Gascoyne Region Water Resources Review and Development Plan 1996

Volume I of II

Water Resource Allocation and Planning Series

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Water and Rivers Commission

GASCOYNE REGION
WATER RESOURCES REVIEW
1996

VOLUME I OF II

by
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Water and Rivers Commission
Policy and Planning

WATER AND RIVERS COMMISSION
WATER RESOURCE ALLOCATION AND PLANNING SERIES
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Introduction

The Gascoyne Region is currently experiencing significant growth. Tourism is a relatively new industry in the region and is the fastest growing, contributing more than $70 million to the economy. Impressive features of the Gascoyne coast includes the Ningaloo Reef, the World Heritage area at Shark Bay and world class game fishing, which provides a suitable back drop for future development of tourism infrastructure. The Carnarvon Horticultural District, although relatively small, is one of the most productive areas per hectare in Australia. Expansion proposals for tourism, horticultural and mining activities in the Gascoyne Region indicate potential dramatic changes in water consumption patterns. These, coupled with possible changes in the management of the Carnarvon Irrigation District, indicate that a strategic understanding of development and the resulting impacts on the region's water resources is imperative. This study is intended to improve that understanding. Up to date information on divertible water resources of the region have been collected and consolidated and the likely water requirements of existing and potential developments have been determined. The study area includes the Wooramel, Gascoyne and Lyndon - Minilya Drainage Basins.

The objectives of this study are:

- To collate current information on existing and potential divertible surface water and groundwater resources in the Gascoyne Region.
- To undertake surface water yield analyses to assess and confirm existing information.
- To consolidate all available groundwater information pertaining to the region.
- To collate current information on domestic, industrial, agricultural and environmental water demands in the region.
- To predict all future water demands within the study area for a thirty year planning horizon.
- To identify possible scenarios for development of the region's water resources to meet future demands.

Water Resources

The most up to date surface water and groundwater resources of the region have been collated, analysed or assessed. These have been grouped according to the relevant drainage basin. Information pertaining to water resources includes the water source (dam site or aquifer), water quality, yield, development potential and development constraints.

This document is primarily an inventory of the water resources in the study area, no attempt is made to consider specific significant environmental issues. However, some general consideration has been given to the environmental values which may be affected by water resource development.

This very preliminary assessment has indicated that in some cases environmental values are likely to be significantly affected by water resource development, while other potential developments may remain relatively unconstrained.

Projections

Population and water demand projections have been undertaken. Population projections for each town and significant settlement were undertaken to form the basis of the community water supply projections.

Total water demands from surface water and groundwater sources have been calculated separately for each drainage basin.

Water Resource Development Plans

All towns and settlements in the region obtain their water supplies from groundwater sources. Most have enough surplus capacity available in the aquifer to allow for expansion of their bore fields.

The Denham town water supply, Monkey Mia, Coral Bay, Useless Loop and the Harold E Holt Naval Base obtain brackish water from the Birdrong Sandstone aquifer. These communities use desalination techniques to provide potable water. As there is no available fresh water in the vicinity of these settlements, it is expected that this practice will continue.

Gascoyne Junction and the Burringurrah Community are supplied from locally available groundwater. There is enough surplus capacity to meet their needs to 2026.

The Carnarvon Town Water Scheme and the Carnarvon Irrigation District obtain their water from the Gascoyne River bed sands. This source is dependent on river flows for recharge and is therefore somewhat droughtprone. A study being undertaken by the Carnarvon Irrigation Augmentation Steering Committee is investigating opportunities to improve the reliability of water supply to the town and the irrigation district. Some possibilities include on - stream storage, off - stream storage and groundwater recharge. The proposal to develop a horticultual district at Rocky Pool will require further use of the Gascoyne River bed sands upstream of Rocky Pool. These will have minimal impact on downstream users.

The Town of Exmouth water supply obtains its water from a thin fresh water lens which lies over deeper salt water. This source is further complicated by the presence of rare and endangered aquatic cave dwelling fauna (stygofauna) and proposed competing land uses related to limestone mining and processing. The options to meet future demands for Exmouth are to extend the existing borefield further south (while accomodating the stygofauna concerns), to integrate the town scheme with that of the Harold E Holt Naval Base, or to desalinate seawater.

Conclusions

A summary of the existing and future water supply and demand for the region is presented in Figure I-1.

The potential surface water supply is presented in Table 14-1. Essentially, potential exists for the development of surface water sources to meet future demands within the region.

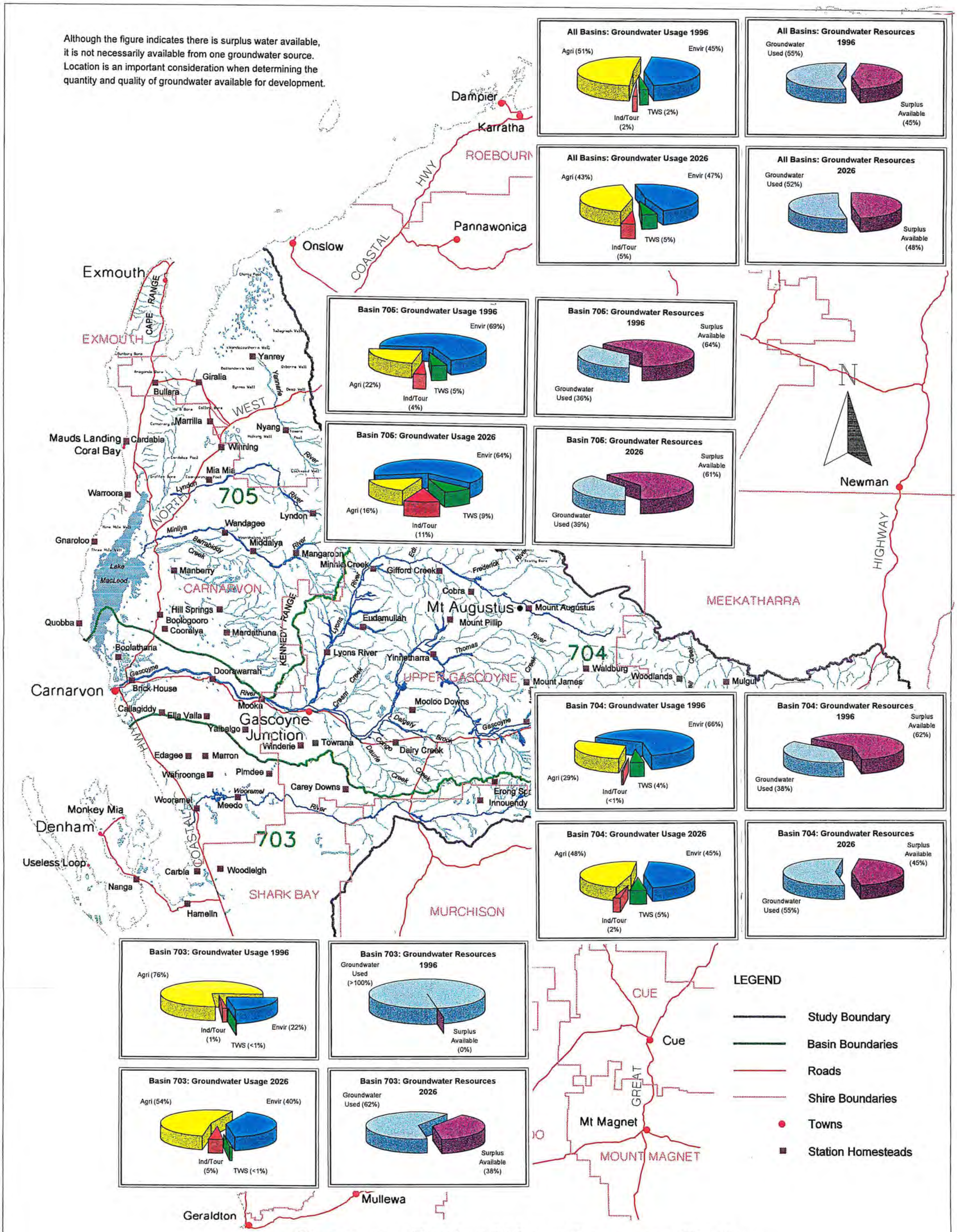
At present, more than half the renewable groundwater resources are utilised. By the year 2026, the amount of groundwater used in the region should decline, provided measures are taken to curb the wastage of water from artesian bores in the pastoral areas. It is anticipated that usage from the artesian aquifer will be reduced to the sustainable yield of the aquifer which would ensure the long term security of the aquifer. The potential groundwater supply is presented in Table 14-2.

A/Director, Policy and Planning

Date 24/10/96.

Chief Executive Officer

Date 25.10.96



Gascoyne Region Water Resource Review

EXECUTIVE SUMMARY - STUDY AREA

Figure I.1

1. Introduction

1.1 Background

The Gascoyne Regional Water Resources Review and Development Plan arises from the need to collect and consolidate up to date information on the divertible water resources of the region and to determine the likely water requirements of existing and potential developments. It proposes possible water resource development scenarios that would meet the needs of those developments. The review is strategic in nature. This means that it is long term and provides for the region's water needs for the next 30 years to the year 2026. The review builds on the existing planning and research. It acknowledges the fact that Carnarvon, through its horticulture and industry is at the heart of the Gascoyne Region and is an essential part of the development of Western Australia.

Significant re-structuring has affected the water industry recently. Consequently, reference is made to the Water and Rivers Commission (WRC), the Water Corporation (WC) and the Office of Water Regulation (OWR) for issues and information referred to after 1 January, 1996.

1.2 Objective and Scope

The objectives of this study are:

- To collate current information on existing and potential divertible surface water and groundwater resources in the Gascoyne Region.
- To undertake surface water yield analyses to assess and confirm existing information.
- To consolidate all available groundwater information pertaining to the region.
- To collate current information on domestic, industrial, agricultural and environmental water demands in the region.
- To predict all future water demands within the study area for a thirty year planning horizon.
- To identify possible scenarios for development of the region's water resources to meet future demands.

1.3 Study Area

The study area (Figure 1-1) comprises three of the Western Australian Water Resources Council (WAWRC, 1987) Drainage Basins. These are the:

- Wooramel River Basin (703)
- Gascoyne River Basin (704)
- Lyndon-Minilya Rivers Basin (705).

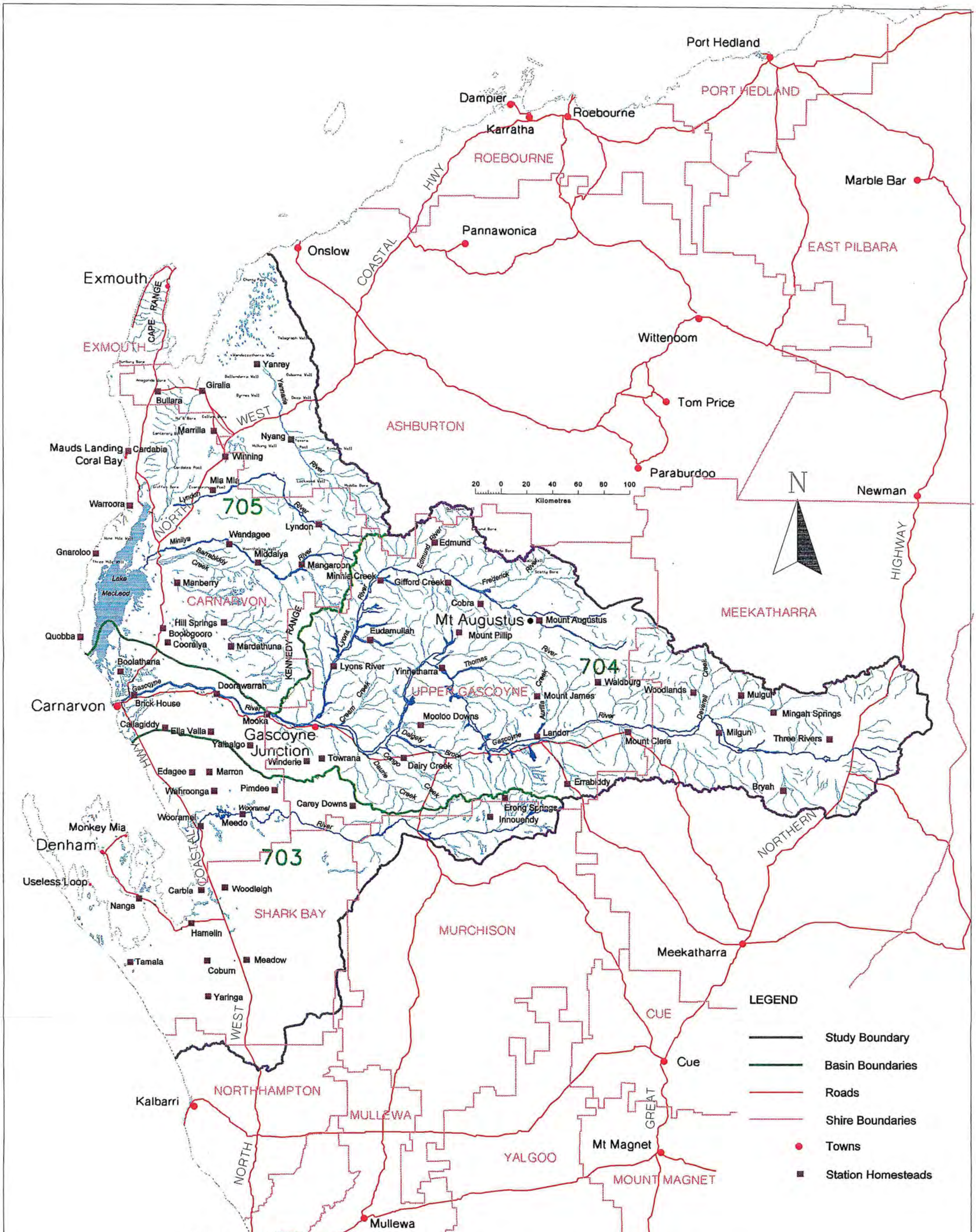
The total area of these three basins is approximately 175,000 km^2. The Shires of Carnarvon and Exmouth are fully contained within the study area. The Shires of Shark Bay, Upper Gascoyne, Meekatharra, Murchison and Ashburton are partly contained within the study area.

The study area is essentially rural. Numerous stations and homesteads are scattered throughout the region and these occupy a vast proportion of the land. Four major population centres exist within the study area. These are Carnarvon, Exmouth, Denham and Gascoyne Junction. Other population centres include Coral Bay, Useless Loop and Burringurrah Aboriginal Community.

The Gascoyne Coast has significant tourism potential. Tourism currently occurs primarily along the North West Cape, at Coral Bay and at Monkey Mia. However, efforts are being made to develop and promote tourism opportunities in the region's vast hinterland.

Horticulture, undertaken near the Gascoyne River at Carnarvon, is a valuable industry to the region. Horticulture, also occurs elsewhere in the region. Other activities of high economic value to the region include salt mining, fishing, fish processing, tourism and pastoral stock production.

For purposes of this study, water yields, demands and projections will be presented for each basin separately and then summarised for the region as a whole. The area of study will be referred to as the 'study area' throughout this text but may also be referred to as 'the region' when appropriate.



Gascoyne Region Water Resource Review

STUDY AREA

Figure 1.1

2. Regional Characteristics

2.1 Climate

The climate of the Gascoyne Region is arid to semi-arid with hot summers and mild winters. Inland climatic conditions are more extreme than those experienced in coastal areas. Intense heat and occasional frost may occur in inland areas during particular times of the year. Average maximum temperatures in the Gascoyne Region range from 31 - 40°C in January to 21- 24°C in July. Average minimum temperatures range from 20 - 23°C in January to 9 - 11°C in July. January and February are the hottest months, while July and August are the coolest months of the year.

Average annual rainfall is approximately 230 mm, but is unreliable and may vary widely from year to year. The highest monthly average rainfall occurs between May and July, due to the passage of rain-bearing depressions of either tropical origin or associated with intense frontal systems which originate in the Southern Ocean. Summer rainfall is derived from cyclonic and thunderstorm activity. Cyclonic winds have the potential to cause damage, attaining speeds of above 80 km/hour.

Rainfall histograms for various towns within the region and representing the three basins are presented in Appendix A. Rainfall isohyets for the region are presented in Figure 2-1.

High evaporation rates occur in the Gascoyne Region. The evaporation ranges from 1,700 to 3,050 mm/year, depending on seasonal conditions. Evaporation isopleths for the region are presented in Figure 2-2.

The climate of Exmouth is characterised by hot summers and low rainfall. A significant feature of the area's climate is the difference in temperature between the eastern and western sides of Cape Range during summer months, as a result of the south west breezes.

The climate of the semi-arid Carnarvon area is suited to the growth of tropical and sub-tropical fruits under irrigation. Temperatures in autumn, winter and spring are ideal for the growth of vegetable crops. Further inland, the temperatures are more extreme and this is expected to influence horticultural activity. The Carnarvon area is influenced by the belt of the South East Trade Winds, which generate southerly winds for most of the year.

Shark Bay has hot, dry summers and mild winters. The low rainfall, high evaporation and high winds combine to create problems with potable water availability and with land stability where vegetation cover is disturbed.

2.2 Physiography

The regional topography and drainage pattern are controlled by the geological structure and geological history of the region. In broad terms the Gascoyne Region can be subdivided into a coastal lowland, a dissected upland, and a partially dissected interior plateau coinciding respectively with the geologically-distinct Western Carnarvon Basin, Eastern Carnarvon Basin and Fractured Rock Province (Figure 4-1). In detail, various geomorphological areas have been recognised by Wyrwoll and Glover (1987), Payne et al. (1987) and Hocking et. al. (1987).

