Surface - 34 m

BÖRE NAME RN NUMBER LAT/LNG	STRATIGRAPHIC SUB-DIVISION	FORMATION TEMPERATURE	AQUIFERS (m)	CASING DETAILS
Wolverion 2 9230 0003 13°10°31° 142°56'18°	0 - 1 m Ferruginous soil/laterite 1 - 9 m Colluvium; Ferruginized in part, motiled 9 - 45 m Fluviatile Gilbert River Foundation 45 - 49 m Transitional Gilbert River Fm/ Seiton Metamorphic 49 - 56 m Seiton Metamorphic muscovite phyllite 88 m 327.2 m Rolling Downs Group			51 mm Surface - 56 m
Strathgordon Homestead 78390 14047*45* 142*25*57*	0 - 7 m Unconsolidated sand/clay 7 - 75 m Wysaba Bods/?Bulimba Formation		69.2 - 70 ш	125 mm Surface - 0 - 71.5 m 3 mm Slots:- 66.5 - 71.5 m
Edward River 1 9201 0001 14°54'14' 141°36'43'	0 - 8 m Unconsolidated sand/ clay/shell grit 8 - 70 m Wyasha Beds		49.7 - 64.2 m	51 mm Surface - 0 - 71 m 3 mm Slots:- 52 - 58 m 64 - 70 m
Edward River 2 9201 0002 14053'43' 141*37'39'	0 - 1 m Unconsolidated sand 1 - 70 m Wyasba Beds		46.2 - 55 m 60.9 - 65 m	51 mm Surface - 0 - 71 m 3 mm Slots:- 58 - 70 m
Olive Vale Station 78220 15*22'25' 144*23'05'	• G.H. 0 - 15 m Tertiary 15 - 219 m Rolling Downs Group 219 - 260 m Battle Camp Fm	42°C	220 - 255 m	219 mm Surface - 0 - 89 m 127 m Surface - 0 - 260 m Slots:- 224 - 257 m

APPENDIX 2 - Summary of Water Type Occurrence

The following abbreviations have been used in the accompanying table.

Aquifer Types:

a - Alluvial

b - Bulimba Formation

b/w - Bulimba Formation/Wyaaba Beds

ga - Garraway Beds

gr - Gilbert River Formation

gr/d - Gilbert River Formation/Dalrymple Sandstone (Laura Basin)

h - Helby Beds i - Igneous

m - Metamorphics

rd - Rolling Downs Group

Water Type characteristics have been summarised in Table 4.4 and 4.5.

151.

APPENDIX 2 - Summary of Water Type Occurrence

RN BORE NUMBER	LATITUDE	LONGITUDE	TECTONIC BASIN	AQUIFER	WATER TYPE (supergroup)
13479A	-12.717	141.931	Carpentaria	ga	В
13479A	-12,717	141.931	Carpentaria	ga	В
13479A	-12.717	141.931	Carpentaria	ga	В
33558A	-15.386	142.108	Karumba	b/w	В
33565A	-15.628	142.694	Karumba	b/w	В
35610A	-12.665	141.871	Carpentaria	gr	В
35611A	-12.663	141.899	Carpentaria	gr	В
35612A	-12.667	141.928	Carpentaria	gr	В
35613A	-12,542	141.830	Carpentaria	gr	В
37199A	-13.008	141.842	Karumba	b/w	A
37235A	-15.825	142.013	Karumba	b/w	В
37291A	-13.026		Carpentaria	gr	В
37291A	-13.026	141.787	Carpentaria	gr	В
37291A	-13.026	141.787	Carpentaria	gr	В
37291A	-13.026	141.787	Carpentaria	gr	В
37291A	-13.026	141.787	Carpentaria	gr	В
37291A	-13.026	141.787	Carpentaria	gr	B
37386A	-12.664		Karumba	b/w	F
37405A	-12.637	141.879	Karumba	b/w	В
37630A	-13.034		Carpentaria	rd	В
38303A	-15.924		Karumba	b/w	A
38303A	-15.924	141.598	Karumba	b/w	A
38303A	-15.924		Karumba	b/w	A
38304A	-15.632		Karumba	b/w	A
38304A	-15.632	141.526	Karumba	b/w	Α
38304A	-15.632	141.526	Karumba	b/w	Α
38304A	-15.632	141.526	Karumba	b/w	A
38305A	-16,117	141.495	Karumba	b/w	Α
38305A	-16.117	141.495	Karumba	b/w	Α
38306A	-16.238	141,419	Karumba	b/w	A
38306A	-16.238	141.419	Karumba	b/w	Α
38306A	-16.238	141.419	Karumba	b/w	A
38307A	-15.923	141.479	Karumba	b/w	A
38307A	-15.923	141,479	Karumba	b/w	В
38307A	-15.923	141.479	Karumba	b/w	F
38307A	-15.923	141.479	Karumba	b/w	F
38307A	-15.923	141,479	Karumba	b/w	В
38307A	-15.923	141.479	Karumba	b/w	В
38308A	-16.286	141.452	Karumba	b/w	Ā
38308A	-16.286	141.452	Karumba	b/w	A
38308A	-16.286	141.452	Karumba	b/w	A

RN BORE NUMBER	LATITUDE	LONGITUDE	TECTONIC BASIN	AQUIFER	WATER TYPE (supergroup)
38308A	-16.286	141.452	Karumba	b/w	A
38472A	-15.581	141.733	Karumba	b/w	Α
38472A	-15.581	141.733	Karumba	b/w	A
38472A	-15.581	141.733	Karumba	b/w	Α
38473A	-15.753	141.464	Karumba	b/w	В
38473A	-15.753	141.464	Karumba	b/w	В
38474A	-15.725	141.483	Karumba	b/w	В
38475A	-15.601	141.560	Karumba	b/w	Α
38475A	-15.601	141.560	Karumba	b/w	A
38475A	-15.601	141.560	Karumba	b/w	A
38475A	-15.601	141.560	Karumba	b/w	A
38475A	-15.601	141.560	Karumba	b/w	Α
38821A	-15.785	141.805	Karumba	b/w	A
38821A	-15.785	141.805	Karumba	b/w	Α
38821A	-15.785	141.805	Karumba	b/w	A
38821A	-15.785	141.805	Karumba	b/w	Α
38821A	-15.785	141.805	Karumba	b/w	Α
38821A	-15.785	141.805	Karumba	b/w	A
38822A	-15.763	141.703	Karumba	b/w	Α
38822A	-15.763	141,703	Karumba	b/w	A
38822A	-15.763	141.703	Karumba	b/w	Α
38822A	-15.763	141.703	Karumba	b/w	A
38922A	-15.644	141.527	Karumba	b/w	Α
38922A	-15.644	141.527	Karumba	b/w	A
38922A	-15.644	141.527	Karumba	b/w	Α
38922A	-15.644	141.527	Karumba	b/w	A
44762A	-15.554	144.447	Laura	rd	Α
45010A	-14.903	141.621	Karumba	b/w	Α
45010A	-14.903	141.621	Karumba	b/w	A
45010A	-14.903	141.621	Karumba	b/w	Α
45010A	-14.903	141.621	Karumba	b/w	A
45010A	-14.903	141.621	Karumba	b/w	A
45010A	-14.903	141.621	Karumba	b/w	Α
45010A	-14.903	141.621	Karumba	b/w	A
45010A	-14.903	141.621	Karumba	b/w	A
45010A	-14.903	141.621	Karumba	b/w	A
45010A	-14.903	141.621	Karumba	b/w	Α
45010A	-14.903	141.621	Karumba	b/w	Α
45010A	-14.903	141.621	Karumba	b/w	Α
45010A	-14.903	141.621	Karumba	b/w	Α
45010A	-14,903	141.621	Karumba	b/w	Α