The coastal lowland is up to 100 km wide. It is relatively flat, and gently rises to about 100 m above sea level along the edge of the dissected upland. Locally there are some areas of higher relief especially along the south-western coast and in the Northwest Cape region. The dissected upland reaches a maximum elevation of about 350 m in the Kennedy Range and is characterised by plains interspersed by ridges, mesas and buttes formed by resistant strata. The interior plateau in the upper reaches of the river basins is a broad, relatively flat region broken by some prominent hills and ranges formed by resistant geological formations.

2.3 Soils And Landforms

The soils in the Gascoyne Region have many features that are common to semi-arid soils. Most obvious is the predominantly red colour of the soil which is due to soil particles covered by oxides of iron.

Towards the coast, sandy calcareous soils are often lighter in colour due to littoral shell fragments and oxide leaching. The browner calcareous earths tend to differ in colour due to the high concentrations of carbonates and lower concentrations of iron oxides. Organic matter is low and generally concentrated within the top few millimetres.

Alluvial soils near the Gascoyne River consist of loamy fine sands and silty loams. These soils are particularly fertile and support the region's horticultural activities, which are centred in Carnarvon. Flooding of the Gascoyne River occurs intermittently, causing the alluvial soils to be extensively redistributed or modified.

Landforms present in the region consist of plains with low relief (relative relief <30m), plains and hills of moderate relief (relative relief 30m to <100m) and hills of marked relief (relative relief >100m). These landforms have erosional surfaces and may be subject to severe degradation if vegetation is cleared. Depositional surface landforms, grouped according to their genesis, consist of aeolian, fluvial, lacustrine and marine forms.

Landforms and geomorphic districts of the Carnarvon Basin (Payne et al, 1980) are listed in Table 2-1 and Table 2-2, together with a brief description of each district.

Table 2.1: Erosional Landforms and Geomorphic Districts of the Carnarvon Basin

Landform	Geomorphic Districts	Description
Plains	Carbla Plateau	A partly dissected, calcrete-duricrusted plateau south of Wooramel River, near the coast.
	Mardathuna Plain	A gentle westward sloping narrow plain near the Kennedy Range, extending north-westerly between the Gascoyne and Minilya Rivers.
	Towera Stony Plains	Broad, stony plains encompassing the head waters of the intermittent Yannarie and Lyndon Rivers
	Wandagee Permian Plains	Plains up to 25m wide following the course of the Minilya River, between the Gooch and Kennedy Ranges.
	Winning Plains	Plains extending 100km eastwards from the Giralia anticline as a narrowing tongue of land.
Plains & Hills	Giralia Range	Dissected limestone hills, undulating stony uplands and outwash plains, including non-contiguous anticlinal structures of the Giralia and Gnargoo Ranges and numerous small folds adjacent to Lake MacLeod.
	Lyndon Proterozoic Hills	Pre-Cambrian metamorphic and plutonic crystalline rocks, located mostly east of the Carnarvon Basin within the tectonic unit of the Gascoyne Province.
	Tamala Limestone Plains	Undulating limestone plains with shallow calcareous sand lying in two distinct areas on Peron Peninsula and Edel Land.
Hills	Cape Range	Deeply dissected limestone ranges and outwash plains, including the Cape and Rough Ranges in the northwest of the study area.
	Permian Hills	Dissected Permian hills, ridge lines and isolated mesas with steep stony slopes and restricted plains, extending southwards to include the Kennedy Range.

Table 2.2: Depositional Landforms and Geomorphic Districts of the Carnarvon Basin.

Landform/ Genesis	Geomorphic Districts	Description
Aeolian	Coastal Dunes	Coastal dunes and undulating plains of shallow calcareous sand over limestone or calcrete, located in two distinct areas on Edel Peninsula and Dirk Hartog Island
	Ridge Dunes	Longitudinal and convergent or occasionally reticulate sand ridges and flat to undulating interdunal plains of aeolian sand, extending between the Wooramel and Minilya Rivers
	Victoria Sand Plain	Extensive flat to gently undulating sand plain with minor dune fields, extending between the Wooramel River and Peron Peninsula
Fluvial	Alluvial Plains	Alluvial deposits with areas of red, aeolian sand banks and dunes and occasional claypans, based on the main channels, floods plains and deltas of the Lyndon, Minilya,Gascoyne and Wooramel Rivers.
Lacustrine & Marine	Lake MacLeod & Saline Plains	Flat saline plains subject to regular inundation, located on the periphery of Lake MacLeod

2.4 Geology

Much of the region is covered by a large sedimentary basin known as the Carnarvon Basin. The sedimentary Carnarvon Basin slopes gently towards the coast and is characterised by low relief, open drainage and large gently undulating sand plains. This contrasts strongly with the small area of Precambrian rocks in the north east of the Gascoyne, which has moderately high relief, a close dendritic drainage pattern and mature valley topography.

The eastern portion of the Carnarvon Basin is made up of a thick sequence of Palaezoic sedimentary rocks which have a westerly regional dip. The sequence consists of limestone, sandstone and shale of varying age and is almost entirely marine in origin.

To the west, these rocks are overlain by cretaceous sandstone, shale, marle and limestone with a total thickness of 600 m. The western most belt of the basin is of Tertiary strata, mainly limestone.

East of the Carnarvon Basin are rocks of the Gascoyne Complex. These comprise granitic intrusions and high grade gniess and metasediment of early Proterozoic Age, overlying Archaean gneissic basement rock.

The north eastern part of the Gascoyne Region is covered by Middle Proterozoic sandstone, shale and dolomite of the Bangemall Basin. These sediments have been subjected to low grade metamorphism, folding and intrusion by numerous dolerite sills.

Rocks in the region are highly weathered or overlain by soil or aeolian sand. Extensive evaporite deposits of gypsum and salt occur in natural depressions near the coast.

Refer to Section 4.5 for a more detailed description of the region's geology.

2.5 Vegetation and Wildlife

The land of the Gascoyne Region is mostly low lying. The vegetation is almost entirely semi arid scrub with little or no tree cover. The natural vegetation has not been cleared over much of the area, however, extensive grazing by sheep, cattle and goats has affected the soil and some plant species.

The natural vegetation consists of the Spinifex (Triodia), Wattle (Acacia) and Poverty Bush (Eremophila) shrub varieties. Along the rivers and adjacent flood plains, several varieties of eucalypt grow, together with Paperbarks (Cadjeputs). Sandalwood clumps were once common but are becoming a rarity.

On the alluvial flats, shrubs present are of the Bluebush

(Maireana) and Saltbush (Atriplex) species, while on wetter sites, the shrub Halosarcia is present. Around coastal areas, there is much growth of Mangrove varieties with the Avicennia marina species particularly prevalent around Shark Bay and Exmouth.

Red kangaroos and euros are common in the region. Smaller marsupials and bats, including rare and endangered species, are found in the less accessible parts of the mainland and on offshore islands.

A wide diversity of birds, both resident and migratory, inhabit the Gascoyne. Corellas, galahs, parrots and emus are common throughout the region. Shark Bay has rich avifauna, with over 230 Australian bird species, including three rare species, being recorded in the area. Lake MacLeod is home to diverse bird species and is an important resting spot for trans-equatorial migratory waders.

There are many species of snakes, lizards and goannas in the Gascoyne Region. Shark Bay is noted for its diversity of amphibians and reptiles and supports nearly 100 species, of which 13 reptile species are threatened. Amphibians include mudskippers in mangrove swamps and frogs which spend most of their life burrowed in the earth.

Dingoes and feral animals such as goats, foxes, cats and rabbits have had a significant effect on the vegetation and fauna of the region. The only natural wild populations of the Banded Hare Wallaby, Western Barred Bandicoot and Shark Bay Mouse are found on Bernier and Dorre Islands, near the entrance to Shark Bay.

The marine fauna of the Gascoyne is diverse and plentiful, due to the warm Leeuwin Current. The coastal environment is an important habitat and migratory site for dophins, dugongs, humpback whales, whale sharks and other marine animals. The Gascoyne coast is also renowned for the best recreational fishing in the State. More than 200 species of coral fauna may be found in the Ningaloo Marine Park. Many tourists are attracted to the region to see the marine animals and partake in some recreational fishing.

Various subterranean fauna are found on the Cape Range peninsula, where unique geological features and climatic influences have created an extraordinary range of underground habitats. Troglobites have evolved to be totally dependent on cave environments. They are eyeless, lack pigmentation and have enhanced non-optic sense organs, due to adaptation to a life in darkness.

2.6 Minerals and Basic Raw Materials

The main mineral product mined in the Gascoyne Region is salt. Ideal conditions exist in the region for the production of salt by solar evaporation or by harvesting naturally occurring brines in salt lakes. The region has two major salt producers at Useless Loop (Shark Bay Salt) and at Lake MacLeod (Dampier Salt).

Gypsum is present at Lake MacLeod and production may commence in the near future (by Dampier Salt), after potential markets are secured. The gypsum operations will require little additional infrastructure due to the close proximity of the site to the existing facilities.

Limestone and hardrock are mined from the region. Most of the construction materials are used locally for road aggregate, road surfacing and general construction. The limestone extracted is of low quality, however, some areas of higher grade limestone have been identified in the Exmouth area.

Coquina shell is mined from a quarry at Shark Bay. The material has been used around Denham for many years for landscaping, footpaths, road surfacing and as shell grit on poultry farms. Shell blocks from Hamelin Pool are used locally as a building material, particularly for the maintenance of historical buildings.

Oil exploration has been undertaken in the study area since 1953, when the first oil discovery in WA was identified at Rough Range. However, there have been no finds which warrant production. Currently, the region is covered by several exploration licenses, with a further offshore tenement within Exmouth Gulf.

The future potential of the petroleum industry in the region depends largely upon production commencing in the region or in adjacent offshore areas. The Gorgon and Pyrenes-Macedon fields, located to the north of Exmouth, may yield production quantities at some stage in the next 20 years. If this occurs, Exmouth may be considered as a site for on-shore support facilities.

Numerous exploration and prospecting licenses exist in the region. These licenses cover a wide range of mineral resources, however, none have been found to be on a commercially viable level.

2.7 Water

Water resources in the region are divided into two components, surface and groundwater. The region conforms to hydrologic boundaries and includes the Wooramel River Basin, Gascoyne River Basin and Lyndon-Minilya Rivers Basin.

The surface water resources include the region's rivers, streams, wetlands, pools and lakes. A number of major and minor rivers flow from the east, combining into a few major river channels which flow generally westward to the sea or to Lake MacLeod. These rivers flow intermittently, usually between January and August, as a direct result of rainfall runoff in the catchment areas.

The Gascoyne River is the most significant river system in the region. Other major rivers are the Wooramel, Lyndon and Minilya Rivers. There is some potential for rivers in the region to be dammed. Dams on the Gascoyne River may have an additional benefit of providing flood mitigation options. Pipeheads may also be used to produce divertible water resources.

The region does not conform to the groundwater area boundaries, however, it includes the Carnarvon Groundwater Area and portions of the Pilbara, Gascoyne and East Murchison Groundwater Areas.

The region's groundwater resources exist primarily within the Carnarvon Basin. The hydrogeology of the basin is controlled by the widespread occurrence of low permeability surficial formations and the general absence of thick and extensive aquifers. This together with the climate, nullifies the potential of the major rivers as large sources of recharge.

A regional water table extends throughout the basin. It occurs at the surface in riverine pools and at depths of over 100 m in elevated areas. Perched water tables and springs occur in the upland areas where Palaeozoic sediments outcrop and extensive karst features occur in the Tertiary limestone underlying Cape Range. The regional flow systems are bounded by the rivers, with flow occurring in the alluvium and Tertiary limestone. Groundwater is generally brackish, however, fresh groundwater occurs beneath and adjacent to the major rivers and in some elevated areas.

The Birdrong Sandstone and Tumblagooda Sandstone are the major confined aquifers. Other minor small confined aquifers extending westwards beneath the coastal lowlands are inferred to occur in Permian and Devonian limestone and sandstone.

The Birdrong Sandstone is the most extensive aquifer in the basin. It varies up to 30 m in thickness and probably contains several flow systems originating from different recharge areas. Artesian groundwater occurs throughout most of the western portion of the aquifer. Groundwater varies from fresh near the Wooramel River to hypersaline at Cape Range, however, it is generally brackish to saline.

The Tumblagooda Sandstone outcrops along the southern margin of the basin and extends at depth in the subsurface beneath the southern two thirds of the basin. It contains brackish to saline groundwater.

2.8 Coast

The Gascoyne region has approximately 600 km of coastline. The coastal features are extremely diverse and consist of tidal flats, shallow bays, coastal dunes, limestone platforms and towering cliffs. The coast is the interface between the marine and terrestrial environments and is influenced by natural processes and human activities. These influences may be local, regional or global.

2.9 Population

The population of the Gascoyne Region study area was approximately 10,130 in 1994. This is based on the Australian Bureau of Statistics (ABS) official Estimated Resident Population (ERS) figures (1994). Population change in the region in recent census periods are presented in Appendix B.

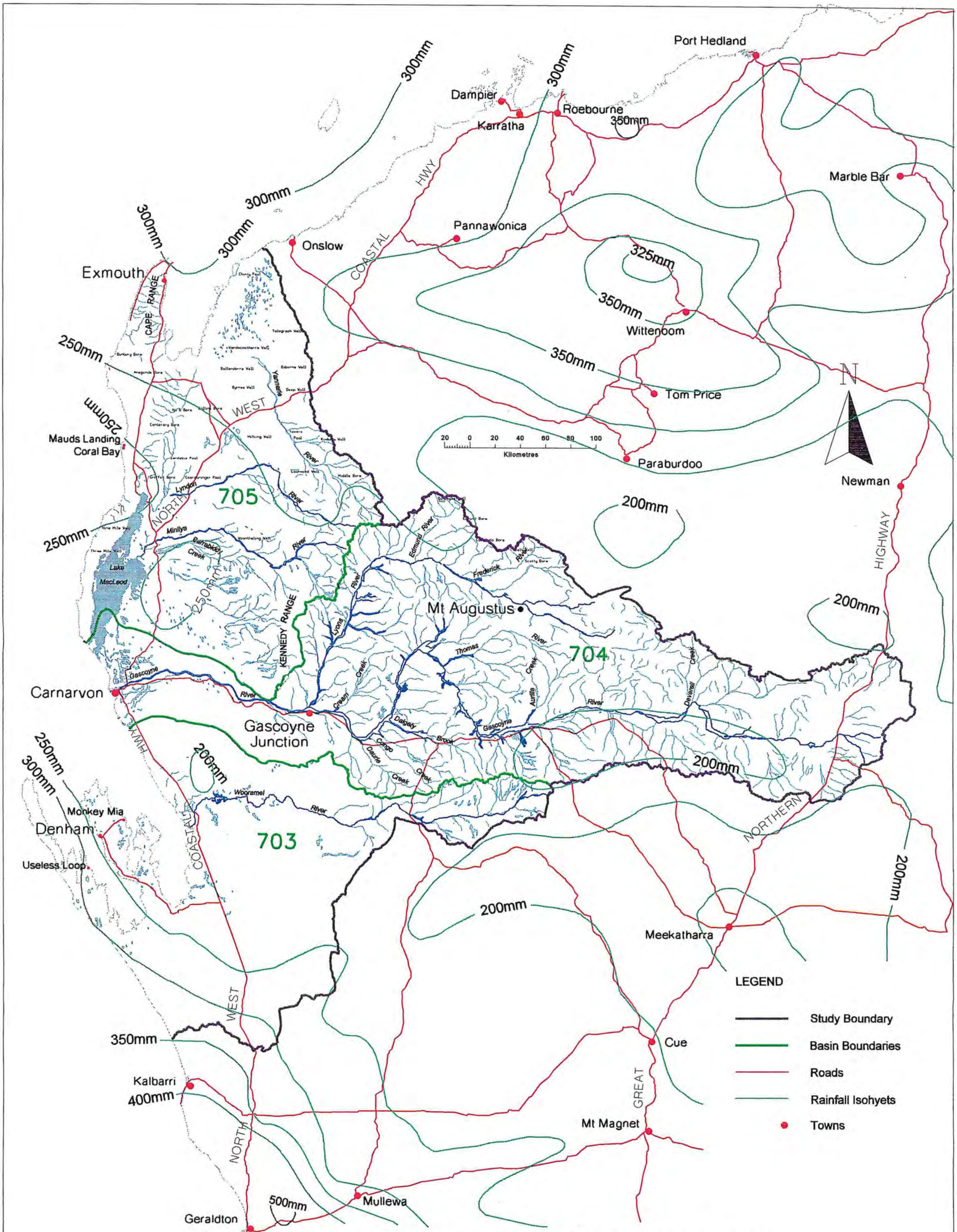
Future population projections (scenarios) are indicated in Appendix B and graphically in Section 9. The medium population projection results in a regional population of approximately 12,674 and 14,970 by the years 2011 and 2026 respectively. The high population projection results in regional populations of approximately 14,005 and 18,949 by the years 2011 and 2026 respectively.

The population projections are sourced from Ministry for Planning Reports coupled with data provided from the Australian Bureau of Statistics (ABS). Two population growth scenarios have been developed - 'Medium' and 'High'. Population growth rates are based on historical evidence with consideration given to major driving forces of each of the scenarios.

Population projections produced by the Ministry for Planning have been used as a basis for the Medium scenario. The High scenario is based on the increased migration as incorporated by the ABS modelling process. This has been referred to as the 'feasible population' and is used to demonstrate the likely maximum needs in the respective areas.