RN BORE NUMBER	LATITUDE	LONGITUDE	TECTONIC BASIN	AQUIFER	WATER TYPE (supergroup)
45011A	-14,903	141.621	Karumba	b/w	B
45011A	-14.903	141.621	Karumba	b/w	E
45011A	-14.903	141.621	Karumba	b/w	E
45011A	-14.903	141.621	Karumba	b/w	A
45011A	-14.903	141.621	Karumba	b/w	A
45011A	-14.903	141.621	Karumba	b/w	Α
45019A	-15.474	141.742	Carpentaria	rd	F
45019A	-15,474	141,742	Carpentaria	rd	Α
45019A	-15.474	141.742	Carpentaria	rd	A
45019A	-15.474	141,742	Carpentaria	rd	A
45019A	-15.474	141.742	Karumba	b/w	A
45020A	-15.475	141.735	Karumba	b/w	A
45020A	-15.475	141.735	Karumba	b/w	A
45020A	-15.475	141.735	Karumba	b/w	A
45020A	-15.475	141.735	Karumba	b/w	A
45020A	-15.475	141.735	Karumba	b/w	A
45020A	-15.475	141.735	Karumba	b/w	A
45057A	-15.561	144,447	Laura	rd	В
45068A	-15.168	141.813	Karumba	b/w	В
45068A	-15.168	141.813	Karumba	b/w	В
45068A	-15.168	141.813	Karumba	b/w	В
45068A	-15.1 6 8	141.813	Karumba	b/w	B
45068A	-15.168	141.813	Karumba	b/w	В
45070A	-12.686	141.885	Karumba	b/w	F
45070A	-12.686	141.885	Karumba	b/w	В
45070A	-12.686	141.885	Karumba	b/w	В
45071A	-12.676	141,886	Karumba	b/w	В
45071A	-12.676	141.886	Karumba	b/w	В
45071A	-12,676	141.886	Karumba	b/w	В
45075A	-15.295	145.100	Laura	gτ/d	D
45080A	-15.296	145.095	Laura	Ъ	D
45080A	-15.296	145.095	Laura	Ъ	В
45080A	-15.296	145.095	Laura	b	D
45080A	-15.296	145.095	Laura	ь	D
45083A	-15.439	145.136	Hodgkinson	m	F
45084A	-15.478	145.224	Hodgkinson	m	F
45084A	-15.478	145,224	Hodgkinson	m	В
45085A	-15.428	145.138	Hodgkinson	b	F
45115A	-14.897	141.610	Karumba	b/w	A
45115A	-14.897	141.610	Karumba	b/w	Α

RN BORE NUMBER	LATITUDE	LONGITUDE	TECTONIC BASIN	AQUIFER	WATER TYPE (supergroup)
45115A	-14.897	141.610	Karumba	b/w	A
45115A	-14.897	141.610	Karumba	b/w	Α
45115A	-14.897	141.610	Karumba	b/w	A
45115A	-14.897	141.610	Karumba	b/w	Α
45115A	-14.897	141.610	Karumba	b/w	Α
45119A	-13.344	141.729	Karumba	b/w	В
45119A	-13.344	141.729	Karumba	b/w	F
45119A	-13.344	141.729	Karumba	b/w	В
45191A	-15.487	145.246	Hodgkinson	ì	G
45191A	-15.487	145.246	Hodgkinson	i	В
45191A	-15.487	145.246	Hodgkinson	i	F
45191A	-15.487	145.246	Hodgkinson	i	F
45191B	-15.487	145.246	Hodgkinson	i	F
45191A	-15.487	145.246	Hodgkinson	i	F
45192A	-15.485	145.242	Hodgkinson	m	F
45193A	-15.480	145.237	Hodgkinson	i	В
45195A	-15,487	145.246	Hodgkinson	m ·	F
45195A	-15,487	145.246	Hodgkinson	m	F
45195A	-15.487	145.246	Hodgkinson	m	F
45195A	-15.487	145.246	Hodgkinson	III.	F
45195A	-15.487	145.246	Hodgkinson	m	F
45196A	-15.476	145.224	Hodgkinson	m	F
45198A	-15.476	145,222	Hodgkinson	m	F
45198A	-15.476	145.222	Hodgkinson	m	F
45198A	-15.476	145.222	Hodgkinson	m	F
45198A	-15.476	145.222	Hodgkinson	m	F
45216A	-14.806	144.399	Laura	gr/d	Α
45219A	-14.413	144.208	Laura	gr/d	Α
45219A	-14.413	144.208	Laura	gr/d	В
45221A	-14.540	144.311	Laura	gr/d	A
45221A	-14.540	144.311	Laura	gr/d	Α
45222A	-14.458	144.229	Laura	gr/d	Α
45222A	-14.458	144.229	Laura	gr/d	A
45223A	-14.533	144.214	Laura	gr/d	A
45223A	-14.533	144,214	Laura	gr/đ	Α
45223A	-14.533	144.214	Laura	gr/d	Α
45223A	-14.533	144.214	Laura	gr/d	A
45223A	-14.533	144.214	Laura	gr/đ	Α
45224A	-14.430	144.237	Laura	gr/đ	A
45224A	-14.430	144.237	Laura	gr/d	Α

RN BORE NUMBER	LATITUDE	LONGITUDE	TECTONIC BASIN	AQUIFER	WATER TYPE (supergroup)
45224A	-14.430	144.237	Laura	gr/d	В
45224A	-14.430	144.237	Laura	gr/d	В
45256A	-12.567	141.816	Karumba	b/w	F
45274A	-14.904	141.625	Karumba	b/w	A
45274A	-14.904	141.625	Karumba	b/w	В
45274A	-14.904	141.625	Karumba	b/w	A
45274A	-14.904	141.625	Karumba	b/w	A
45299B	-15.921	145.339	Hodgkinson	a	В
45299A	-15.921	145.339	Hodgkinson	а	В
45299A	-15.921	145.339	Hodgkinson	a	В
45334A	-12.464	141.996	Karumba	b/w	Α
45358A	-14.547	143.711	Laura	gr/d	A
45358A	-14.547	143.711	Laura	gr/d	Α
45358A	-14.547	143.711	Laura	gr/đ	Α
45359A	-14,367	143.650	Laura	gr/d	В
45443A	-15.427	141.579	Karumba	b/w	В
45443A	-15.427	141.579	Karumba	\mathbf{b}/\mathbf{w}	A
45443A	-15.427	141.579	Kanumba	b/w	A
45444A	-15.495	141.591	Karumba	b/w	A
45444A	-15.495	141.591	Karumba	b/w	Α
45444A	-15.495	141.591	Karomba	b/w	Α
45444A	-15.495	141.591	Karumba	b/w	A
45445A	-15.367	141.650	Karumba	b/w	A
45445A	-15.367	141.6 5 0	Karumba	b/w	Α
45445A	-15.367	141.650	Karumba	b/w	Α
45445A	-15.367	141.650	Karumba	b/w	A
45446A	-15.494	141.615	Karumba	b/w	Α
45446A	-15.494	141.615	Karumba	b/w	Α
45446A	-15,494	141.615	Karumba	b/w	Α
45446A	-15.494	141.615	Karumba	b/w	Α
45451A	-15.550	141.735	Karumba	b/w	A
45451A	-15.550	141.735	Karumba	b/w	Α
45465A	-12.788	143.344	Coen	i	F
45466A	-12.789	143.341	Coen	i	F
45466A	-12.789	143.341	Coen	ì	F
45472A	-15.265	144.784	Laura	gr/d	A
45473A	-15.283	144.699	Laura	gr/d	В
45490A	-15.479	145.207	Hodgkinson	m	В
45490B	-15.479	145.207	Hodgkinson	m.	F
45490B	-15.479	145.207	Hodgkinson	m	F

RN BORE NUMBER	LATITUDE	LONGITUDE	TECTONIC BASIN	AQUIFER	WATER TYPE (supergroup)
45490A	-15.479	145.207	Hodgkinson	m	В
45490A	-15.479	145.207	Hodgkinson	m	В
45490B	-15.479	145.207	Hodgkinson	m	F
45490A	-15.479	145.207	Hodgkinson	m	В
45496A	-15.479	145.226	Hodgkinson	រា	F
45498A	-15.483	145.208	Hodgkinson	ក្លា	F
45498A	-15.483	145.208	Hodgkinson	m:	F
45498A	-15.483	145.208	Hodgkinson	m	F
45498A	-15.483	145,208	Hodgkinson	m	F
45498A	-15.483	145.208	Hodgkinson	m	F
45498A	-15.483	145.208	Hodgkinson	III	F
45499A	-15.483	145.211	Hodgkinson	m	В
45500A	-15.485	145.213	Hodgkinson	m	F
45500A	-15.485	145.213	Hodgkinson	m	F
45500A	-15.485	145.213	Hodgkinson	m	F
45500A	-15.485	145.213	Hodgkinson	m	F
45501A	-15.492	145.210	Hodgkinson	m	F
45501A	-15.492	145.210	Hodgkinson	m	F
45501A	-15.492	145.210	Hodgkinson	m	F
45501A	-15.492	145.210	Hodgkinson	m	F
45501A	-15.492	145.210	Hodgkinson	m	F
45501A	-15.492	145.210	Hodgkinson	m	F
45555A	-13,344	141.729	Karumba	b/w	В
45555A	-13.344	141.729	Karumba	b/w	В
45556A	-13,344	141.729	Karumba	b/w	В
45556A	-13.344	141.729	Karumba	b/w	В
45557A	-13.344	141.729	Karumba	b/w	В
45557A	-13.344	141.729	Karumba	b/w	В
45560A	-13.344	141.729	Karumba	b/w	F
45599A	-14.517	141.607	Karumba	b/w	A
45599A	-14.517	141.607	Karumba	b/w	Α
45599A	-14.517	141.607	Karumba	b/w	A
45599A	-14.517	141,607	Karumba	b/w	A
45599A	-14.517	141.607	Karumba	b/w	A
45601A	-14.687	141.618	Karumba	b/w	В
45601A	-14.687	141.618	Karumba	b/w	В
45601A	-14.687	141.618	Karumba	b/w	В
45601A	-14.687	141.618	Karumba	b/w	В
45602A	-15,117	141.775	Karumba	b/w	В
45602A	-15.117	141.775	Karumba	b/w	В

RN BORE NUMBER	LATITUDE	LONGITUDE	TECTONIC BASIN	AQUIFER	WATER TYPE (supergroup)
45602A	-15.117	141,775	Karumba	b/w	В
45602A	-15.117	141.775	Karumba	b/w	В
45632A	-15.833	142.026	Karumba	b/w	В
45632A	-15.833	142.026	Karumba	b/w	В
45632A	-15.833	142.026	Karumba	b/w	В
45633A	-15.902	142.166	Karumba	b/w	В
45633A	-15.902	142.166	Karumba	b/w	В
45634A	-15.772	141.958	Karumba	b/w	В
45634A	-15.772	141.958	Karumba	b/w	Α
45657A	-15.448	141.600	Karumba	b/w	В
45657A	-15.448	141.600	Karumba	b/w	Α
45657A	-15.448	141.600	Karumba	b/w	\mathbf{A}
45657A	-15,448	141.600	Karumba	b/w	В
45657A	-15.448	141.600	Karumba	b/w	A
45657A	-15.448	141.600	Karumba	b/w	В
45657A	-15.448	141.600	Karumba	b/w	В
45657A	-15.448	141.600	Karumba	\mathbf{b}/\mathbf{w}	В
45658A	-15.538	141.844	Karumba	b/w	В
45658A	-15.538	141.844	Karumba	b/w	В
45658A	-15.538	141.844	Karumba	b/w	В
45666A	-15.297	145.094	Laura	gr/d	D
45666A	-15.297	145.094	Laura	gr/d	D
45666A	-15.297	145.094	Laura	gr/d	D
45666A	-15.297	145.094	Laura	gr/d	D
45669A	-15.287	145.096	Laura	b	D
45669A	-15.287	145.096	Laura	ь	D
45670A	-15.291	145.096	Laura	gr/d	D
45672A	-15.289	145.096	Laura	а	D
45701A	-15.482	145.209	Hodgkinson	a	F
45922A	-16,201	141.493	Karumba	b/w	Α
45922A	-16.201	141.493	Karumba	b/w	F
45923A	-16.172	141.659	Karumba	b/w	A
45924A	-16.255	141.655	Karumba	b/w	A
45925A	-16.316	141.409	Karumba	b/w	A
45925A	-16.316	141.409	Karumba	b/w	A
45940A	-15.491	145.216	Hodgkinson	m	F
45941A	-15.486	145.219	Hodgkinson	៣	F
45941A	-15.486	145.219	Hodgkinson	m	F
45941A	-15.486	145.219	Hodgkinson	m	F
45941A	-15.486	145.219	Hodgkinson	m	F