Speculative developments are not considered. It should be noted that the above projections are subject to a range of changing circumstances and are, therefore, subject to amendment from time to time.

Comprehensive discussion and projections for each town are undertaken and presented graphically in Chapter 9.



Gascoyne Region Water Resource Review

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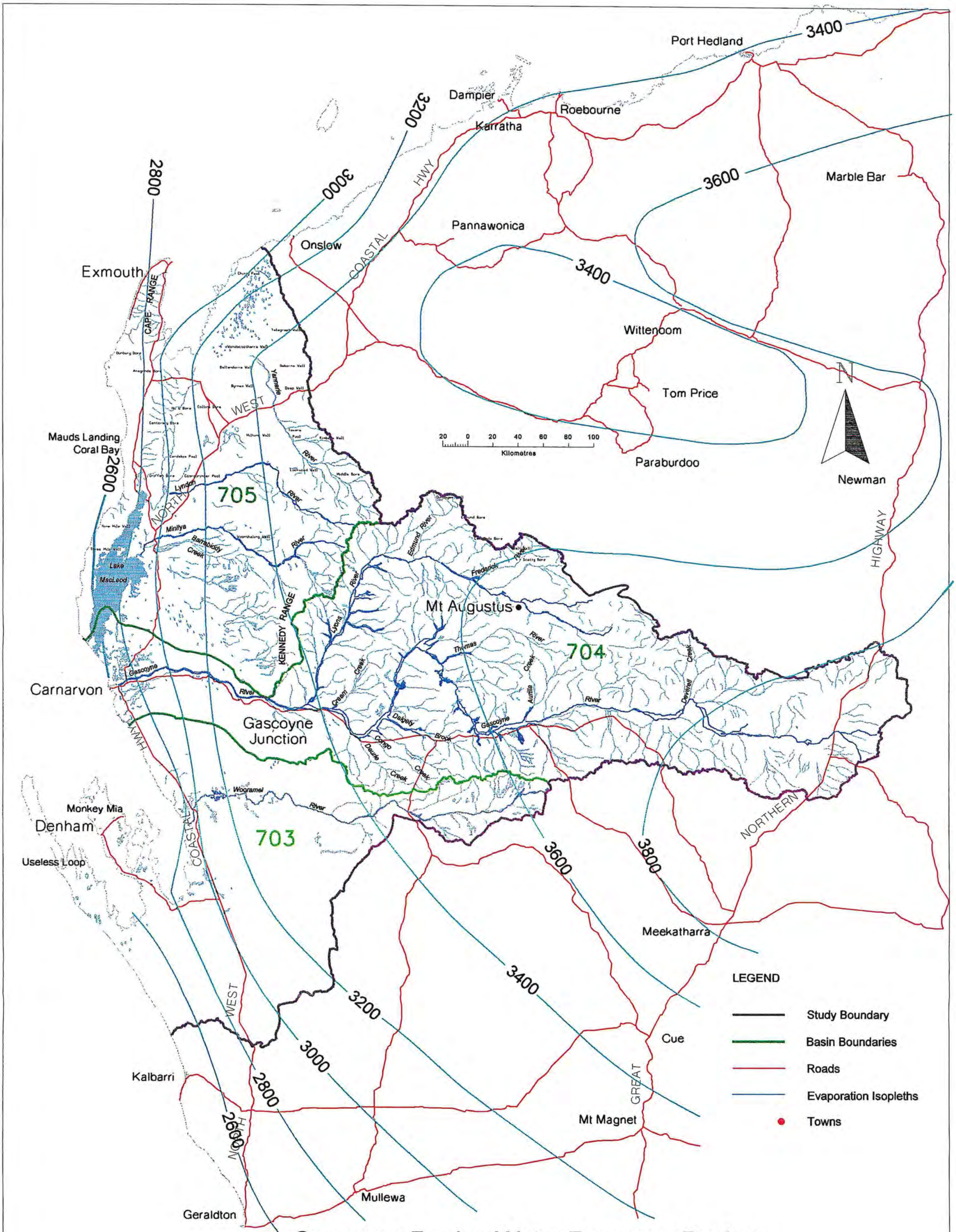
Figure 2.1



Gascoyne Region Water Resource Review

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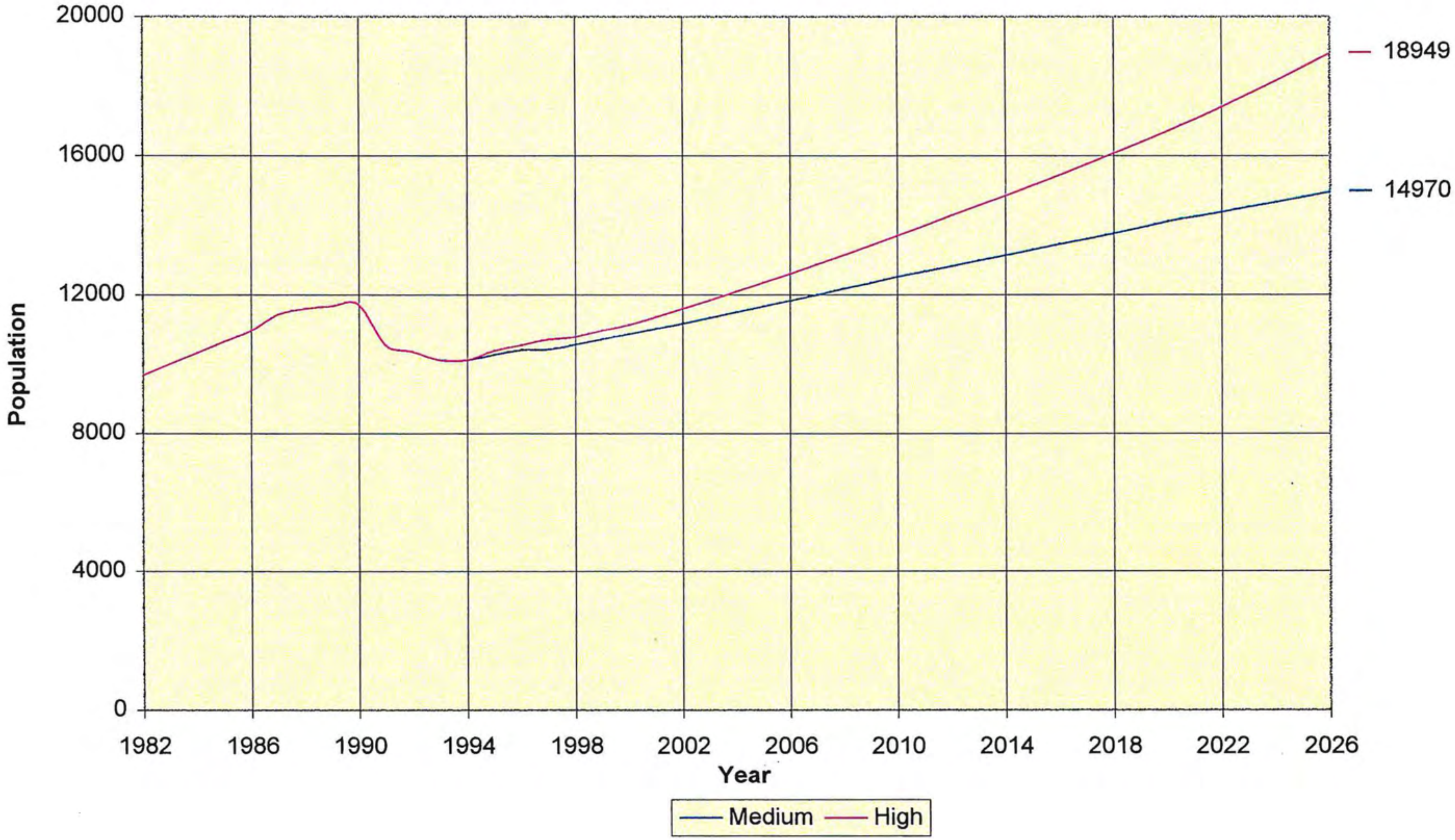
Figure 2.2

Figure 2.3 : Gascoyne Region Population Projections



3. Surface Water

3.1 Introduction

Background information for each river basin is presented in the following sub-section. Potential surface water sources are then described in the next subsection. There are currently no developed existing surface water sources in the Gascoyne Region.

Known potential surface water development sites are shown in Figure 3-1 and are listed in Appendix C. The sources are grouped under Australian Water Resources Council river basins and are listed from upstream to downstream (ie. as each sub-catchment contributes to the total catchment). Information sheets relating to each site are presented in Appendix C.

The hydrology for each site, based on the most up to date data, has been analysed for this study. Only the Mean Annual Flow (MAF) and the yield for a specific reservoir capacity are presented in this report. Should a more comprehensive yield analysis be required, all the necessary data and analysis spreadsheets are available from the Hydrologic Services Section of the Water and Rivers Commission.

3.2 River Basins

River flows in the Gascoyne Region are intermittent and are the result of rainfall runoff in the river catchments. Numerous small tributaries drain into each major river system, particularly in the upper reaches of the catchment.

In the Gascoyne Region, river water is typically turbid, particularly at the commencement of a river flow. Debris, such as leaves and branches are carried down the river, as are red surface sediments of the sparsely vegetated surrounding landscape which gives the river its reddish hue. Considerable redistribution of the river bed alluvium typically occurs with each river flow.

There has generally been no significant clearing in the Gascoyne Region river basins. However, some overgrazing of the natural vegetation has occurred from open range grazing of sheep and cattle on pastoral leases.

3.2.1 Wooramel River Basin (703)

The Wooramel River Basin (703) covers a total area of approximately 40,500 km^2. The Wooramel River rises from sparsely vegetated rangelands situated approximately 350 km inland. It flows through pastoral land for most of its length, descending gradually to the coast in a westward direction, where it discharges into Herald Loop in Shark Bay.

The width of the river channel is highly variable and can be up to 200 m in places. The channel is relatively shallow along it length, being perhaps a maximum depth of 3 m. Moderately spaced woodland, where present, protects the river embankments from degradation.

Surface water data has been collected in the Wooramel River basin since 1973 from gauging stations along the Wooramel River. Duration of river flow averages about 100 days per annum, with the maximum frequency of flow occurring between February and May.

3.2.2 Gascoyne River Basin (704)

The Gascoyne River Basin (704) is the largest basin in the study region, enveloping a total area of approximately 77,600 km^2. The Gascoyne River rises from rangelands situated approximately 780 km inland. It flows through pastoral land for most of its length, descending gradually to the coast, where it discharges into the Indian Ocean at Carnarvon. The Gascoyne River flows generally westwards, although, in its descent it deviates significantly around obstructing ranges before returning to its westward course.

The width of the river channel is highly variable and can be up to 1 km in places. The channel is relatively shallow along it length, being perhaps a maximum depth of 7 m. Moderately spaced woodland, where present, protects the river embankments from degradation. Downstream of Fishy Pool, there is evidence of several distributary or ancestral channels of the Gascoyne River. It is believed that the changes in the river course resulted from changes in sea level or climate or from disruptions caused by faulting.

Surface water data has been collected in the Gascoyne River basin since 1957 from gauging stations along the Gascoyne River. Gauging stations are also located on Yandoo Creek and Lyons River, however, the data from these stations are limited. Duration of flow along the Gascoyne River averages about 100 days per annum at Nine Mile Bridge. The duration of flow is greater at Fishy Pool and averages approximately 150 days per annum. The majority of flow along the Gascoyne River occurs between the months of February and August, although, in some years there is no flow.

Heavy rainfall in the Gascoyne River Basin has the potential to cause severe flooding. A levee, on the southern side of the Gascoyne River near Carnarvon, was constructed to protect the town after significant flooding of the river in 1960 caused widespread damage. The onset of subsequent severe flooding has resulted in the gradual extension of the levee system protecting Carnarvon. Further flood mitigation work is proposed for the town.

3.2.3 Lyndon-Minilya Rivers Basin (705)

The Lyndon-Minilya Rivers Basin (705) covers a total area of approximately 48,300 km^2. The Lyndon and Minilya Rivers are two discrete rivers, which originate from rangelands situated approximately 200 km inland. The Minilya River flows generally westwards, before discharging into Lake MacLeod. From its source, the Lyndon River flows in a northwestward direction. It then diverts to a westward direction and finally flows to the south, before it also discharges into Lake MacLeod. The rivers flow through pastoral land for most of their lengths.

The width of the river channels are variable and may be up to 500 m in places. The river channels are relatively shallow along their length, being perhaps a maximum depth of 3 m. Moderately spaced woodland, where present, protects the river embankments from degradation.

Surface water data has been collected in the Lyndon-Minilya Rivers basin since 1974 from gauging stations along the Lyndon and Minilya Rivers. The duration of flow in the Minilya River averages about 80 days per annum. The duration of flow is less in the Lyndon River and averages approximately 30 days per annum. The majority of flow along the rivers occurs between the months of March and August, although, in some years there is no flow.

3.3 Potential Surface Water Sources

3.3.1 General

The following information is relevant to potential surface water sources such as dams and pipehead dams. Values are interim results and should be treated with due care. There are no existing surface water sources of this nature in the Gascoyne Region. Alternative water source options are described in Chapter 8.

3.3.1.1 Site Classification

Sites are classified as follows:

- DS = Dam site (potential)
- PHS = Pipehead site (potential)

Sites are identified by the distance in kilometres from the ocean or Lake MacLeod or upstream of the confluence with a larger stream or river. Distances are rounded to the nearest kilometre.

3.3.1.2 Streamflow Data

Streamflow data has been based on the period of record from 1975 to 1995. The mean annual flow for specific sites is based on at-site data and regional relationships. The regional relationships have been derived from the average annual rainfall and the level of clearing.

3.3.1.3 Reservoir Yield Data

The reservoir yield data has been based on water balance modelling at specific sites and regional relationships. The water balance modelling is preliminary and is based on the period of record. The regional relationships have been derived, based on the variation of inflow to the reservoirs.

3.3.2 Wooramel River Basin (703)

There are no potential dam sites or pipehead sites in the Wooramel River Basin. Any diversion of flows fromthe Wooramel River Basin must take into consideration any impacts on wetlands near Shark Bay and any impacts on the ecosystems of the Shark Bay heritage area.

3.3.3 Gascoyne River Basin (704)

Several studies between 1978 and 1986 were produced on Gascoyne River yield estimates, simulations, droughts, etc. The most up-to-date statistics are contained in the 1986 Water Authority study "Review of Alternative Sources to Augment Water Supplies to Carnarvon" by Wark and Ventriss.

Estimates in the 1986 report used streamflow simulations which were generated for the Gascoyne River in 1978. These simulations were used in all subsequent studies until 1991 when comparisons were made with more recent statistics which proved the simulated data to be very inaccurate. Despite results being based on streamflow data of poor quality, the 1986 study contains the only available information on the likely yields.

More accurate results would be possible if more detailed modelling was undertaken to include the additional 20 years of streamflow record now available.

Streamflow at the sites in the Gascoyne River Basin are likely to be turbid, due to the erosion of surface sediments from the sparsely vegetated landscape by rainfall runoff. Overgrazing of the natural vegetation by sheep and cattle may increase the risk of erosion, thus increasing the turbidity of the water source. Water treatment may be necessary if the water from these sites is to be used for residential and industrial purposes.

3.3.3.1 Gascoyne River - Lockier Range (Site DS292)

The Gascoyne River has the potential to be regulated by a dam at Site DS292 with a catchment area of 37,000km^2. This dam could be approximately 15m high, producing a storage surface area of 58.5km^2 at the Full Storage Level (FSL) of 250m AHD. The estimated annual average streamflow at the site is 248.6 GL, which produces an estimated annual divertible yield of 50.7GL. The reliability of this estimate is reasonable as the mean annual flow is derived from regional estimates.

If implemented, this resource would most likely be used to supplement the town water supplies to Carnarvon and Gascoyne Junction. The resources could also be used to supplement the water supplies to the Carnarvon irrigation area and possible future developments at Rocky Pool.

The distance from this dam site to any development is likely to be a major constraint to the implementation of this water resource.

3.3.3.2 Gascoyne River - Kennedy Range (Site DS154)

The Gascoyne River has the potential to be regulated by a dam at Site DS154 with a catchment area of 69,792km^2. This dam could be approximately 25m high, producing a storage surface area of 61.6km^2 at the Full Storage Level (FSL) of 140m AHD. The estimated annual average streamflow at the site is 805GL, which produces an estimated annual divertible yield of 235.7GL. The reliability of this estimate is reasonable as the mean annual flow is based on regional estimates obtained from data recorded close to the dam site.

If implemented, this resource would most likely be used to supplement the town water supply to Carnarvon. The resource could also be used to supplement the water supplies to the Carnarvon irrigation area and future developments at Rocky Pool.

The major constraints of this dam site are considered to be the poor storage basin shape and the high evaporation, which may lead to salinity failure of the water resource. Gascoyne Junction may be subject to permanent inundation if this site is implemented, as the town is located just within the likely dam reservoir.

3.3.3.3 Gascoyne River - Rocky Pool (Site DS55)

The Gascoyne River has the potential to be regulated by a pipehead dam at Site DS55 with a catchment area of 73,615km^2. This dam could be approximately 5 m high, producing a storage surface area of 18.2km^2 at the Full Storage Level (FSL) of 43m AHD. The estimated annual average streamflow at the site is 689.7GL, which produces an estimated annual divertible yield of 92.6GL. The reliability of this estimate is reasonable as the mean annual flow is based on regional estimates obtained from data recorded close to the dam site.