RN BORE NUMBER	LATITUDE	LONGITUDE	TECTONIC BASIN	AQUIFER	WATER TYPE (supergroup)
45942A	-15.491	145,213	Hodgkinson	m	F
45943B	-15,483	145.208	Hodgkinson	m	В
45943A	-15.483	145.208	Hodgkinson	m	F
45943A	-15.483	145.208	Hodgkinson	m	В
45944A	-15.481	145.207	Hodgkinson	m	В
45944C	-15.481	145.207	Hodgkinson	m	G
45944B	-15.481	145.207	Hodgkinson	m	G
45944 B	-15.481	145.207	Hodgkinson	m	В
45944A	-15.481	145.207	Hodgkinson	m	В
45945A	-15.479	145.205	Hodgkinson	a	F
45948A	-15.484	145.218	Hodgkinson	m	F
45948A	-15.484	145.218	Hodgkinson	m	F
72033A	-14.444	144.265	Laura	gr/d	A
72033A	-14,444	144.265	Laura	gr/d	D
72034A	-14.574	144,199	Laura	gr/d	Α
72034A	-14.574	144.199	Laura	gr/d	Α
72034A	-14.574	144.199	Laura	gr/d	Α
72034A	-14.574	144.199	Laura	gr/đ	Α
72034A	-14.574	144,199	Laura	gr/d	A
72035A	-14.636	144.267	Laura	gr/d	Α
72035A	-14.636	144.267	Laura	gr/d	Α
72035A	-14.636	144.267	Laura	gr/d	Α
72035A	-14.636	144.267	Laura	gr/d	Α
72036A	-14.792	144.269	Laura	gr/d	D
72036A	-14.792	144.269	Laura	gr/d	Α
72037A	-14.612	144.238	Laura	gr/d	А
72037A	-14.612	144.238	Laura	gr/d	Α
72151A	-12.054	141.909	Karumba	b/w	F
72171A	-13,944	143,193	Coen	នា	В
72172A	-13.949	143.197	Coen	នា	F
72173A	-15.861	144.850	Hodgkinson	m	F
72188A	-15.481	145.233	Hodgkinson	m	B
72194A	-16,173	141.391	Karumba	b/w	A
72194A	-16.173	141.391	Karumba	b/w	Α
72195A	-16.127	141.477	Karumba	b/w	A
72239A	-15.708	143.537	Karumba	Ī	Α
72240A	-15.648	143.662	Yambo	i	Α
72241A	-15.653	143.623	Yambo	i	В
72242A	-15.662	143.589	Yambo	a	A
72244A	-15.689	143.560	Yambo	a	Α

RN BORE NUMBER	LATITUDE	LONGITUDE	TECTONIC BASIN	AQUIFER	WATER TYPE (supergroup)
72246A	-15.537	143.406	Coen	m	D
72247A	-15.513	143.368	Kanımba	a	Α
72262A	-12.788	142.406	Carpentaria	ga	В
72262A	-12.788	142.406	Carpentaria	ga	В
72262A	-12,788	142.406	Сатрептатіа	ga	В
72262A	-12.788	142.406	Carpentaria	ga	В
72262A	-12.788	142.406	Carpentaria	ga	В
72273A	-15.094	143.344	Coen	m	D
72274A	-15.116	143.308	Coen	m	D
72275A	-15.660	141.855	Carpentaria	gr	Α
72275A	-15.660	141.855	Carpentaria	gr	Α
72275A	-15.660	141.855	Karumba	b/w	Α
72275A	-15.660	141.855	Karumba	b/w	Α
72339A	-15.281	145.096	Laura	b	В
72341A	-15.281	145.100	Laura	b	Α
72341A	-15.281	145.100	Laura	b	D
72341A	-15.281	145.100	Laura	b	D
72341A	-15.281	145.100	Laura	ь	D
72341A	-15.281	145.100	Laura	b	Ð
72342A	-15.285	145.096	Laura	b	D
72342A	-15.285	145.096	Laura	ь	D
72342A	-15.285	145.096	Laura	b	D
72 344 A	-15.291	145.110	Laura	b	A
72 344A	-15.291	145.110	Laura	b	Α
72344A	-15.291	145.110	Laura	Ъ	A
72361A	-12.788	143.308	Coen	m	В
72421A	-12.092	142.558	Carpentaria	gr	F
72449A	-15.429	145,136	Hodgkinson	m	Α
72571A	-15.091	141.728	Kanımba	b/w	В
72571X	-15.091	141.728	Karumba	b/w	В
72571X	-15.091	141.728	Karumba	b/w	В
72643A	-15.533	144.439	Laura	gr/d	A
72643A	-15.533	144.439	Laura	gr/d	A ·-
72763A	-13.764	143.111	Coen	i	В
72763A	-13.764	143.111	Coen	i	В
72778A	-15.190	143.872	Laura	gr/d	Ā
72782A	-12.194	142.889	Carpentaria	ga	В
72783A	-12.261	142.928	Carpentaria	ga	F

RN BORE NUMBER	LATITUDE	LONGITUDE	TECTONIC BASIN	AQUIFER	WATER TYPE (supergroup)
72789A	-11.975	142,969	Carpentaria	h	В
72790A	-11.957	142.883	Carpentaria	h	₿
72791A	-11.994	142.872	Carpentaria	h	В
72853A	-15.351	145.032	Laura	gr/d	D
72853X	-15.351	145.032	Laura	gr/d	D
72860A	-15.479	145.257	Hodgkinson	i	В
72880A	-12.142	142.625	Carpentaria	rd	В
72881A	-12.030	141.899	Karumba	b/w	В
72881A	-12.030	141.899	Karumba	b/w	В
78180A	-13.058	142.478	Carpentaria	rd	В
78220A	-15.374	144.385	Laura	gr/d	Α
78221A	-15,354	144.219	Laura	rd	В
78284A	-12.790	143.347	Coen	i	F
78285A	-12.790	143.349	Coen	i	F
78390A	-14.796	142.433	Karumba	b/w	В
78390A	-14.796	142.433	Karumba	b/w	В
78390A	-14.796	142.433	Karumba	b/w	В
78390A	-14.796	142.433	Karumba	b/w	В
78422A	-15,297	143.977	Laura	gr/d	A
78422A	-15.297	143.977	Laura	gr/d	, A
78452A	-14. 46 6	144.273	Laura	gr/d	Α
78457A	-14.470	144.267	Laura	gr/d	Α
78464A	-15.448	144.017	Laura	gr/d	D
78464A	-15.448	144.017	Laura	gr/d	D
78475A	-15.180	143.781	Laura	gr/d	A
78476A	-15.214	143.763	Laura	gr/d	Α
78477A	-15.208	143.828	Laura	gr/d	A
78482A	-15.469	143.465	Coen	i	D
78483A	-15,427	143,492	Coen	i	F
78484A	-15.431	143.493	Coen	i	D
78488A	-15.379	143.467	Coen	i	D
78489A	-15.327	143.448	Coen	i	F
78490A	-15.156	143.187	Coen	m	Ð
78491A	-15.159	143.273	Coen	m	D
78492A	-15.071	143.398	Coen	m	F
78493A	-13.957	143.191	Coen	m	F
78496A	-12.770	143.287	Coen	b	F
78500A	-12.770	143.289	Coen	b	F
78651A	-14.519	144.224	Laura	gr/d	Α
78651A	-14.519	144.224	Laura	gr/d	Α
78656A	-14.609	144.321	Laura	gr/d	Α

RN BORE NUMBER	LATITUDE	LONGITUDE	TECTONIC BASIN	AQUIFER	WATER TYPE (supergroup)
78658A	-14.574	144.262	Laura	gr/d	A
78658A	-14,574	144.262	Laura	gr/d	A
78661A	-14.450	144,272	Laura	rd	В
78666A	-12.663	142.675	Carpentaria	gr	В
78667A	-12.778	143.306	Coen	m	В
78678A	-15.248	143.724	Laura	gr/d	В
78681A	-15.267	143.696	Laura	gr/d	C
78683A	-15.236	143.738	Laura	gr/d	Α
78684A	-15,260	143.711	Laura	gr/d	C
78685A	-15.191	143.712	Laura	gr/d	B
78689A	-15.184	143,804	Laura	gr/d	D
78690A	-15.285	143,736	Laura	gr/d	В
78691A	-15.143	143.726	Laura	gr/d	A
78691A	-15.143		Laura	gr/d	Α
78692A	-15,201	143.854	Laura	gr/d	Α
78692A	-15.201	143.854	Laura	gr/d	Α
78692A	-15.201	143.854	Laura	gr/d	В
78693A	-15.214		Laura	gr/d	В
78694A	-15.318		Laura	gr/d	A
78806A	-14.895		Hodgkinson	a	F
78807A	-14.826		Hodgkinson	a	В
78808A	-14.753	144.834	Hodgkinson	a	Α
78836A	-14.502		Laura	gr/d	D
78839A	-14.403		Laura	gr/d	В
78850A	-14.418		Laura	gr/d	D
78862A	-12.651	142.092	Karumba	b/w	В
78864X	-12.650	142.089	Karumba	b/w	В
78921A	-14.655	144,223	Laura	gr/d	Α
92114A	-16.283	141.450	Karumba	b/w	В
92114A	-16.283		Karumba	b/w	В
92125A	-13.667		Carpentaria	rd	A
92000001A			Karumba	b/w	В
92000001A	•		Karumba	b/w	В
92010001A			Karumba	b/w	B
92010001A			Karumba	b/w	A
92100001A			Karumba	b/w	A
92300002A			Karumba	b/w	A
92300002A			Karumba	b/w	В
92300002A			Karumba	b/w	В
92300002F			Karumba	b/w	A