If implemented, this resource would most likely be used to supplement the town water supply to Carnarvon. The resource could also be used to supplement the water supplies to the Carnarvon irrigation area and future developments at Rocky Pool.

The height and capacity of this dam are constrained due to the poor topographic characteristics of the site. The width of the Gascoyne River is narrow in this area and the topographic relief is extremely low. If development at Rocky Pool occurs, this could possibly constrain construction of a dam at this site. Several distributary or ancestral channels are present in the area and these may flow when the Gascoyne River is in flood.

3.3.3.4 Gascoyne River -Nine Mile Bridge (Site PHS15)

The Gascoyne River has the potential to be regulated by a pipehead dam at Site PHS15 with a catchment area of 73,746 km^2. This dam could be approximately 5m high, producing a storage surface area of 60.8km^2 at the Full Storage Level (FSL) of 13m AHD. The estimated annual average streamflow at the site is 684.0GL, which produces an estimated annual divertible yield of 4.5GL (80% monthly reliablilty). The reliability of this estimate is good as the mean annual flow is based on data obtained at the dam site.

If implemented, this resource would most likely be used to supplement the water supply to the Carnarvon irrigation area. The resource could also be used to supplement the town water supply to Carnarvon.

The height and capacity of this dam are constrained due to the poor topographic characteristics of the site. The width of the Gascoyne River is narrow in this area and the topographic relief is extremely low. Several distributary or ancestral channels are present in the area and these may flow when the Gascoyne River is in flood.

The area in the vicinity of Carnarvon has value for its fertile land and horticultural developments and should be managed with the goal of maintaining this.

3.3.3.5 Mooka Creek (Site DS16)

Mooka Creek, a tributary of the Gascoyne River, has the potential to be regulated by a dam at Site DS16 with a catchment area of 86km^2. This dam could be approximately 41m high, producing a storage surface area of 3.6km^2 at the Full Storage Level (FSL) of 200m AHD. The estimated annual average streamflow at the site is 0.11GL, which produces an estimated annual divertible yield of 0.04GL. The reliability of this estimate is poor as the mean annual flow is derived from regional estimates.

If implemented, this resource would most likely be used to supplement the water supply to future developments in the Mooka area.

The major constraints of this dam site are considered to be the small catchment area and the lack of sufficient rainfall to the area, which suggests that the dam may rarely be filled to capacity.

3.3.3.6 Mungarra Creek (Site DS18)

Mungarra Creek, a tributary of the Lyons River, has the potential to be regulated by a dam at Site DS18 with a catchment area of 141km^2. This dam could be approximately 45m high, producing a storage surface area of 4.8km^2 at the Full Storage Level (FSL) of 220m AHD. The estimated annual average streamflow at the site is 0.18GL, which produces an estimated annual divertable yield of 0.07GL. The reliability of this estimate is poor as the mean annual flow is derived from regional estimates.

If implemented, this resource would most likely be used to supplement the town water supply to Gascoyne Junction. The resource could also be used to supplement the water supply to future developments in the Mooka area.

The major constraints of this dam site are considered to be the small catchment area and the lack of sufficient rainfall to the area, which suggests that the dam may rarely be filled to capacity.

3.3.4 Lyndon-Minilya Rivers Basin (705)

As for the Gascoyne River Basin, the rivers of the Lyndon-Minilya Rivers Basin experience turbidity problems. These are outlined briefly in Section 3.3.3.

Lake MacLeod and the complex to the south and east of Exmouth Gulf are wetlands of international significance. Any diversion of water from the rivers draining towards and into these needs to be reviewed critically from that viewpoint.

3.3.4.1 Lyndon River (Site PHS193)

The Lyndon River has the potential to be regulated by a pipehead dam at Site PHS193 with a catchment area of 386km². This dam could be approximately 15m high, producing a storage surface area of 29km² at the Full Storage Level (FSL) of 250m AHD. The estimated annual average streamflow at the site is 1.3GL, which produces an estimated annual divertable yield of 0.2GL. The reliability of this estimate is reasonable as the mean annual flow is derived from regional estimates.

If implemented, this resource would most likely be used to supplement the water supply to future developments in the area.

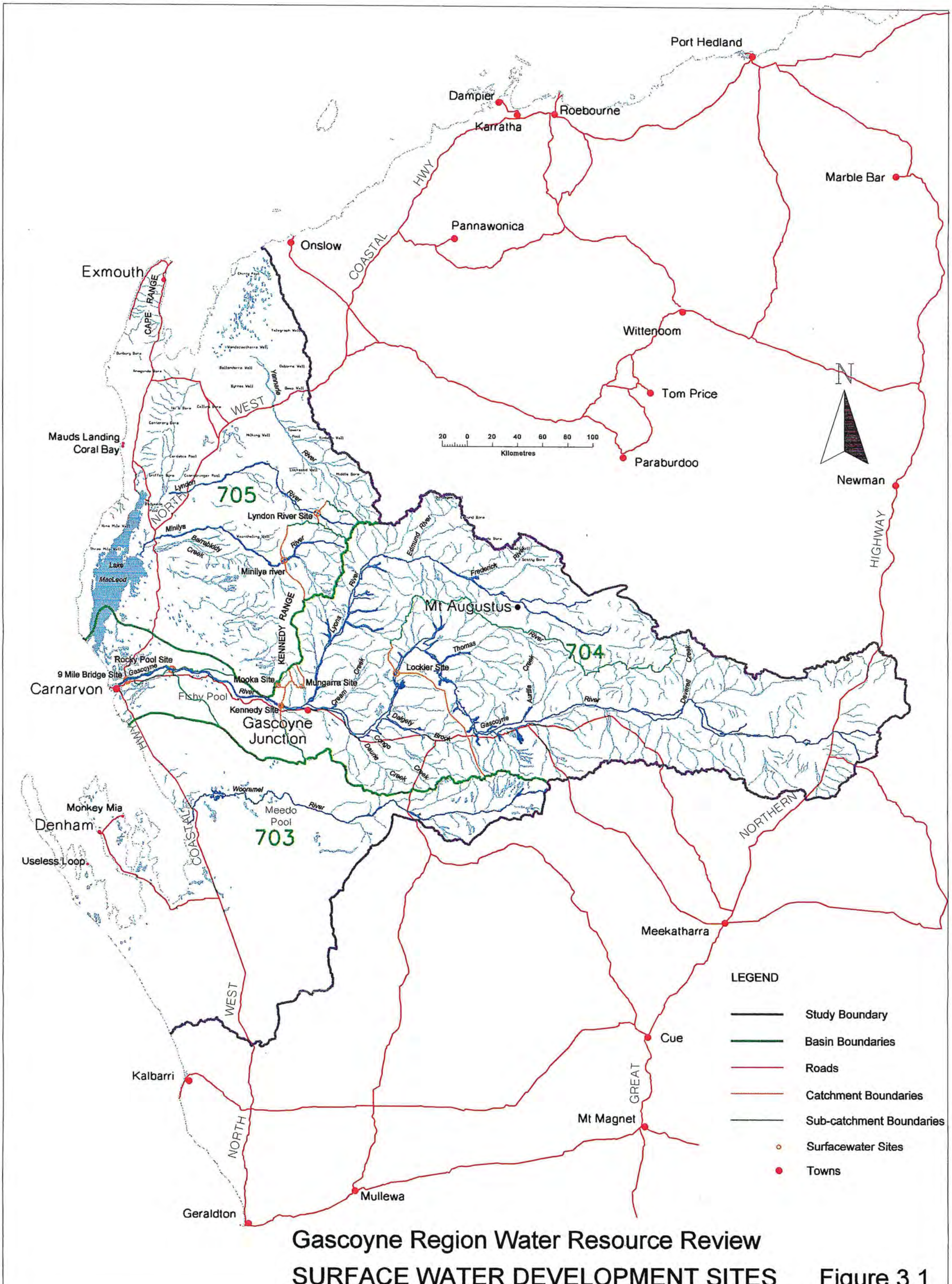
The major constraints of this dam site are considered to be the small catchment area and the lack of sufficient rainfall to the area, which suggests that the dam may rarely be filled to capacity.

3.3.4.2 Minilya River (Site PHS150)

The Minilya River has the potential to be regulated by a pipehead dam at Site PHS150 with a catchment area of 2,142km². This dam could be approximately 10m high, producing a storage surface area of 46.5km² at the Full Storage Level (FSL) of 180m AHD. The estimated annual average streamflow at the site is 20.2GL, which produces an estimated annual divertible yield of 4.7GL. The reliability of this estimate is reasonable as the mean annual flow is derived from regional estimates.

If implemented, this resource would most likely be used to supplement the water supply to future developments in the area.

The major constraints of this dam site are considered to be the small catchment area and the lack of sufficient rainfall to the area, which suggests that the dam may rarely be filled to capacity.



Gascoyne Region Water Resource Review

SURFACE WATER DEVELOPMENT SITES Figure 3.1

4. Groundwater Resources

4.1 Previous Work

Broad-scale estimates of the groundwater resources in the Wooramel, Gascoyne and Lyndon-Minilya River Basis have previously been made for reviews of Australia's water resources, most recently in AWRC (1987). These reviews identify the possible renewable resources in surficial, sedimentary, and fractured rock aquifers within defined salinity ranges. They do not identify the location of major aquifers and are useful mainly for identifying the order of magnitude of available groundwater resources, and for inter-regional comparisons.

Two possible groundwater sources capable of yielding more than 10 GL/year of fresh-marginal groundwater were identified in the Gascoyne Region along the Lower Gascoyne River and in the Birdrong Sandstone by Allen et. al. (1992) in a review of the major groundwater resources in Western Australia for the Kimberley Water Resources Development Office. Four possible groundwater sources in the alluvium and Birdrong Sandstone along the Gascoyne and Wooramel Rivers, possibly suitable for horticultural use, have also been identified by Panasiewicz (1995), who recommended they should be tested.

The regional hydrogeology of the Carnarvon Basin has been described by Allen in Hocking et. al. (1987), and briefly by Allen (1991). The hydrogeology of the fractured rock province to the east has been reviewed by Allen and Davidson (1982), and in the upper part of the Wooramel River Basin by Laws (1994).

Results of specific groundwater projects on the Gascoyne River are given by Baxter (1966), Passmore (1968), Allen (1972), and Martin (1990, 1992). The results of drilling programmes for Exmouth water supply are given by Forth (1973) and Martin (1990), and a general description of the hydrogeology of Cape Range by Allen (1993). Results of drilling for groundwater supplies for construction of the natural gas pipeline and for access roads, mainly in the east Carnarvon Basin, are given in unpublished consultant reports (Rockwater, 1982a-f). These reports give drilling results for bores into the alluvium, Birdrong Sandstone, Mallens Sandstone, Moogooloo Sandstone, and fractured rocks, and provide useful information on groundwater salinity and bore yields.

Other, more general hydrogeological information is available in scheme reviews for the public water supplies and in the explanatory notes for the 1:250,000 geological maps of the area. Various other minor reports by the Geological Survey and consultants reports relating to availability of public, pastoral, industrial and resort water supplies are also available but are not reviewed here.

The information wihch follows is based on work undertaken by Allen (1996) with Rockwater Pty Ltd.

4.2 Runoff

Runoff data for the Wooramel, Gascoyne, and Lyndon-Minilya Rivers are available from the W&RC. River flows are intermittent usually for 3 to 4 months per year, but in some years flow may not occur. Experience indicates that rainfall exceeding about 20 mm (depending on preceding catchment conditions) may produce river flows which vary widely in size and duration depending on the amount and location of rainfall.

4.3 River Basins

The designated river basins (Figure 4-1) follow the river catchments on the dissected upland and interior plateau but on the coastal lowland they include areas not strictly in the basin. For example, the Wooramel River Basin includes large areas of poorly-integrated drainage together with a large area of the lower Gascoyne River delta; and the Lyndon-Minilya River Basin includes small distinct drainage basins such as Yannarie River and on Cape Range.

The areas of the river basins together with respective areas on the Carnarvon Basin and on the Fractured Rock Province are given in Table 4-1.

Table 4.1: Adopted Areas of River Basins in Gascoyne Region

River Basin	Area* (km^2)	Rivers/Minor Drainage	Area (km^2)	Area on Carnarvon Basin (km^2)	per cent	Area on Fractured Rock Province	per cent
Wooramel (703)	40,500	Wooramel R Minor Drainages	17,400 23,100	13,150 23,100	76 100	4,250 -	24 -
Gascoyne (704)	77,600	Gascoyne R**	77,600	24,400	31	53,200	31
Lyndon-Minilya (705)	48,300	Yannarie R Lyndon R Minilya R Minor Drainages	9,200 10,200 8,100 20,800	5,100 8,200 7,050 20,800	55 80 87 100	4,100 2,000 1,050 -	45 20 13 -
TOTALS	166,400		166,400	101,800	-	64,600	-

* Areas from AWRC (1987)
** Does not include large area asssigned to Wooramel River Basin

4.4 Carnarvon Basin

The Carnarvon Basin contains up to 10,000 m of Silurian to Quaternary sedimentary rocks of predominantly marine origin. Over 60 different geological formations are recognised, but of these only about 6 are major aquifers.

The basin is subdivided into a number of structural subdivisions which for simplicity and ease of description have been combined into areas referred to as the western and eastern Carnarvon Basin (Figure 4-1). In the western Carnarvon Basin the strata are generally flat-lying with some faulting and gentle folding, whereas in the eastern Carnarvon Basin they are extensively faulted, locally folded and more-steeply dipping (Figure 4-2). Extensive alluvial deposits associated with the major rivers occur in the western Carnarvon Basin but are only thin and poorly developed in the eastern Carnarvon Basin.

A detailed description of the geology of the basin is given in Hocking et. al. (1987). Other areas are described in the explanatory notes accompanying the 1:250,000 geological maps for the Gascoyne Region.

4.5 Fractured Rock Province

The Fractured Rock Province comprises five major tectonic units of Archaean - Proterozoic age viz the Yilgarn Craton, Gascoyne Province, Bangemall Basin, Glengarry Basin, and Marymia Dome. These units contain metasedimentary rocks including quartzite, banded iron formations, schist, gneiss; and dolerite and granitic intrusive rocks. The rocks are faulted and folded, and range from relatively undeformed to intensely faulted and tightly folded. Numerous large faults and shears occur within the province. Late Tertiary alluvial sediments and calcrete overlie large areas along the main drainages.

Details of the geology can be obtained from the relevant 1:250,000 geological maps.

4.6 Hydrogeology

4.6.1 Occurrence Of Groundwater

A water table recharged from rainfall infiltration and stream flow extends throughout the Gascoyne Region. It occurs irrespective of rock-type at depths ranging to about 40 m below surface in areas of high relief. Below the water table groundwater moves under gravity in shallow, mainly catchment-controlled flow systems of regional extent towards the rivers in the interior plateau and dissected upland, and away from the rivers but towards the coast, on the coastal lowland. Local groundwater mounds occur in some coastal areas (eg. Cape Range), along major drainage divides (eg. between Gascoyne and Lyons Rivers), and possibly beneath some hills and ranges formed by outcropping strata. In the sedimentary basin in favourable situations such as outcrops of sandstone, some of the groundwater moves downward into deep confined flow systems in which the general direction of groundwater movement is towards the coast.

Discharge from the shallow (unconfined groundwater) takes place by subsurface flow into riverine pools, by evapotranspiration, and outflow along the coast. In the confined flow systems, groundwater discharge is inferred to occur offshore via faults or by upward leakage into overlying formations.

Aquifers occur within surficial sediments such as alluvium, calcrete, and coastal dunes, in both the Carnarvon Basin and the Fractured Rock Province. In the sedimentary basin, aquifers occur in discrete formations of sandstone or limestone. In the Fractured Rock Province they occur in localised areas such as fracture zones associated with faults and shears, and in weathered zones. Occasionally, some rock units such as quartzites and dolerites may be aquifers

From inspection of bore data, the salinity of groundwater in the Gascoyne Region is indicated to be mainly in the range 1,500 - 5,000 mg/L TDS with areas of lower-salinity groundwater in recharge areas, along rivers on the coastal lowland, and in areas of high relief. Higher-salinity groundwater occurs at depth in the confined aquifers.

Potentially large groundwater resources occur in the extensive aquifers beneath the western Carnarvon Basin, whereas only moderate to small groundwater resources are likely to occur in the more steeply dipping, folded and faulted aquifers beneath the eastern Carnarvon Basin. In the Fractured Rock Province there are only relatively small groundwater resources in the bedrock. However, there can be moderate to large groundwater resources in the surficial sediments within both the Carnarvon Basin and Fractured Rock Province.

4.6.2 Major Aquifers

The major aquifers identified in the Gascoyne Region are listed in Table 4-2 according to aquifer type (AWRC 1987) together with brief descriptions of their main hydrogeological features. More detailed descriptions of the various aquifers are given below.

4.6.3 Alluvium

The alluvial deposits of the coastal lowland and interior plateau are distinct and considered separately.

On the coastal lowland, the alluvium consists of flood plain (deltaic) deposits which comprise sand in the bed of the river (river bed sand), and various levee and overbank deposits consisting mainly of silt and clay interbedded with sand and minor gravel from former river beds and distributary channels with variable carbonate and ferruginous cementation. The alluvium varies from about 20 m in thickness at the eastern edge of the coastal lowland to about 50 m along the coast. Low salinity groundwater occurs immediately beneath the river beds and for variable distances, up to about 1 km, from the river beds. The siting of high yielding bores within the alluvium is difficult, but sites can be selected with the assistance of geophysics and exploratory drilling. Bores located too far from the river may induce lateral movement of saline groundwater and become brackish. Pumping large supplies of groundwater may affect riverine vegetation and the persistence of some riverine pools.