RN BORE NUMBER	LATITUDE	LONGITUDE	TECTONIC BASIN	AQUIFER	WATER TYPE (supergroup)
92400001A	-12.746	141.885	Karumba	b/w	В
92400002A	-12.743	141.884	Karumba	b/w	В
92400003A	-12.739	141.884	Karumba	b/w	Α
92400005A	-12.746	141.880	Karumba	b/w	F
92400006A	-12.743	141.880	Karumba	b/w	F
92400008A	-12.739	141.880	Karumba	b/w	В
92400009A	-12.735	141.880	Karumba	b/w	В
92400010A	-12.735	141.880	Karumba	b/w	F
92400011A	-12,746	141.877	Karumba	b/w	F
92400014A	-12,735	141.876	Karumba	b/w	В
92400017A	-12.739	141.873	Karumba	b/w	В
92400018A	-12.736	141.873	Karumba	b/w	F
92400019A	-12,747	141.868	Karumba	b/w	В
92400021A	-12.740	141.869	Karumba	b/w	В
92400023A	-12.748	141.865	Karumba	b/w	В
92400025A	-12.744	141.865	Karumba	b/w	В
92400026A	-12.740	141.865	Karumba	b/w	В
92400027A	-12.740	141.865	Karumba	b/w	В
92400028A	-12.736	141.865	Karomba	b/w	В
92400030A	-12,747	141.873	Karumba	b/w	F
92500001X	-12.661	142.913	Carpentaria	gr	B
92500001X	-12.661	142.913	Carpentaria	gr	В
92500002A	-12.663	142,669	Carpentaria	gr	В
92500002A	-12.663	142.669	Carpentaria	gr	В
92500003A		142,794	Carpentaria	gr	A
92500003A			Carpentaria	gr	Α
92500003A	-12.646	142.794	Carpentaria	gr	Α
92500003A	-12.646	142.794	Carpentaria	gr	Α
92500003A			Carpentaria	gr	Α
92500005A	-13.074	142,766	Carpentaria	gr	F
92500005A	-13,074	142,766	Carpentaria	gr	F
92500005A			Carpentaria	gr	В
92600001X	-11.822	142.516	Carpentaria	h	В
92600002A			Carpentaria	h	Α
92600002A			Carpentaria	h	Α
92700001X			Carpentaria	h	F

APPENDIX 3

CAPE YORK PENINSULA GROUNDWATER INVESTIGATION

M.A. Habermehl

Australian Geological Survey Organisation

Canberra, A.C.T.

1.0 INTRODUCTION

The Cape York Peninsula Land Use Strategy - Natural Resources Analysis Program (CYPLUS - NRAP) Cape York Peninsula Groundwater Investigation Project NR16 was jointly carried out by the Queensland Department of Primary Industries - Water Resources and the Australian Geological Survey Organisation - Environmental Geoscience and Groundwater Division.

The Queensland Department of Primary Industries - Water Resources (QDPI-WR) and the Australian Geological Survey Organisation (AGSO) collected, compiled, analysed, interpreted and synthesised, existing hydrogeological data, data from water bores, from petroleum and mineral exploration drill-holes and other previous investigations, and stored the data in the QDPI-WR Groundwater Database system and the CYPLUS-GIS. The geological and hydrogeological data have been analysed to determine the aquifer geometry and characteristics, the groundwater hydrodynamics and the recharge and discharge relationships of the groundwater system.

The hydrochemical and isotope hydrology studies of the groundwater system carried out by AGSO provide an overview of the quality of the groundwater, its origin and movement, and complement the investigation of the extent and quantity of the groundwater resources of Cape York Peninsula.

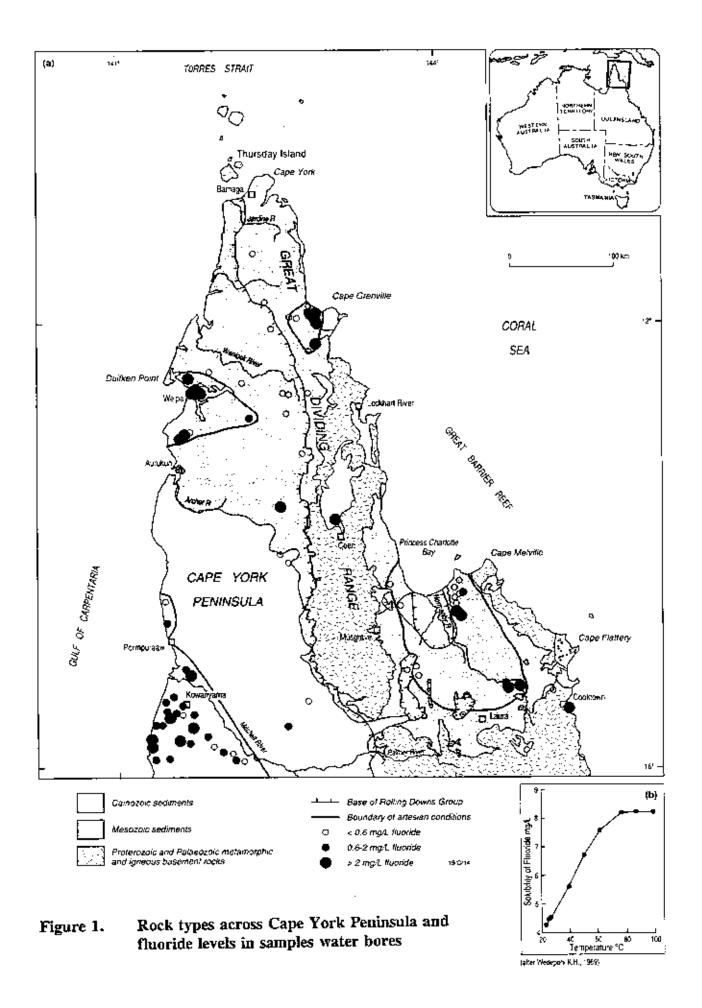
The Cape York Peninsula region contains identified groundwater resources, some of which are developed, though the understanding of the groundwater resources prior to this investigation was poor.

Groundwater is an important source for the supply of domestic, town, industrial, pastoral and agricultural water. Groundwater is a significant component in the biophysical environment, and its interaction with inland and coastal streams and wetlands indicates the dependence of surface water quantity and quality on the groundwater regime.