On the interior plateau, alluvium occurs along the major drainage lines. It results from aggradation of the rivers and infills former deeper channels in the river. The alluvium comprises sand, gravel, clay and local hydrochemical deposits of calcrete and silcrete, possibly deposited in former lakes. It varies considerably in thickness but may be up to 30 m thick in some palaeovalleys. Low salinity groundwater occurs in the upper reaches of the river basins but toward the dissected upland groundwater tends to become brackish. The location of suitable bore-sites can be determined by geophysical methods or drilling transects of bores. Groundwater in these aquifers may become more saline with depth. Pumping may induce movement of adjacent brackish groundwater affecting the groundwater salinity, and could affect riverine pools.

4.6.4 Calcrete

On the interior plateau extensive areas of valley calcrete occur along the main drainage lines. They generally occur upstream of bars of resistant bedrock and are about 10 m thick. The calcrete consists of silty and gravelly limestone and local silcrete. It has large solution openings with resultant high porosity and permeability.

Table 4.2: Major Aquifers in the Gascoyne Region

Aquifer Type	Name & Lithology	Age*	Approx. Max. Thickness (m)	Location**	Salinity Range (mg/L TDS)	Bore Yields (m^3/d)	Remarks
Surficial	River bed sand: fine to very coarse, poorly sorted angular to sub-angular	Q	10		200-800	3000	On flood plains and deltas tend to be silty and clayey, fresh groundwater below and adjacent to rivers
	Alluvium: interbedded, clay and silt, with minor beds of sand and gravel	Q	45	WCB	200-10000	3000	
	Alluvium: interbedded sand, silt, gravel, calcrete and silcrete	LT	?30	FRP	200-10000	?1000	In valleys, more coarse grained than on coastal palin, palaeovalleys may occur
	Calcrete: silty limestone with layers of silcrete and gravel	LT	?10	FRP	200-5000	?2000	In valleys, often partly dissected, may be mainly above water table
	Tamala Limestone: aeolian and shallow water marine limestone	LT	100	WCB	200-6000	?2000	South-west coast, lenses of freshwater on seawater
Sedimentary	Tertiary limestone (undifferentiated): friable to dense limestone, local interbeds of sand, karstic	LT	500	WCB	600-10000	?1000	Large bore yields may be obtainable from karstic limestone; lenses of freshwater on seawater
	Birdrong Sandstone: fine to coarse, glauconitic, carbonaceous, pyritic and conglomeratic	K	30	WCB	500-35000	4500	Occurs beneath all of western Carnarvon Basin; artesian over wide areas, fresh in recharge areas
	Mallens Sandstone: fine to medium, fossiliferous	P	150	ECB	500-10000	2000	Numerous faults, locally folded, possible local artesian flows
	Moogooloo Sandstone: fine to coarse, with minor beds of conglomerate and siltstone	P	50	DU ECB	500-6000	1500	Numerous faults, possible local artesian flows
	Tumblagooda Sandstone: partially silicified, medium to coarse, with local interbeds of siltstone	S	1000+	CL ECB	5000-10000	1820	Extensive aquifer; deep, warm water, probably artesian over a large area
Fractured Rock	Metamorphic and igneous rocks (undifferentiated)	A-P	-	FRP	200-10000	?1000	Groundwater from fractured resistant units, faults, shears and weathered zones

* Q = Quaternary; LT = Late Tertiary; ET = Early Tertiary; k = Cretaceous; P = Permian; S = Silurian; A-P = Archaean to Proterozoic.
** WCB = Western Carnarvon Basin; ECB = Eastern Carnarvon Basin; FRP = Fractured Rock Province

Immediately upstream of the Carnarvon Basin the calcretes are dissected and may not contain significant groundwater, but towards the head of the rivers they are not dissected and are likely to be significant aquifers. Large individual bore yields are possible and small areas may have significant resources. The groundwater salinity may deteriorate if there are long periods without recharge.

4.6.5 Tamala Limestone

The Tamala Limestone comprises coastal dune deposits with some local shallow marine sand. It consists primarily of fine to medium calcareous sand which has been cemented by calcium carbonate to form a friable limestone with a hard capstone. The formation is up to 100 m above sea level along the south coast but probably extends only about 30 m below sea level. Groundwater in the limestone occurs as a lens overlying seawater or above a sea water wedge. In some locations bores have to be pumped at low rates to prevent upconing and pumping of saline groundwater.

4.6.6 Tertiary Limestone

The Tertiary limestone comprises several geological formations which are exposed on Cape Range. The formations consist of friable to dense fossiliferous limestone and marl with local interbeds of sand. Some of the pure and friable limestone has undergone extensive solution and caves and large solution openings have developed. The limestone is up to 500 m thick but the main aquifer potential and highest bore yields are limited to a zone about 100 m thick whose location and exposure is controlled by the geological structure. The groundwater overlies seawater along the coast which limits pumping rates because of upconing of seawater. In addition, in cave systems around the coast, unique aquatic troglobite fauna is present and pumping of groundwater has to be carefully managed.

4.6.7 Birdrong Sandstone

The Birdrong Sandstone is a fine to coarse friable, pebbly and silty sandstone about 30 m thick. It extends over an area of about 50,000 km^2 and is the most extensive aquifer in the Gascoyne Region. It is locally exposed along the eastern edge of the Coastal Lowland but for most of its extent is confined beneath sediments of low permeability. Artesian conditions occur over a wide area and fresh groundwater is limited to recharge areas. Relatively large bore yields can be obtained but before large borefields are established, the extent of fresh groundwater needs to be determined so that pumping, inducing capture of brackish groundwater, can be avoided.

4.6.8 Mallens Sandstone

The Mallens Sandstone is a fine to medium grained sandstone confined between thick formations consisting mainly of siltstone and shale. The formation is up to 150 m thick but its extent and continuity is broken by faulting and folding. It contains confined groundwater and can yield large supplies. As for the Birdrong Sandstone, the extent of any freshwater would need to be defined and the behaviour of the aquifer, especially with respect to boundary conditions, determined before any large-scale schemes were established.

4.6.9 Moogooloo Sandstone

The Moogooloo Sandstone is a fine to coarse grained sandstone with interbeds of conglomerate and siltstone about 50 m thick. It commonly forms local hills and ranges and is dislocated by numerous faults. Appropriately designed bores can yield large supplies of groundwater but the location of any wellfields would need to be carefully selected and pumping managed to prevent possible ingress of brackish groundwater.

4.6.10 Tumblagooda Sandstone

The Tumblagooda Sandstone is a partially silicified medium to coarse sandstone about 1,000 m thick occurring at depth beneath all of the western Carnarvon Basin. Bores can yield large supplies of artesian groundwater. However, the salinity is likely to be highly variable and increase with depth and the temperature of the groundwater is likely to be more than 40°C.

4.6.11 Fractured Rocks

The fractured rocks comprise metamorphic and igneous rocks such as schist, quartzite, banded iron formations, and basic volcanics, intruded by dolerite and granitic rocks. Local aquifers occur in fractured and weathered zones. Bore yields are generally small and salinity is likely to be highly variable. Successful sites may be difficult to locate and bores need to be carefully tested to determine their long-term yields. The salinity of groundwater from the bores may vary with time. Groundwater from these aquifers should be analysed for trace elements prior to use.

4.7 Groundwater Resources

4.7.1 Methods

The areas of the major aquifers were measured to the nearest 5 km^2 (except alluvium on Gascoyne and Wooramel Rivers) from the 1:250,000 geological maps. The areas of alluvium, particularly on the Fractured Rock Province are somewhat subjective, while the area of outcrop of the Mallens Sandstone and Moogooloo Sandstone were taken to include some areas occurring beneath alluvium. The sub-crop of the Birdrong Sandstone and Tumblagooda Sandstone were measured from 1:1,000,000 maps from Hocking et. al. (1987).

The renewable groundwater resources for the major aquifers were estimated as follows:

- Alluvium (Coastal Lowland): the groundwater resources were calculated from an assumed area of river bed and daily infiltration rate, multiplied by the average number of days of recorded river flow from stream gauging data. The validity of this method is the subject of debate between hydrogeologists. Storage curves are an alternative method used to determine storage estimates and are derived from water levels.
- Alluvium (Interior Plateau), calcrete, Tamala Limestone, Tertiary limestone, Mallens Sandstone and Moogooloo Sandstone and undifferentiated fractured rocks: the groundwater resources were calculated from the area of outcrop, multiplied by the annual rainfall and a recharge factor adopted from values used in the national review of water resources (AWRC 1987).
- Birdrong Sandstone and Tumblagooda Sandstone: the groundwater resources were calculated by throughflow calculations based on assumed aquifer thickness, hydraulic conductivities, and isopotential gradients given by Allen in Hocking et. al. (1987). The isopotential gradient in the Tumblagooda Sandstone was assumed to be the same as for the Birdrong Sandstone at the southern end of the Carnarvon Basin. This method may produce estimates which are higher than the actual yields of the aquifers.

The stored groundwater resources were estimated from the areas of the aquifers multiplied by an assumed thickness and specific yield. In the case of the Mallens Sandstone and Moogooloo Sandstone, because of the structural complexity, the volume in storage relates only to an area the size of the outcrop and is an underestimate of the stored groundwater resources. In the fractured rocks, the stored groundwater resources were assumed to occur for 30 m below the water table.

The salinity categories were determined from maps of the known bores and wells on which the salinity data had been plotted, which were loaned by the W&RC.

The various calculations by locality for the renewable and stored groundwater resources are given in Appendix D.

4.7.2 Wooramel River Basin

Data for the Wooramel River Basin are summarised below and the estimated groundwater resources by aquifer and locality are given in Table 4-4. The locations of the major aquifers are shown in Figure 4-3.

Geographical Data

AWRC No.: 703
Nominal Area: 40,500 km^2
River Catchment Area: 17,400 km^2 (approx.)
Climate: Arid - semi arid
Average Rainfall: 300 mm - 220 mm (coast - inland)
Average Pan Evaporation: 2,600 mm - 3,400 mm (coast - inland)
Length of River; 350 km (approx.)
Mean Annual Flow: 46 GL
Mean Flow Duration: 103 days*

Hydrogeological Data

Area on Carnarvon Basin: 36,690 km^2
Area on Fractured Rock Province: 3,810 km^2
Major Aquifers: Surficial
- Alluvium (CB) 0.5 km^2
- Alluvium (FRP) 1,460 km^2
- Tamala Limestone 900 km^2
- Calcrete 150 km^2

Sedimentary
- Birdrong Sst 14,600 km^2
- Mallens Sst 155 km^2
- Moogooloo Sst 160 km^2
- Tumblagooda Sst 9,600 km^2

Fractured Rock
- Undifferentiated 2,200 km^2

Table 4.3: Groundwater Resources in Major Aquifers

	<1000 (mg/L TDS)	1000 - 3000 (mg/L TDS)	>3000 (mg/L TDS)
Renewable Resources (GL)	2.2	36.0	6.4
Stored Resources (GL)	1,420	17,800	323,700

*Flow duration has been obtained from 1982 data and will be updated by the Hydrology Section in due course.

*Table 4.4: Wooramel River Basin Estimated Groundwater Resources in Major Aquifers for Localities**

Ref No.	Aquifer	Locality	Area (km^2)	Renewable (GL) Salinity (mg/L TDS)			Stored (GL) Salinity (mg/L TDS)				Comments
				<1000	1000-3000	3000-10000	<1000	1000-3000	3000-10000	>10000	
1	Alluvium	Wooramel - Meedo	0.4	1.8	-	-	30	-	-	-	Renewable 35km x 50m Stored 35km x 200m
2	Alluvium	Upper Wooramel	1460	-	2.9	-	-	590	-	-	Assumed 8m saturated
3	Tamala	Dirk Hartog Island	700	-	-	21.0	-	-	4900	-	High saltfall affects salinity
4	Tamala	Heirisson Prong	200	-	-	6.0	-	-	1400	-	High saltfall affects salinity
5	Calcrete	Innouendy	100	-	1.0	-	-	160	-	-	Assumed 8m saturated
6	Calcrete	Salt Bore	50	-	0.5	-	-	70	-	-	Assumed 8m saturated
7	Birdrong Sst	Coastal	14600	0.3	1.0	3.6	1200	6900	27680	8100	Stored resources proportioned from isohaline map
8	Mallens Sst	Bogadie Syncline	155	?	1.7	-	-	2250	-	-	Stored resources in outcrop only. Possilbe areas <1000mg/L
9	Moogooloo Sst	Pindilya	85	?	0.9	-	-	390	-	-	Possible areas <1000mg/L
10	Moogooloo Sst	Darcy Hill	60	?	0.7	-	-	270	-	-	Possible areas <1000mg/L
11	Moogooloo Sst	Ballythanna Anticline	15	-	0.2	-	-	680	-	-	-
12	Tumblagooda Sst	Coastal	9600	-	-	2.8	-	-	?144000	?144000	Estimates very doubtful
13	Fractured Rock (Undifferentiated)	Upper Wooramel	2200	0.1	0.1	-	140	160	100	-	No large sources indentified

* *see Figure 4.3*

4.7.3 Gascoyne River Basin

Data for the Gascoyne River Basin are summarised below and the estimated groundwater resources by aquifers and locality are given in Table 4-6. The locations of the major aquifers are shown in Figure 4-4.

Geographical Data

AWRC No.: 704
Nominal Area: 77,600 km²
River Catchment Area: Large area of delta not included
Climate: Arid - semi arid
Average Rainfall: 250 mm - 200 mm (coast - inland)
Average Pan Evaporation: 2,600 mm - 3,800 mm (coast - inland)
Length of River; 780 km (approx.)
Mean Annual Flow: 684 GL (nine-mile bridge)
Mean Flow Duration: 105 days (nine-mile bridge)*

Hydrogeological Data

Area on Carnarvon Basin: 24,400 km² (approx)
Area on Fractured Rock Province: 53,200 km² (approx)
Major Aquifers: Surficial
- Alluvium (CB) 105 km²
- Alluvium (FRP) 8,720 km²
- Calcrete 9,310 km²

Sedimentary
- Birdrong Sst 9,200 km²
- Mallens Sst 190 km²
- Moogooloo Sst 530 km²
- Tumblagooda Sst 8,000 km²

Fractured Rock
- Undifferentiated 47,000 km²

Table 4.5: Groundwater Resources in Major Aquifers

	<1000 (mg/L TDS)	1000 - 3000 (mg/L TDS)	>3000 (mg/L TDS)
Renewable Resources (GL)	66.7	18.3	10.2
Stored Resources (GL)	5,110	20,830	258,560

* Flow duration has been obtained from 1982 data and will be updated by the Hydrology Section in due course.

*Table 4.6: Gascoyne River Basin Estimated Groundwater Resources in Major Aquifers for Localities**

Ref No.	Aquifer	Locality	Area (km²)	Renewable (GL) Salinity (mg/L TDS)			Stored (GL) Salinity (mg/L TDS)				Comments
				<1000	1000-3000	3000-10000	<1000	1000-3000	3000-10000	>10000	
1	Alluvium	Gascoyne mouth - Rocky Pool	55	28.5	-	-	140	-	-	-	River bed 35km and zone 1km wide to 50m assumed aquifer
2	Alluvium	Rocky Pool - Fishy Pool	50	16.0	-	-	90	-	-	-	River bed 35km and zone 1km wide to 35m assumed aquifer
3	Alluvium	Upper Lyons R	1990	1.5	2.2	0.7	280	400	120	-	Includes local calcrete
4	Alluvium	Upper Gascoyne R	6730	7.0	4.4	3.4	1280	800	610	-	Includes local calcrete
5	Calcrete	Alma Island	260	-	2.9	-	-	420	-	-	Upper Lyons
6	Calcrete	James creek	95	-	-	1.1	-	-	150	-	Upper Gascoyne
7	Calcrete	Scrubber Bore	110	-	-	1.2	-	-	180	-	Upper Gascoyne
8	Calcrete	Sawback Pool	50	-	-	-	-	80	-	-	Upper Gascoyne
9	Calcrete	Beasley Well	75	0.8	0.6	-	120	-	-	-	Upper Gascoyne
10	Birdrong Sst	Coastal	9200	12.4	-	-	150	12150	15300	-	Renewable resource assumed all <1000mg/L
11	Mallens Sst	Binthabooka	120	?	1.3	-	?	1740	-	-	Possible area <1000mg/L
12	Mallens Sst	Bitter Well	70	-	0.8	-	-	1020	-	-	Assumed all 1000- 3000mg/L
13	Moogooloo Sst	Tabletop	70	-	0.8	-	?	320	-	-	Possible area <1000mg/L
14	Moogooloo Sst	Pell Range	70	-	0.8	-	-	320	-	-	Drilled for gas pipeline (Rockwater 1982d)
15	Moogooloo Sst	Boonaberrie	100	-	1.1	-	-	450	-	-	Assumed all 1000-3000mg/L
16	Moogooloo Sst	Yinnillia	65	-	0.7	-	-	300	-	-	Assumed all 1000-3000mg/L
17	Moogooloo Sst	Jar Creek	125	-	1.4	-	-	570	-	-	Assumed all 1000-3000mg/L
18	Moogooloo Sst	Daurie Creek	100	-	1.1	-	-	450	-	-	Assumed all 1000-3000mg/L
19	Tumblagooda Sst	Brickhouse	8000	-	-	3.4	-	-	?120000	?120000	Estimate very doubtful
20	Fractured rocks (Undifferentiated)	Upper Lyons	14850	0.1	-	-	810	-	-	-	Local aquifers and local areas of high and low salinity
21	Fractured rocks (Undifferentiated)	Upper Gascoyne	32150	0.4	0.1	0.3	2240	870	1720	-	Local aquifers and local areas of high and low salinity

* *see Figure 4.4*

4.7.4 Lyndon-Minilya River Basin

Data for the Lyndon-Minilya River Basin are summarised below, and the estimated groundwater resources by aquifers and locality are given in Table 4-8. The locations of the major aquifers are shown in Figure 4-5.

Geographical Data

AWRC No.:	705
Nominal Area:	48,300 km^2
River Catchment Area:	27,500 km^2 for Lyndon, Minilya and Yannarie (approx.)
Climate:	Arid - semi arid
Average Rainfall:	250 mm
Average Pan Evaporation:	2,800 mm - 3,400 mm (coast - inland)
Length of River;	1200 km (approx.)
Mean Annual Flow:	Lyndon: 13 GL Minilya: 42 GL
Mean Flow Duration:	Lyndon: 15 days* Minilya: 75 days*

Hydrogeological Data

Area on Carnarvon Basin: 41,150 km^2 (approx)
Area on Fractured Rock
Province: 7,150 km^2 (approx)
Major Aquifers: Surficial
- Alluvium (CB) 115 km^2
- Alluvium (FRP) 60 km^2
- Calcrete 70 km^2

Sedimentary
- Tertiary limestones 7,200km^2
- Birdrong Sst 24,500 km^2
- Moogooloo Sst 155 km^2
- Tumblagooda Sst 8,000km^2

Fractured Rock
- Undifferentiated 7,300 km^2

Table 4.7: Groundwater Resources in Major Aquifers

	<1000 (mg/L TDS)	1000 - 3000 (mg/L TDS)	>3000 (mg/L TDS)
Renewable Resources (GL)	22.2	26.8	-
Stored Resources (GL)	1,035	14,355	14,700

*Flow duration has been obtained from 1982 data and will be updated by the Hydrology Section.

*Table 4.8: Lyndon - Minilya River Basin Estimated Groundwater Resources in Major Aquifers for Localities**

Ref No.	Aquifer	Locality	Area (km²)	Renewable (GL) Salinity (mg/L TDS)			Stored (GL) Salinity (mg/L TDS)				Comments
				<1000	1000-3000	3000-10000	<1000	1000-3000	3000-10000	>10000	
1	Alluvium	Yannarie R	100	0.2	0.1	-	25	20	-	-	River infiltrates into lowland, does not reach sea.
2	Alluvium	Lyndon R	60	-	0.2	-	-	30	-	-	May includes minor calcrete
3	Alluvium	Minilya R	15	-	0.1	-	-	5	-	-	May include minor calcrete
4	Calcrete	Brady Ck	30	-	0.4	-	-	50	-	-	May include minor calcrete
5	Calcrete	Mountain Ck	40	-	0.5	-	-	60	-	-	May include minor calcrete
6	Tertiary Lst (undifferentiated)	Cape Range	5600	20.0	10.0	-	800	2000	-	-	Large part inaccessible or National Park
7	Tertiary Lst (undifferentiated)	Quobba	1600	-	4.0	-	-	800	-	-	Groundwater lens over seawater
8	Birdrong Sst	Coastal	24500	2.0	8.6	-	200	9600	9800	4900	Stored resources estimated from isohaline map (Allen 1987)
9	Moogooloo Sst	Moogooloo Hill	115	-	1.3	-	-	520	-	-	Stored resources in outcrop only
10	Moogooloo Sst	Karla Well	25	-	0.3	-	-	110	-	-	Stored resources in outcrop only
11	Moogooloo Sst	Red Monkey B	15	-	0.2	-	-	70	-	-	Stored resources in outcrop only
12	Fractured rocks (undifferentiated)	Upper Basin	7300	-	0.2	-	-	1100	-	-	No major aquifers

* *see Figure 4.5*

4.7.5 Fresh Groundwater Resources

The fresh groundwater resources in the Gascoyne Region are listed in Table 4-9 and their locations (from Figure 4-3 to Figure 4-5) plotted in Figure 4-6. It can be seen that the estimated renewable groundwater resources are only about 90 GL in total and vary widely in size between different sources. Also, that resources of uncertain, but probably small size, occur in a number of areas.

The largest fresh groundwater resources known with certainty are in the alluvium along the lower Gascoyne River and in the Tertiary limestones on Cape Range. Other actual or potential fresh groundwater resources, especially in the Birdrong Sandstone and in alluvium and calcrete in the upper Gascoyne catchment, need to be confirmed.

4.8 Current Groundwater Usage

The Gascoyne Region is sparsely populated. The majority of people live in the townships, with families and smaller communities living on pastoral properties and mine-sites. In addition, mainly during the winter months, there is a large transient population at various popular tourist locations.

Domestic water supplies for Exmouth, Carnarvon, Gascoyne Junction and Denham are provided by the Water Corporation (Table 4-10). Small self-supplied domestic supplies utilised on remote, tourist developments, pastoral properties, roadhouses and elsewhere are drawn from bores and wells tapping a variety of aquifers. Some roadhouse establishments obtain water from superficial aquifers, while others draw water from artesian aquifers which may require desalination.

Stock water supplies from shallow wells and bores are used throughout the Gascoyne Region. In the western Carnarvon Basin these supplies are frequently obtained from uncontrolled flows from partially collapsed artesian bores most of which are about 80 years old. The uncontrolled flow taking place is expected to be in the order of 45 GL per annum (Allen, 1986). This estimate may be high, however, even if it was conservatively estimated, it would still exceed the total recharge of 27.9 GL per annum to the aquifer of which only 17.3 GL per annum is recharged to the most heavily exploited part of the aquifer.

Capping of the artesian bores to limit the uncontrolled flow of water is desirable. The main effect of controlling the artesian flows would be to maintain artesian pressures over a relatively large area for an indefinite period. This would reduce the necessity for windmills or pumps in some areas and thus reduce operating costs to some station owners. A secondary effect of controlling artesian flows is to conserve groundwater.

Industrial supplies are obtained from artesian bores at saltworks on Lake MacLeod and on Heirisson Peninsula. The tourist resorts at Coral Bay and Monkey Mia also uses artesian groundwater, some of which is desalinated for domestic use.

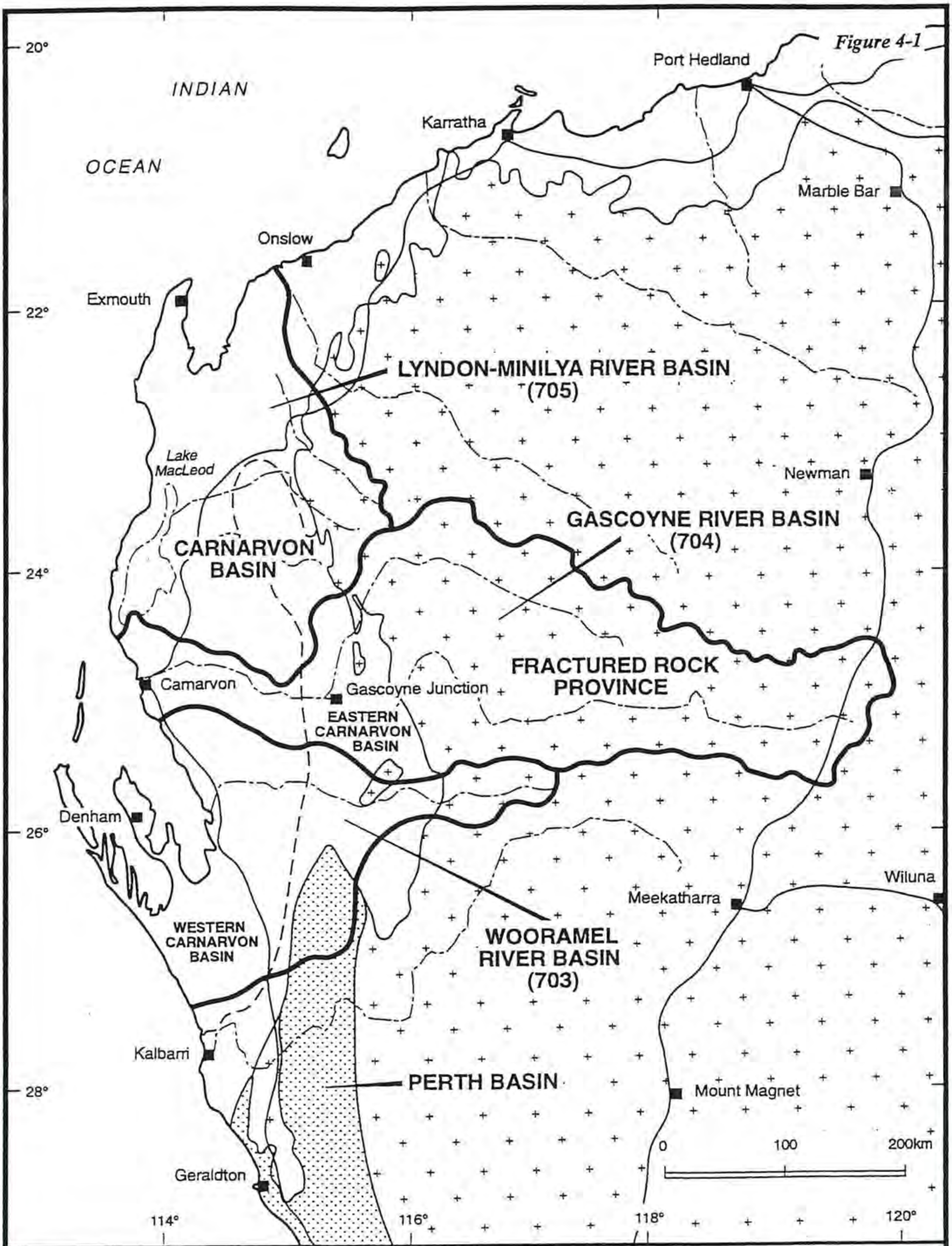
Table 4.9: Gascoyne Region Fresh Groundwater resources in Major Aquifers

Ref No.	Aquifer	Locality	Area (km^2)	Renewable (GL)	Stored (GL)	Comments
LM-1	Alluvium	Yannarie R	100	0.2	25	Untested
G-1	Alluvium	Gascoyne Mouth - Rocky Pool	55	28.5**	140	Proximity of adjacent brackish groundwater in alluvium
G-2	Alluvium	Rocky Pool - Fishy Pool	50	16.0***	90	Proximity of adjacent brackish groundwater in alluvium and need to protect vegetation upstream of Rocky Pool
W-1	Alluvium	Wooramel - Meedo	0.4	1.8	30	Untested
G-3	Alluvium	Upper Lyons River	1990	1.5	280	Possible impact on riverine pools and vegetation
G-4	Alluvium	Upper Gascoyne River	6730	7.0	1280	Possible impact on riverine pools and vegetation
G-9	Calcrete	Beasley Well	75	0.8	120	Untested; calcrete may be mainly above water table
LM-8	Tertiary limestone	Cape Range	5600	20.0	800	Most of aquifer inaccessible because of topography and presence of Nation Park; fresh groundwater overlies seawater; aquatic fauna in caves*
LM-8	Birdrong Sst	Coastal (Kennedy Range)	24500	2.0	200	Proximity of large area of brackish groundwater
G-10	Birdrong Sst	Coastal (Mooka Area)	9200	12.4	150	Recharge area from Gascoyne River, untested
W-7	Birdrong Sst	Coastal (Meedo Area)	14600	0.3	1200	Recharge area from Wooramel River, untested
G11	Mallens Sst	Binthabooka	120	?	?	Possible recharge area from Lyons River, untested
W8	Mallens Sst	Bogardie Syncline	155	?	?	Possible recharge area from Wooramel River, untested
G13	Moogooloo Sst	Table Top	70	?	?	Possible recharge area from Lyons River, untested
W9	Moogooloo Sst	Pindilya	85	?	?	Possible recharge area from Wooramel River, untested
W10	Moogooloo Sst	Darcy Well	60	?	?	Possible recharge area from Wooramel River, untested
G20	Fractured rocks (undifferentiated)	Upper Lyons	14850	0.1	810	Numerous possible sites for small water supplies, possible impact on riverine pools and vegetation
G21	Fractured rocks (undifferentiated)	Upper Wooramel	32150	0.4	2240	Numerous possible sites for small water supplies, possible impact on riverine pools and vegetation
			TOTALS:	91.0	7365	

** see Figure 4.6 ** Differs from Martin (1990) because of different assumptions. *** Differs from Panasiewicz (1995) because of different length of river considered*

Table 4.10: Summary of Public Water Supply Schemes operating in Gascoyne Region

Scheme	Aquifer	Yield (GL)	Description
Exmouth	Tertiary limestone	0.96	Borefield extends 8km along coastal plan on eastern side of Cape Range. Comprises 44 bores pumping from freshwater lens overlying seawater.
Carnarvon	Alluvium	5.76	Borefield extends 33km along Gascoyne River, comprises 63 bores pumping from river bed and immediately underlying alluvium. Used for public water supply and Gascoyne Irrigation Scheme.
Gascoyne Junction	Alluvium	0.30	Borefield near town, comprises 3 bores in river bed sand. Groundwater tends to become saline when long period between river flows.
Denham	Birdrong Sandstone	0.08	Two artesian bores (one standby) in townsite yielding groundwater of 4500mg/L TDS and 45°C, is desalinated in reverse osmosis plant which delivers water with salinity of about 150 - 500mg/L TDS. Problems experienced with clogging of membrane by algae.