The potential for interaction between groundwater systems and established and future land use development is an important aspect of the Cape York Peninsula Land Use Strategy.

Significant aquifers are present in the sedimentary rocks of the Mesozoic Carpentaria and Laura Basins and the Cainozoic (Tertiary) Karumba Basin (Figure 1 and body of report Figure 2.1). Groundwater in these aquifers is generally of good quality, and provides the only reliable year-round water supplies for homesteads and towns and the pastoral and mining industries in Cape York Peninsula.

Surface water is abundant for only part of the year in Cape York Peninsula, with its highly seasonal summer rainfall, and many areas are devoid of surface water during the dry season. Even so, groundwater use in Cape York Peninsula is still low and the available waterbore data is sparse.



The Cape York Peninsula area studied contains five major hydrogeological provinces:

- Carpentaria Basin
- Laura Basin
- Karumba Basin
- Coen Inlier
- Hodgkinson Basin.

The sedimentary areas (Figure 1) comprise the Carpentaria, Laura and Karumba Basins, and are the most important groundwater provinces. The study has concentrated on these basins which contain sedimentary aquifers with primary porosity and permeability. The Carpentaria Basin is a component of the hydrogeological Great Artesian Basin which comprises the Eromanga, Surat, Carpentaria, Bowen and Galilee Basins.

The basement rock areas (Figure 1) of the Coen Inlier and the Hodgkinson Basin contain fractured rock aquifers.

2.0 OBJECTIVES

The objectives of the Cape York Peninsula Groundwater Investigation Project were to determine the nature, extent and availability of the groundwater resources of Cape York Peninsula. Particular emphasis was placed on the assessment of the groundwater quantity and quality, on the potential for sustainable development of the groundwater resources, and on the potential for pollution problems of the groundwater resources of Cape York Peninsula.

The objectives of the AGSO component of the CYPLUS - NRAP Groundwater Project were:

- to collect, compile, analyse and synthesise existing hydrogeological data, and
- to collect and analyse groundwater samples for hydrochemistry and isotope hydrology

The Project established the general occurrence, quantity and quality of the groundwater in Cape York Peninsula. It determined the hydrodynamics and hydrochemistry of the groundwater resources, and resulted in an assessment of the resources and a determination of the potential for development.

The results of the CYPLUS - NRAP Groundwater Project will contribute to the development of management options for the groundwater resources and groundwater related problems which are important factors in land use decisions in Cape York Peninsula.

3.0 METHODOLOGY

3.1 Hydrogeological Data and New Drill-Holes

AGSO provided one full-time staff member, Ms E.A. Derrington, to the CYPLUS - NRAP Groundwater Project for the period 1 April 1992 to 30 June 1994. This AGSO staff member was based in Brisbane and Mareeba. Activities included the collection, analyses, interpretation and compilation of existing geological and hydrogeological data, the transfer of data to the QDPI-WR Groundwater Database, the definition of the stratigraphic, test and observation drill-holes, drilled by QDPI-WR as part of the CYPLUS-NRAP Groundwater Project, the well-site geology of the drill-holes, and the preparation of well completion reports of the ten stratigraphic, test and observation holes drilled by QDPI-WR at selected sites in areas of sparse information in the Carpentaria and Karumba Basins.

Palynological examination by Dr D. Burger, an AGSO micro-palaeontologist, of drill cutting samples from the CYPLUS drill-holes produced enhanced stratigraphic subdivisions for the drilled sections, and estimated ages for the sampled sequences. The environments of deposition of the sediments containing the plant microfossils were interpreted, and AGSO reports were prepared for the well-site geologist about the palynological results.

The drill-holes did provide data on the occurrence, extent and quality of the groundwater, and pump tests of the holes carried out by QDPI-WR determined the hydraulic characteristics of the aquifers encountered. Several drill-holes have been equipped by QDPI-WR with solar powered data loggers to record groundwater level changes, and to record the rainfall in adjoining rain gauges.

In addition, bore census activities were carried out by the AGSO staff member based in Mareeba to obtain detailed information on existing water bores in several parts of Cape York Peninsula. For this purpose, the water bores were visited together with QDPI-WR staff, and the water bores were sampled for hydrochemical analyses, to be carried out by QDPI-WR in their Brisbane laboratories.

Field examinations of areas of specific interest were carried out, including recharge and discharge areas of the main groundwater basins.

3.2 LANDSAT Analysis

A LANDSAT satellite image analysis of the Cape York Peninsula was carried out under contract to AGSO by Dr B.R. Senior, to produce additional information on the geology and hydrogeology of the area, and in particular to define geological structures and hydrogeological features.

LANDSAT TM Band 4 images were used, which were processed in AGSO from digital data held in AGSO, and printed as panchromatic laser printer copies at scale 1:250 000 for analyses and for the preparation of map overlays.

The CYPLUS LANDSAT TM Structural Study resulted in eight maps at scale 1: 250 000 which include the land area of Cape York Peninsula shown on the fourteen map sheets at scale 1: 250 000 and covering the entire CYPLUS area.

The lineaments and geological structures, and some drainage patterns shown on the maps, emphasise different geological structures, and are a valuable addition for the interpretation of geological data for the understanding of hydrogeological features in the Cape York Peninsula. A detailed interpretation is required to determine the relationship between the lineaments which were identified in the analysis of the LANDSAT images and the geological and hydrogeological features of the area. A comparison needs also to be made between these lineaments and the results of structural geology studies carried out by AGSO in the area. Major lineaments or lineament zones could relate to faults, which if they have major throws could partly or completely displace and/or disconnect aquifers, and cause groundwater stagnation or partial obstruction of groundwater flow. Vertical leakage along the faults could cause groundwater to move from one aquifer to another or even result in leakage to the surface.

Paper print copies of the maps have been submitted to CYPLUS, and are held in AGSO and QDPI-WR. Digitising of the maps is currently (1994) being carried out by AGSO.

3.3 Hydrochemistry

AGSO - Environmental Geoscience and Groundwater Division staff, undertook groundwater sampling from the new drill-holes drilled by QDPI-WR as part of the CYPLUS-NRAP Groundwater Investigation and from existing water bores. A total of 78 selected, representative and well-distributed existing flowing artesian and pumped water bores in Cape York Peninsula, including water bores in the Carpentaria, Laura and Karuruba Basins and the Coen Inlier were sampled (Figure 2).

Measurements of the physical characteristics of the groundwater, and the hydrochemical analyses of the groundwater samples taken, enhanced the information on groundwater quality and the occurrence and distribution of chemical elements. It also provided information on changes along the groundwater flow paths, and about groundwater movement patterns.

Isotope analyses of the groundwater samples collected provided data to interpret the source, origin, groundwater flow rates and the residence times (ages) of the groundwater, and allowed valuable interpretations to be made about the recharge of the groundwater and the groundwater movement.

3.4 Groundwater Database and CYPLUS-GIS

The results of the investigations of the groundwater resources of Cape York Peninsula have been presented as a comprehensive set of data, including waterbore data, hydrogeological data, hydrological data, stratigraphy and hydrochemistry, in a standard PC and workstation based database within the QDPI-WR Groundwater Database, and the CYPLUS - GIS. The results of the Cape York Groundwater Investigation have been compiled in a report by QDPI-WR, and the report includes a large number of maps and diagrams.

The detailed hydrochemistry data produced by AGSO are also available in MS Windows EXCEL Spreadsheet, submitted to CYPLUS and QDPI-WR, and in the CYPLUS - GIS. Data include registered number of the waterbore, name of the waterbore, latitude, longitude, 1:250,000 map sheer name, date collected, date analysed, submitted by, laboratory name, AGSO laboratory sample number, pH, electrical conductivity/specific conductance, total dissolved solids, alkalinity, total hardness, and the analysis results for cations and anions of Na, K, Mg, Ca, Cl, F, Br, I, SO₄, CO₃, HCO₃, NO₃, PO₄, SiO₂, and the elements Al, Fe, Mn, Cu, Zn, Sr, Li, Pb, Si, B, U, Ba, V, and several ionic ratios including Sr/Ca, Cl/Br, S/SO₄, anions/cations balance, TDS/conductivity, and TDS measured/TDS calculated.

This report presents mainly the methodology of the study and several important results. A detailed interpretation of the hydrochemistry and isotope hydrology is required to fully understand the groundwater chemistry and its evolution and its significance in relation to the definition of groundwater movement and groundwater flow patterns. The groundwater quality assessment also required a more detailed interpretation of the available data.

The assessment of the quantity and quality of the groundwater resources in Cape York Peninsula, and the information on its sustainable development, provided by this study, will form an important part of any future planning by the Cape York Peninsula community, its natural resource managers and the Cape York Land Use Strategy.

4.0 HYDROCHEMISTRY

4.1 Field Sampling

The bores shown in Figure 2 were sampled during August and September 1992 or July and August 1993.

Measurements in the field of the physical characteristics of the groundwater in the water bores sampled included pH, electrical conductivity, temperature, dissolved oxygen and the redox potential Eh. Measurements were carried out with portable TPS combined meters, and the pH and conductivity meters were calibrated with standard solutions at each measurement site.

Water samples for hydrochemical analyses were collected in 1 L polyethylene bottles, and included a number of non-treated, acidified (1 mL of nitric acid per 1 L of water), non-filtered

and filtered (using $0.45~\mu m$ membrane filters) samples, which were returned to the AGSO Hydrochemistry Laboratory for measurements and analyses.

The selection of the sampled water bores was a function of several factors, including the availability of information on the water bores, the stratigraphy of the aquifers tapped by the water bores, their distribution, the actual existence of the water bores, and the status of, and the access to the water bores, as determined in the field. Water bores tapping only one aquifer were considered, and water bores intersecting more than one aquifer were not selected for sampling, as the mixing of groundwater from different aquifers in a waterbore will cause mixed chemistry results.

Out of an original list of about 400 water bores in the CYPLUS area, less than 80 existing water bores fulfilled most criteria, and were selected for sampling, and of those, it became clear in the field that several could not be sampled, or were not accessible. However, the ten new CYPLUS drill-holes were added to the list of holes sampled, and a total of 78 water bores were sampled in Cape York Peninsula as part of the CYPLUS -NRAP Groundwater Project (Figure 2).

4.2 Laboratory Analyses

Laboratory measurements carried out in the AGSO Hydrochemistry Laboratory included pH, electrical conductivity/specific conductance, total dissolved solids, alkalinity, and the determination of cations and anions of Na, K, Mg, Ca, Cl, F, Br, I, SO₄, CO₃, HCO₃, NO₃, PO₄, SiO₂, and the elements Al, Fe, Mn, Cu, Zn, Sr, Li, Pb, Si, B, U, Ba, V.

Standard laboratory techniques were used for the analytical procedures, including ion chromatography and inductively coupled plasma (ICP) analyses.

4.3 Groundwater Chemistry Results

The groundwater sampled in the water bores in the CYPLUS area is derived from aquifers in the Jurassic and Lower Cretaceous sedimentary sequence of the Carpentaria and Laura Basins and the Cainozoic sequence of the Karumba Basin.

No water bores were sampled in the Coen Inlier and in the Hodgkinson Basin, with the exception of a waterbore in Cainozoic deposits covering the Coen Inlier rocks at the Coen Airport.

The groundwater of the water bores sampled is chemically of the Na - HCO₃ - Cl, Na - Cl - HCO₃, Na - Cl, Na - Mg - Ca - HCO₃ - Cl, and Na - Mg - HCO₃ - Cl types. These types relate to the characteristics of the recharge areas, the different aquifers and their lithology and mineralogy, and the differences in hydrochemical evolution along the groundwater flow paths.

The aquifers in the Mesozoic (Jurassic/Cretaceous) Gilbert River Formation of the Carpentaria and Laura Basins produce mainly Na - HCO₃ - Cl and Na - Cl - HCO₃ type groundwater, and

the aquifers in the Cainozoic (Tertiary) Wyaaba Beds and the Bulimba Formation of the Karumba Basin produce mainly Na - HCO₃ - Cl, Na - Cl, Na - Mg - Ca - HCO₃ - Cl and Na - Mg - HCO₃ - Cl type groundwater.

The values for pH, Total Dissolved Solids (TDS), chloride and fluoride are some of the indicators for the quality of the groundwater in Cape York Peninsula:

The following publications provide quality criteria:

- Guidelines for Drinking Water Quality in Australia National Health and Medical Research Council and Australian Water Resources Council, 1987, Australian Government Publishing Service, Canberra.
- (Draft) Australian Drinking Water Guidelines National Health and Medical Research Council and Agricultural and Resource Management Council of Australia and New Zealand, June 1994

Drinking Water Standards - World Health Organisation

Water Quality Standards for Stock Use.

The pH values of the groundwater sampled ranges from 4.4 to 8.6, though the majority of the water bores have pH values of 7.5 to 8.0 (Figure 3). The desirable drinking water quality criteria for pH range from 6.5 to 9.2, with the long term objective being 7.0 to 8.5. If the pH is less than 6.5 or more than 9.2, than the health authority should be notified. Water quality standards for stock use recommend a pH range of 5.5 to 9.0.

Low pH values, below the drinking water quality standard, are present in several water bores at Aurukun, Wolverton, Miller's Camp, Holroyd River, near Kalinga Homestead and in the Hann River area. Low pH values correlate with shallow aquifers, which generally contain groundwater with low to very low TDS values. The groundwater in several of these shallow water bores is relatively "young", ie. it has been derived from recently recharged groundwater.

The Total Dissolved Solids (TDS) values for the groundwater from the water bores sampled range from 6 to 8890 mg/L, but the majority of the TDS values for the water bores sampled is less than 500 mg/L. Higher TDS values of more than 1000 mg/L occur in several (artesian) water bores at Weipa, and in water bores at Batavia Downs, Holroyd River, north of Pormpuraaw, north and southwest of Kowanyama, at Strathgordon, near Cape Melville and near Battle Camp (Figure 4).

The desirable drinking water quality criteria for Total Dissolved Solids is 1500 mg/L, and the long term objective is 500 mg/L. The water quality standard for stock use recommends a limit for Total Dissolved Solids of 8000 mg/L, though the actual values are dependent on the type of stock and the available feed.

Chloride values for the groundwater from the water bores sampled range from 3 to 3530 mg/L. The majority of the chloride values is less than 50 mg/L, though a number of water bores have values between 200 and 1000 mg/L. Some of the higher chloride values occur in water bores at Batavia Downs, Holroyd River, north of Pormpuraaw, north and southwest of Kowanyama, at Strathgordon, near Cape Melville and near Battle Camp (Figure 5).