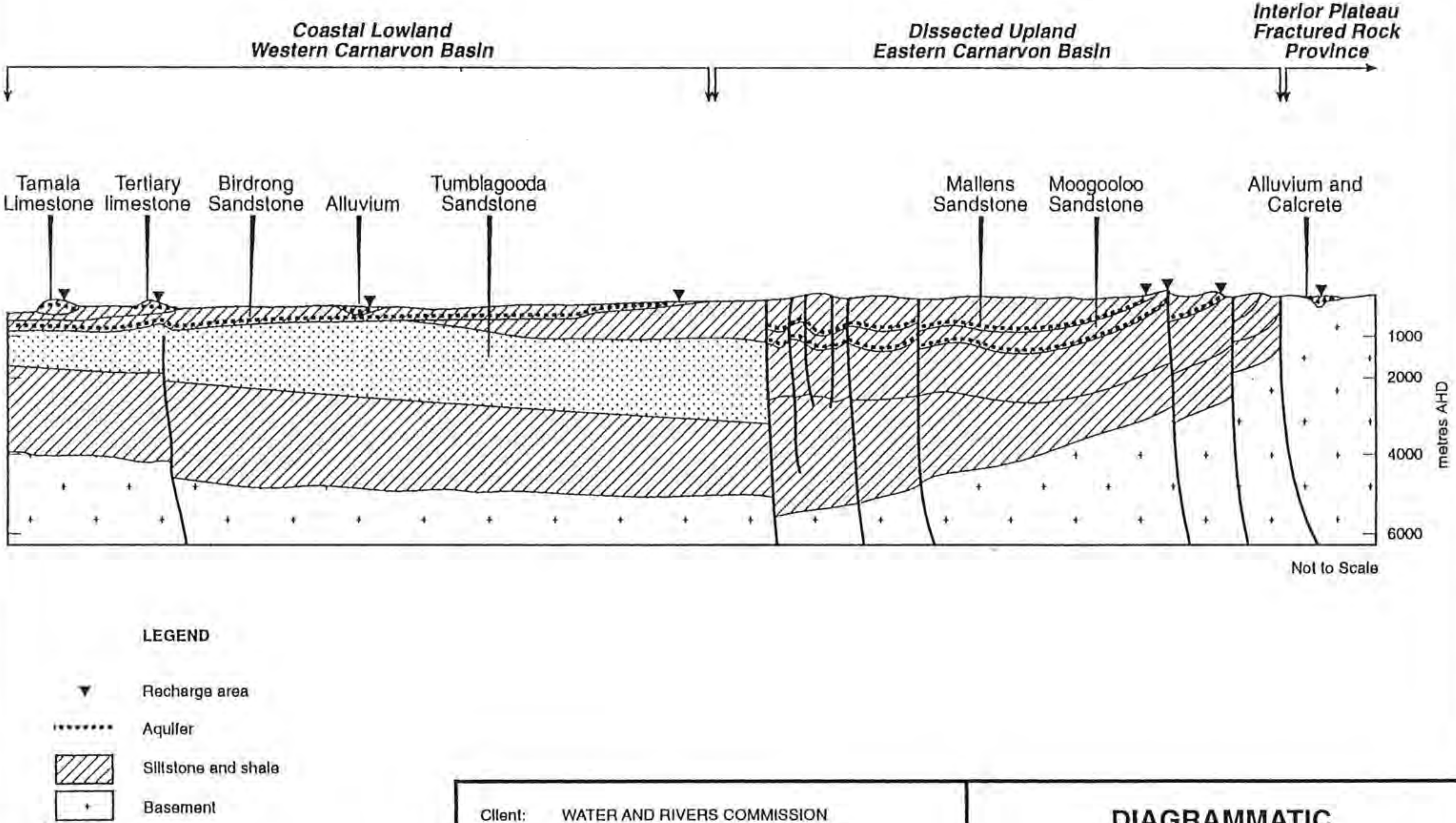
Client: WATER AND RIVERS COMMISSION

Project: GROUNDWATER RESOURCES OF THE GASCOYNE REGION

Date: JULY 1996 Dwg. No: 107.12/96/1-1

LOCATION MAP

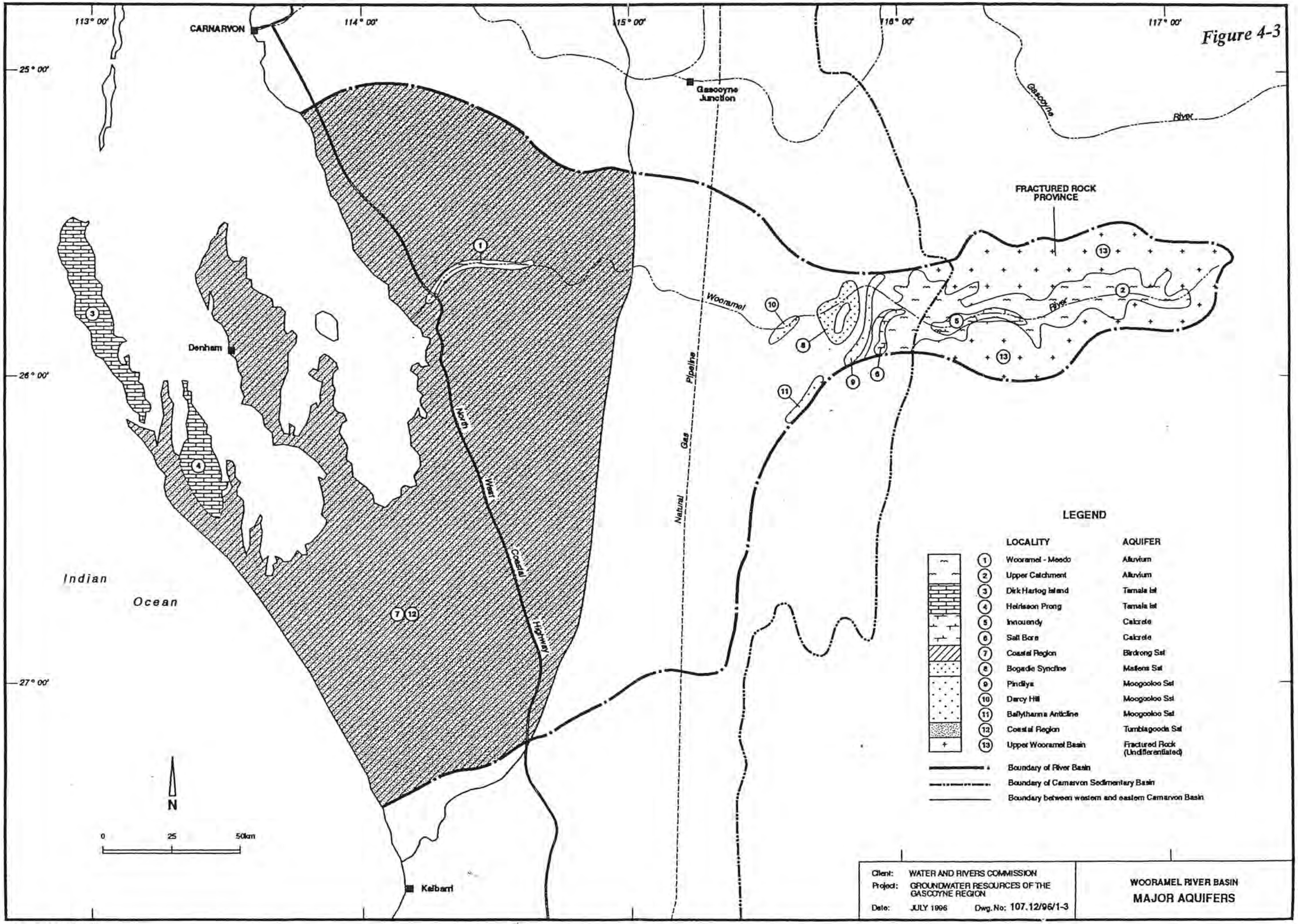
Figure 4-2



Client: WATER AND RIVERS COMMISSION Project: GROUNDWATER RESOURCES OF THE GASCOYNE REGION Date: JULY 1996 Dwg. No: 107.12/96/1-2	**DIAGRAMMATIC HYDROGEOLOGICAL CROSS SECTION**

ROCKWATER PTY LTD

Figure 4-3



113° 00'
114° 00'
115° 00'
116° 00'
117° 00'
25° 00'
26° 00'
27° 00'
CARNARVON
Gascoyne Junction
Gascoyne
River
FRACTURED ROCK PROVINCE
Wooramel
River
Denham
Indian
Ocean
North West Coastal Highway
Natural Gas Pipeline
Kalbarri
N
0
25
50km
LEGEND
LOCALITY
AQUIFER
1 Wooramel - Meedo — Alluvium
2 Upper Catchment — Alluvium
3 Dirk Hartog Island — Tamala lst
4 Heirisson Prong — Tamala lst
5 Innouendy — Calcrete
6 Salt Bore — Calcrete
7 Coastal Region — Birdrong Sst
8 Bogadie Syncline — Mallens Sst
9 Pindilya — Moogooloo Sst
10 Darcy Hill — Moogooloo Sst
11 Ballythanna Anticline — Moogooloo Sst
12 Coastal Region — Tumblagooda Sst
13 Upper Wooramel Basin — Fractured Rock (Undifferentiated)
Boundary of River Basin
Boundary of Carnarvon Sedimentary Basin
Boundary between western and eastern Carnarvon Basin
Client: WATER AND RIVERS COMMISSION
Project: GROUNDWATER RESOURCES OF THE GASCOYNE REGION
Date: JULY 1996
Dwg. No: 107.12/96/1-3
WOORAMEL RIVER BASIN
MAJOR AQUIFERS

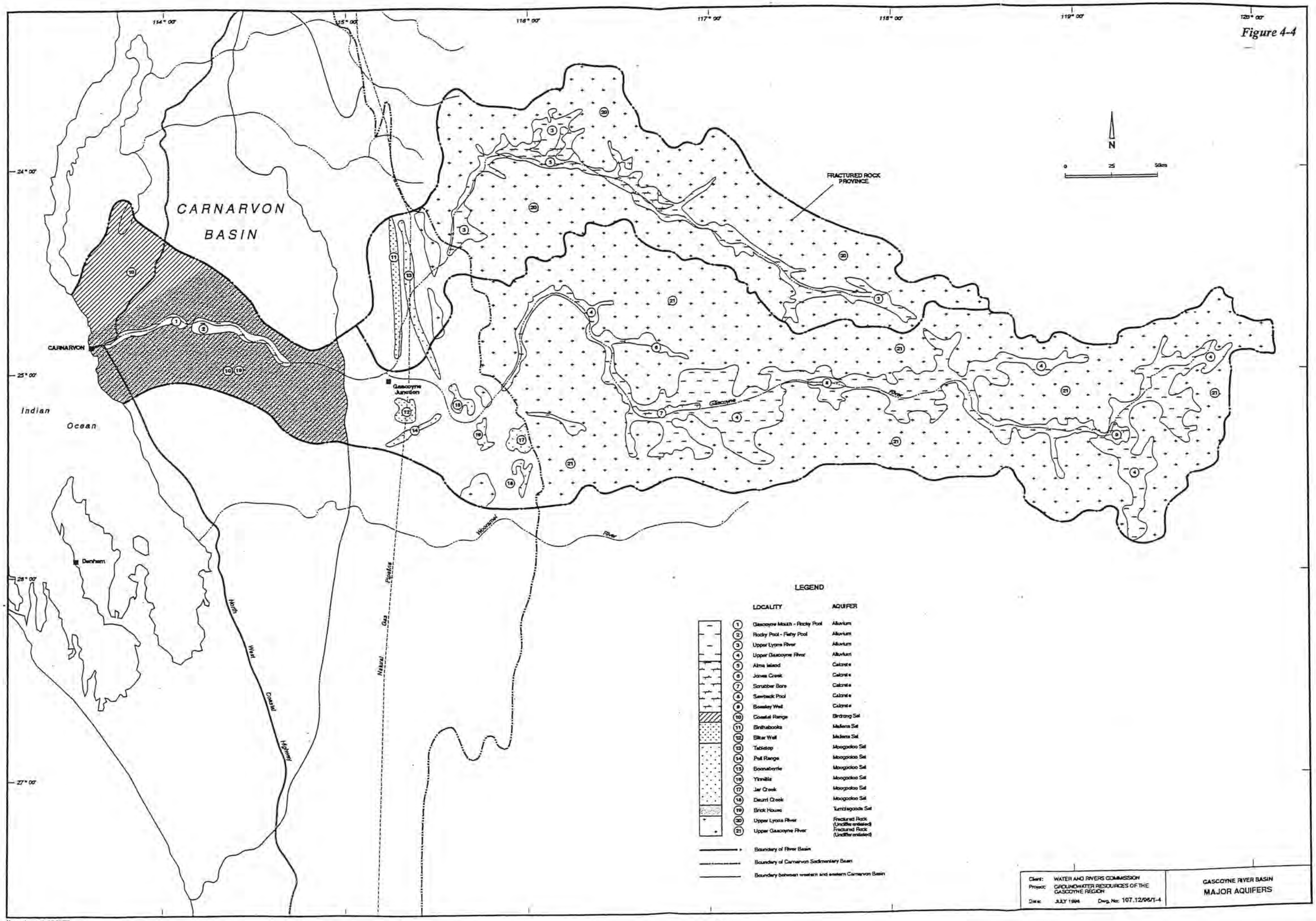


Figure 4-4
114° 00'
115° 00'
116° 00'
117° 00'
118° 00'
119° 00'
120° 00'
24° 00'
25° 00'
26° 00'
27° 00'
N
0 25 50km
CARNARVON
BASIN
FRACTURED ROCK
PROVINCE
CARNARVON
Gascoyne
Junction
Indian
Ocean
Denham
Gascoyne
River
Wooramel
River
North West Coastal Highway
Natural Gas Pipeline
LEGEND
LOCALITY
AQUIFER
1 Gascoyne Mouth - Rocky Pool — Alluvium
2 Rocky Pool - Fishy Pool — Alluvium
3 Upper Lyons River — Alluvium
4 Upper Gascoyne River — Alluvium
5 Alma Island — Calcrete
6 Jones Creek — Calcrete
7 Scrubber Bore — Calcrete
8 Sawback Pool — Calcrete
9 Beasley Well — Calcrete
10 Coastal Range — Birdrong Sst
11 Binthubooka — Mallens Sst
12 Bitter Well — Mallens Sst
13 Tabletop — Moogooloo Sst
14 Pell Range — Moogooloo Sst
15 Boonabberrie — Moogooloo Sst
16 Yinnilla — Moogooloo Sst
17 Jar Creek — Moogooloo Sst
18 Deurri Creek — Moogooloo Sst
19 Brick House — Tumblagooda Sst
20 Upper Lyons River — Fractured Rock (Undifferentiated)
21 Upper Gascoyne River — Fractured Rock (Undifferentiated)
Boundary of River Basin
Boundary of Carnarvon Sedimentary Basin
Boundary between western and eastern Carnarvon Basin
Client: WATER AND RIVERS COMMISSION
Project: GROUNDWATER RESOURCES OF THE GASCOYNE REGION
Date: JULY 1996
Dwg. No: 107.12/96/1-4
GASCOYNE RIVER BASIN
MAJOR AQUIFERS

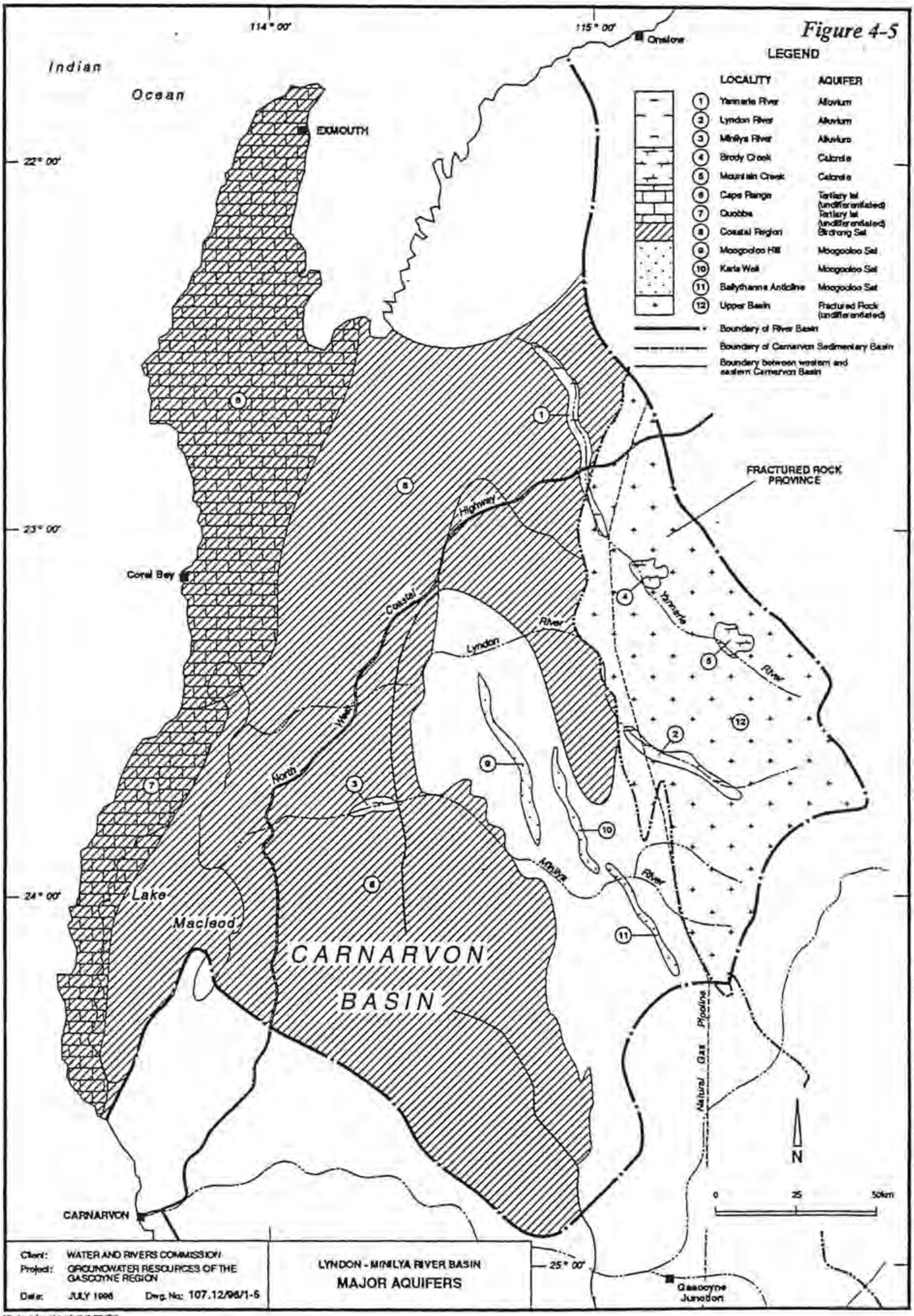
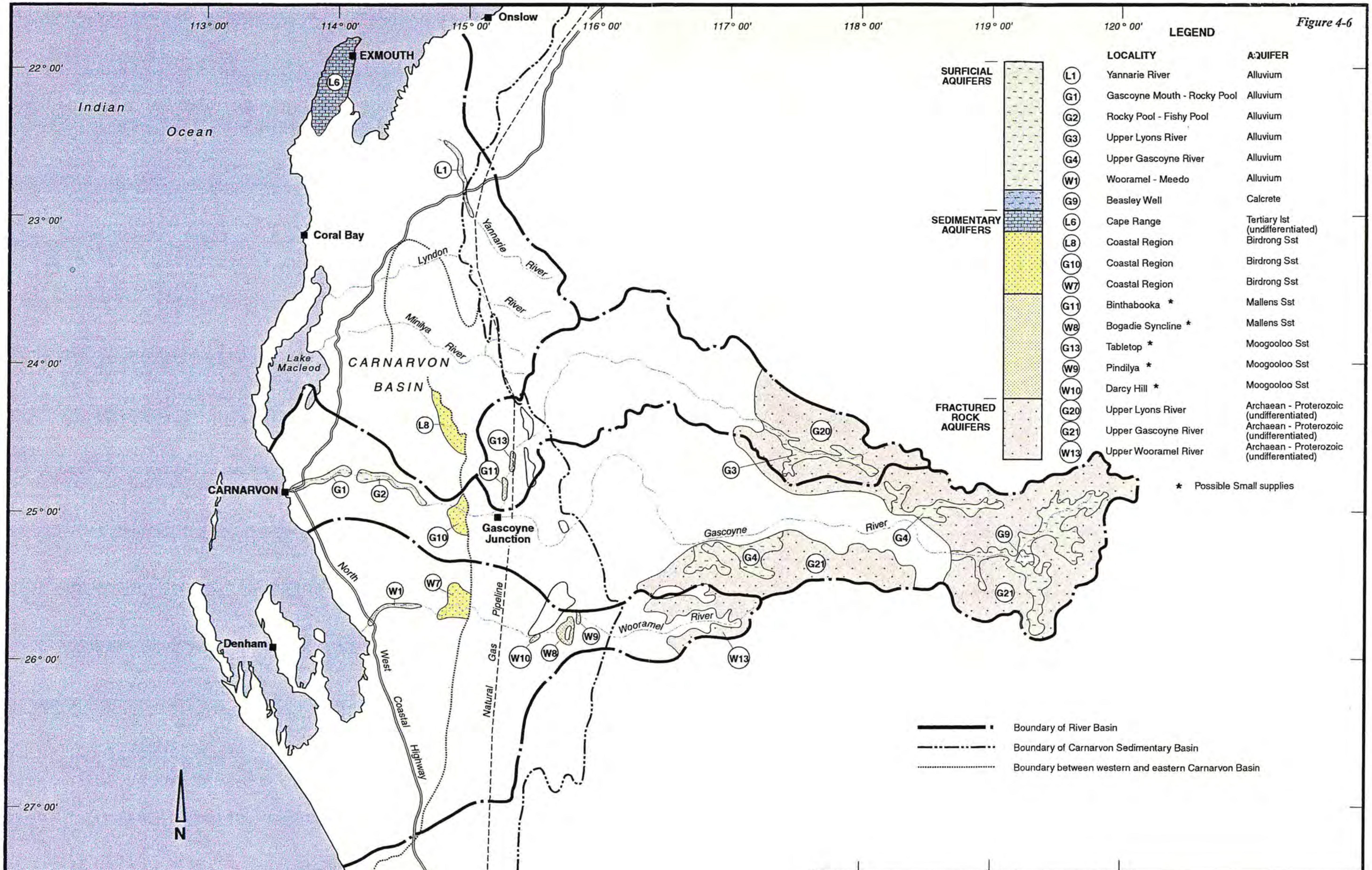