The desirable drinking water quality criteria for chloride is 600 mg/L, and the long term objective is 200 mg/L.

Fluoride values of the groundwater sampled range from <0.1 to 9.9 mg/L (Figure 1 and body of report Figure 4.17). Several water bores in the Weipa, Coen, Kowanyama, Bathurst Range and Battle Camp areas have fluoride values between 1.4 and 9.9 mg/L.

Using new and existing hydrochemistry data, five areas in Cape York Peninsula have been shown to have fluoride values greater than 1 mg/L in groundwater, which relate to:

- two areas in the basal Jurassic aquifer of the Mesozoic Carpentaria Basin at Weipa and Cape Grenville respectively,
- one area in the basal Jurassic aquifer of the Mesozoic Laura Basin near the Bathurst Range,
- one area in the Cainozoic aquifers of the Karumba Basin at Kowanyama,
- one area in the Palaeozoic basement granite and Cainozoic sedimentary rocks at Cooktown.

The first four high fluoride occurrences are all in Jurassic and Cainozoic sedimentary aquifers, in deeper, confined groundwater basins, indicated by flowing artesian water bores and groundwater with elevated temperatures up to 78° C.

Fluoride is common in ?Proterozoic metamorphic and Palaeozoic igneous basement rocks of the Coen and Yambo Inliers in Cape York Peninsula. Fluoride associations could occur in basement rocks overlain by the Mesozoic (Jurassic and Cretaceous) sedimentary rocks of the Carpentaria and Laura Basins and the Cainozoic rocks of the Karumba Basin. It is suggested that fluoride ions are transported upwards in groundwater from the ?Proterozoic and Palaeozoic basement rocks to the basal Jurassic aquifers, and in some areas further upward to the Cainozoic aquifers.

High hydraulic heads in artesian aquifers, upward directed groundwater flows, elevated groundwater temperatures and widespread availability of fluoride in the basement rocks are the main controls on the occurrence of groundwater with high levels of fluoride in Cape York Peninsula.

The desirable drinking water quality criteria for fluoride, and the long term objective is 1.5 mg/L, though permissive values of 1.0 mg/L and excessive values of 1.5 mg/L are also used.

Fluoride in drinking water for humans should not exceed 0.6 mg/L in areas with an average maximum daily air temperature of 28° - 32° C.

Fluoride values greater than 1 mg/L delineate areas of interest, and values greater than 5.0 mg/L require notification of the health authority. As shown above, several areas in Cape York Peninsula fall within this category.

Drinking water for livestock should have fluoride values of less than 2.0 mg/L, with a limit of 5.0 mg/L, and if the livestock feed contains fluoride, the drinking water limit should be reduced to 1.0 mg/L.

Nitrate values are well below the recommended limit of 45 mg/L in all water bores sampled, though some samples show elevated values, with up to 16 mg/L at Coen Airport. Other water bores in the Aurukun, Lakeland Downs and Weipa (sub-artesian bore) areas show slightly higher values.

Several water bores have total iron values which are higher than the desirable drinking water quality criteria of 1.0 mg/L, and the long term objective of 0.1 mg/L.

In general, the groundwater quality of most water bores is well within the permissive standards given in the Guidelines listed.

Potentiometric surface contours shown in the map - Groundwater Resources of Queensland 1987, scale 1:2 500 000, by the Queensland Water Resources Commission and Queensland Department of Mines, and shown in the map - Hydrogeology of Australia, 1987, scale 1:5,000,000 by the Bureau of Mineral Resources, Geology and Geophysics are generalised and based on limited data. Additional data from the present study confirms these results. The regional flow directions derived from these potentiometric surface contours show that groundwater flow in the Mesozoic and Cainozoic aquifers in the Carpentaria Basin is generally directed from East to West, in relatively regular patterns in a basinwards direction away from the recharge areas along the eastern margins of the basin.

The groundwater flow in the Mesozoic aquifers in the Laura Basin is generally directed in a Northerly direction.

Changes in the hydrochemistry of the groundwater occur along the groundwater flowlines within the aquifers, as well as changes in TDS values, though the limited number of samples require further detailed analyses to interpret the hydrochemical evolution.

Vulnerability of the groundwater to contamination is high in areas where the aquifers are unconfined, and in particular in the recharge areas of the aquifers which further basinwards are confined, and produce flowing artesian water bores. Any land use changes and development in areas of unconfined aquifers and recharge areas should consider the significant effects which these changes could have on the aquifers and the groundwater, especially as any changes to recharge, or any contamination could have very long term effects. Contamination could result from a large number of causes, including different land uses and the application of fertilisers,

pesticides and herbicides, mining and high density pastoral activities, urban settlements, disposal and storage facilities and many other activities.

Recharge to some of the shallow aquifers is quite rapid and any changes in recharge because of land use changes, or contamination of the aquifer, could result in significant effects, as the groundwater flow rates are low, and groundwater travels very slow over large distances, and any remediation would require very long time frames.

Changes to the quality of the groundwater, and changes to specific hydrochemical components as a result of groundwater exploitation is another matter of concern, and any such occurrence requires careful monitoring.

4.4 Isotope Hydrology

Oxygen and hydrogen stable isotope ratios for the groundwater from the Mesozoic and Cainozoic aquifers range from -36.2 to -51.4 for δ D, and from -5.55 to -7.34 for δ ¹⁸O, and provide information on the origin of the groundwater, and the changes along the groundwater flow paths. The oxygen and hydrogen stable isotope ratios plot on and along the Meteoric Water Line, confirming the source and origin of the groundwater as rainfall, which infiltrated without significant evaporation effects.

Groundwater ages determined from ¹⁴C and ³⁶Cl measurements show indications or some patterns of increasing residence times from the recharge areas along the groundwater flow lines in basinwards directions. Early indications are that the groundwater flow rates in the confined aquifers of the Carpentaria Basin are comparable to the groundwater flow rates in confined aquifers in other parts of the Great Artesian Basin, ie. in the order of 1 - 5 m/year. However, the data is limited, and detailed interpretation of the results is required, in order to delineate groundwater movement and groundwater travel times.

5.0 CONCLUSIONS

The AGSO component of the CYPLUS - NRAP Groundwater Project has made a considerable contribution to the determination of the nature, extent and availability of the groundwater resources of Cape York Peninsula through the collection, compilation, analyses and synthesis of existing and new hydrogeological data.

The storage of the hydrogeological data in the QDPI-WR Groundwater Database and the CYPLUS-GIS allows the development of management options for the groundwater resources and groundwater related problems in regard to land use decisions in Cape York Peninsula.

The hydrochemical and isotope hydrology studies by AGSO of the groundwater system provide an overview of the quality of the groundwater, its origin and movement, and complement the investigation of the extent and quantity of the groundwater resources of Cape York Peninsula. The study shows that in general the groundwater is of good quality and suitable for most purposes, though some restrictions apply, as several constraints, related to low pH, high fluoride values and some other factors, are present.

Any changes to land use or development in the CYPLUS area should seriously consider the effects which such changes could have on the groundwater recharge and the possible contamination of groundwater. Because of the long response times, and the very low flow rates or long travel times of groundwater, any changes could result in very long term effects.