Figure 4-5
LEGEND
LOCALITY
AQUIFER
1 Yannarie River Alluvium
2 Lyndon River Alluvium
3 Minilya River Alluvium
4 Brody Creek Calcrete
5 Mountain Creek Calcrete
6 Cape Range Tertiary lst (undifferentiated)
7 Quobba Tertiary lst (undifferentiated)
8 Coastal Region Birdrong Sst
9 Moogooloo Hill Moogooloo Sst
10 Karla Well Moogooloo Sst
11 Ballythanna Anticline Moogooloo Sst
12 Upper Basin Fractured Rock (undifferentiated)
Boundary of River Basin
Boundary of Carnarvon Sedimentary Basin
Boundary between western and eastern Carnarvon Basin
Indian Ocean
114° 00'
115° 00'
22° 00'
23° 00'
24° 00'
25° 00'
Onslow
EXMOUTH
Coral Bay
Lake Macleod
CARNARVON BASIN
CARNARVON
FRACTURED ROCK PROVINCE
Coastal Highway
North West
Lyndon River
Yannarie River
Minilya River
Natural Gas Pipeline
Gascoyne Junction
N
0 25 50km
Client: WATER AND RIVERS COMMISSION
Project: GROUNDWATER RESOURCES OF THE GASCOYNE REGION
Date: JULY 1996 Dwg. No: 107.12/96/1-5
LYNDON - MINILYA RIVER BASIN
MAJOR AQUIFERS

Figure 4-6



Client: WATER AND RIVERS COMMISSION
Project: GROUNDWATER RESOURCES OF THE GASCOYNE REGION
Date: JULY 1996 Dwg. No: **107.12/96/1-6**

MAJOR AQUIFERS WITH FRESH GROUNDWATER RESOURCES

Merrison Associates (+61 9) 321 8598

5. Resources Management and Development Issues

5.1 Natural Resource Management

5.1.1 General

The Gascoyne Region's tourism assets are found in sensitive marine and terrestrial environments. The coastal environment is particularly susceptible to damage. One of the greatest problems for the entire region is its low and sporadic rainfall. Vegetation regeneration is slow and damage to vegetation by vehicles soon leads to the establishment of new tracks.

Also, due to the lack of water, fire is difficult to control. The region has seven population centres; Denham, Carnarvon, Exmouth, Gascoyne Junction, Coral Bay, Useless Loop and Burringurrah Aboriginal Community. The concentration of population in these centres and the isolation of much of the region has served to protect it from more widespread environmental impacts. However, while the region's environment is largely free of serious environmental problems, it is likely to come under increasing pressure as a result of increasing human activity in the future.

The combination of economic growth pressure, increased tourist numbers and the sensitive environment requires careful management and thorough educative processes. This is particularly so in coastal areas which are not currently subject to public sector management. While the extension of National Parks areas such as Cape Range will address localised issues, management practices are needed which apply to both the public and private sectors.

Current and proposed conservation reserves are shown in Figure 5-1.

The major challenges facing the Gascoyne are firstly to encourage further development of new and existing industries while managing and protecting the region's unique environment, and secondly, the region needs to source additional freshwater supplies to facilitate the emergence of new industries.

Industry standards will be achieved best through cooperation between operators and resource managers. Coordination and cooperation between resource managers within the various Government Departments involved will also be required. Industry standards developed between CALM and whale shark diving operations is the best local model at present.

5.1.2 Ecologically Sustainable Development

Ecologically sustainable development recognises that continued economic development and improved quality of life are dependent on the effective management of natural resources, including the maintenance of ecosystems (Resource Assessment Commission, 1993).

All developments should be consistent with ecologically sustainable development ·principles, however, difficulties may arise in the practical application of defined goals and objectives which some consider to be unachievable and/or mutually exclusive. This is mainly because the successful application of the method assumes a high level of knowledge and understanding about the terrestrial and marine ecosystem relationships within the study area. The limited availability of existing information makes it very difficult to determine level of development which is ecologically sustainable in the Gascoyne Region.

In accordance with the overriding principle of ecologically sustainable development, regional strategies recognise that planning for, and management of, settlement patterns and resource use needs to be integrated with protection and management of the natural environment. Before localised decisions about land and marine uses are taken, an understanding of the capability of the land and marine environments to sustain uses is required.

Groundwater, like surface water, should be considered a sustainable natural resource, not a resource or some other element to be mined. Consequently, the aim of water resources management is to:

achieve efficient, sustainable and equitable management of the water resources, whilst maximising the contribution of industry and rural regions to the effective economic and social well being of the West Australian community.

Water resources management policies and practices need to be consistent with the aims of the National Strategy for Ecologically Sustainable Development (ESD), the National Water Quality Management Strategy (NWQMS) and the COAG water reform agenda.

The general principles of ESD are especially relevant to groundwater because of its large storage volume, its hidden nature, its slow movement, its slow flushing characteristics and its higher risk exposure compared with surface water, in the sense that groundwater processes are, for the most practical purposes, irreversible.

ESD principles applicable to groundwater management are:

- integrating economic and environmental goals in policies and practices,
- ensuring that environmental assets are appropriately valued,
- providing equity within and between generations, dealing cautiously with risk and irreversibility, and recognising the global dimension.

Achieving the above in groundwater allocation and management can be complex and costly due to the uncertainty in determining the resource boundaries and its parameters. In addition, groundwater resource allocation and protection are interdependent management tasks. Consequently, any groundwater allocation policies and practices must be complimentary to groundwater protection policies and processes.

The cost of restoring groundwater, after it has been permanently depleted and/or polluted, can be extremely high, if, indeed, it is technically possible at all. Therefore, the need to deal cautiously with risk and irreversibility is especially critical.

5.2 Allocation Planning

5.2.1 Water Allocation Process

Water is our most precious resource and is vital for all life. The challenge is to manage our water resources to safeguard their most important current and long term values which include environmental, recreational and cultural uses as well as water supply uses for domestic, horticultural and industrial purposes. Various sections of the community place different values on the water resource uses as described above. This inevitably creates conflict between groups who perceive that water should be allocated for other uses.

Under the Rights in Water and Irrigation Act (1914), the right to use, flow and control groundwater is vested in the Crown. The Act requires the licensing of all confined wells throughout Western Australia. Similarly, unconfined wells within specific areas proclaimed as Groundwater Areas under the Act, require licensing. Provisions exist for the exemption of stock and domestic supplies from licensing requirements in certain cases. The study area incorporates the Carnarvon Groundwater Area and also includes portions of the Gascoyne, Pilbara and East Murchison Groundwater Areas. Groundwater license allocations are aimed at ensuring the equitable use of the available groundwater resources, whilst ensuring it's protection.

5.2.2 Carnarvon Allocation Strategies

Controls to limit the abstraction of groundwater from the Gascoyne River were introduced in 1959 as a result of requests from growers who were concerned about decreased supply during droughts and rising salinity levels.

The concept of a "basic allocation" was introduced in 1959 and was determined as the quantity of water required through the latter part of an extended drought to sustain the "basic area" of 1.6 hectares of the perennial crop (bananas) for the single family unit. This equated to about 32.5 ML/year.

By the end of 1962, a relatively complex allocation formula had evolved to provide for the equitable allocation of excess water available in good seasons and to provide for development of the industry.

By 1978, it was realised that the developed groundwater resource was fully committed. Accordingly, the granting of Irrigation Allocations was pegged, however, demand continued to increase. In the operation of the scheme and in setting allocations, the main consideration was whether the groundwater resource could sustain the proposed draw.

In 1980, work commenced on developing a computer model to represent the groundwater system of the scheme area. This modelling work suggested that the aquifer could, subject to verification, supply the annual draws as set out in Table 5-1. The Gascoyne River has been divided into 11 management basins (A to L, excluding I). Growers abstract from Basin A, whilst Basins B to L are pumped by the Water Corporation.
In 1984, a new simplified allocation formula was

Table 5.1: Assessed Safe Annual Draw from the Gascoyne River Aquifers

Shallow Aquifer Storage Level	Private (Basin A) (million kL) Irrigation	Scheme (Basin B - L) (million kL) Irrigation/TWS		Total Annual Draw (million kL)
> 80 (full)	5.0	3.75	1.85	10.6
64 - 80 per cent	3.8	2.75	1.85	8.4
51 - 64 per cent	1.5	1.2	1.5	4.2
< 51 per cent	-	-	1.5	1.5

adopted. More recently, the process for setting allocations was streamlined by simply setting an allowance based on the aquifer storage position and the time since the river flowed. No pumping restrictions are enforced during periods when the river is flowing. When the aquifer is considered to be full, growers receive an allocation of 72 ML/year. At times, however, the allocations as indicated in Table 5-1 could not be met.

The restructure of the Water Industry has meant that after January 1, 1996, the Water Corporation and the Water and Rivers Commission (WRC) have different responsibilities. This has necessitated a change in both management and allocation procedures.

The Carnarvon Groundwater Advisory Committee (CGAC) proposes to prepare guidelines concerning groundwater allocation. Further investigation is required to formulate the allocation and management strategy and work is being performed by the WRC to address the strategies pertinent to the effective and equitable groundwater allocation and management.

5.2.3 Transferable Water Entitlements

Carnarvon is typical of places with a mature water economy, being characterised by expensive new supply options and strong competition for the existing supplies. This environment usually operates most effectively with a flexible system of water allocation, so that the available water supplies are put to the best possible use.

Significant changes to the setting of individual grower allocations could be achieved by the introduction of Transferable Water Entitlements (TWE). The concept of TWE was introduced to the Carnarvon Irrigation District Advisory Committee (CIDAC) in 1990, but to date has not been accepted by the Committee.

5.3 Reliability and Security of Water Supplies

5.3.1 Water Conservation

With large scale economic development proceeding throughout the State, especially in the tourism industry in the Gascoyne, a coordinated, comprehensive strategy to promote water conservation and efficiency in water use is a vital component of State water resource management and planning. The development of the State's water resources in terms of water conservation and water use efficiency are relatively new concepts.

A State Water Conservation Strategy is currently being prepared by the Water and Rivers Commission. The State Water Conservation Strategy will set out the means by which the Water and Rivers Commission plans to achieve water conservation and improve the efficiency of use of the State's water resources. It provides the framework for water efficiency program development for priority sectors of water use and priority regions of the State.

The continuity of water supplies to the Carnarvon horticultural district is dependent on the Gascoyne River flows. In the horticultural area, conversion to water efficient irrigation systems means that valuable water resources are not wasted. These generated savings in water usage could enable the production area to be further developed, which would realise greater returns to the growers, the region and the State.

A new irrigation technique allowing up to 75 per cent reduction in water use by vegetable crops has been trialed by the Gascoyne Research Station. This technique applies water to the seed bed through low volume trickle pipe systems. The whole seed bed and the trickle pipe are covered with a polythene sheet. This method is known as 'polydrip' irrigation. Low volume 'beneath the tree' sprinkler systems have also been installed under some banana and fruit tree plantations to improve water use efficiencies.

A water efficiency program, undertaken by the Shire of Exmouth and the Water Authority, focussed on ways to encourage the efficient use and reuse of water. The Shire, as the largest water user, was the major participant in the study. The Shire also has control of the wastewater plant and reuses the effluent on grassed areas and ovals. The study explored ways in which this use of wastewater could be increased in Exmouth.

The water efficiency study assumed that water efficiencies and savings could be made across the whole community by educating the Shire, who would ideally adopt the water efficiency measures and enforce them on businesses and householders. The study objectives were not achieved, although, the Shire of Exmouth has set up a task force to look at ways of improving the Shire's overall water efficiency.

Water supply strategies in other parts of WA have evaluated a variety of water efficiency measures. These include leak reduction, efficient toilets, efficient shower heads, efficient clothes washers and efficient domestic irrigation. These measures could be included in a similar study of the Gascoyne Region.

Many pastoral artesian bores have been in operation for 50 to 70 years. The groundwater from the Birdrong Sandstone is corrosive, therefore, the condition of the bores varies considerably. Management is difficult as many artesian bores are in a state of disrepair. In most cases, it would not be possible to cap a bore and even if this could be achieved, the casing would probably fail causing the artesian flow to occur outside the casing.

Recasing or plugging old artesian bores can be fraught with difficulties and the cost depends on various factors, including drill-rig access and the condition of the bores. Agriculture WA are currently conducting an audit of the pastoral artesian bores in the Carnarvon Basin. It is expected that a strategy for the management of artesian bores will be formulated based on the findings of the audit. Financial assistance is also being sought from the Commonwealth Government to alleviate the financial burden of bore rehabilitation which is expected to cost several million dollars.

5.3.2 Catchment Protection

The Water and Rivers Commission has adopted a differential protection approach to the management of surface water and groundwater catchments throughout the State. This approach entails classification of water supply catchments and establishing protection objectives for each classification. Three classifications have been defined for existing and future water supply groundwater catchments. Whilst there are currently no water supply protection catchments in the Gascoyne Region, it is intended that the classifications will eventually cover the region's water reserves.

Priority 1 (P1) source protection areas are defined to ensure there is no degradation of the water source. They cover land normally owned by the State where the provision of the highest quality public drinking water is the prime beneficial land use. Generally development is not permitted.

Priority 2 (P2) source protection areas are defined to ensure there is no increased risk of pollution to the water source. They are generally areas where low intensity development (such as rural) has occurred. Provision of public water supply is a high priority in these areas. Development may occur under specific guidelines.

Priority 3 (P3) source protection areas are defined to minimise risk of pollution to the water source. They are areas where substantial water resources of economic or strategic importance exist, but where there has been significant development. The aim is to manage land use rather than restrict development so public drinking water can be provided without the need for complex treatment processes. Usually alternative water sources are available if the source becomes unsafe to use or if treatment is not an economical option.

In addition to priority classification, wellhead protection zones are defined to protect the aquifer from contamination in the immediate vicinity of production wells. The area of wellhead protection zones are usually circular, with a radius of 500 m in P1 areas and 300 m in P2 and P3 areas. They do not extend outside water reserves. Restrictions apply to storage of fuels, solvents, oils and pesticides within these zones.

5.3.3 Drought Management

The effects of drought on groundwater availability varies according to the hydrogeological characteristics of the resource, particularly storage. A small superficial aquifer will be largely affected by short term climatic variations. Large confined aquifers, however will be essentially unaffected as the storage characteristics and recharge mechanisms attenuate the effects of climatic variations. The approach to groundwater management during drought should therefore take account of these differences in sensitivity to climatic variations, with long term sustainability being the primary common objective.

Management of groundwater during drought should be tailored to reflect the characteristics of the aquifer, with impacts on water users and long term sustainability of the resource as primary considerations.

Drought conditions act as a test on both the quality of the management practices operating within the State and also to the community consultation process. A broad variety of different management practices operate during droughts, including:

- Do nothing,
- Temporary reduction of licence allocation, and
- Introduction of rosters.

Salinity increase due to excessive pumping is a major reason for restricting usage.

The major approach adopted during droughts, in consultation with the community, is to arrive at fair pumping restriction arrangements and technical assistance in the development of deeper wells.

In Carnarvon, the water supply for irrigation relies on the resources available from the Gascoyne River and its aquifers. These limited resources are allocated to ensure that the horticultural industry can be sustained through all but extended drought periods. The Water and Rivers Commission has powers delegated to it under the provisions of the Rights in Water and Irrigation Act to manage and administer the use of water in the Carnarvon Groundwater Area which incorporates all of the Basin A horticultural area.

To assist in water allocation and groundwater licensing, the Water and Rivers Commission relies on advice from the Carnarvon Irrigation District Advisory Committee (CIDAC) and the newly formed Carnarvon Groundwater Advisory Committee (CGAC) which was appointed as a consequence of the water industry reform in January 1996. These committees generally meet twice a year and consider the annual allocations in April, prior to the commencement of the 'irrigation year' in May.

The allocations are set based on the aquifer storage position as shown in Table 5-1 and on the time since the river flowed. During months when the river flows at Bibbawarra Crossing, the use of water is unrestricted. When this occurs, not all pumping is debited against the annual allocation. The water use that is debited against the annual allocation is calculated at the expected rate of usage in the month if the normal restrictions had applied.

5.3.4 Carnarvon Management Strategy

The developed groundwater resource which supplies Carnarvon's town and irrigation needs has been fully committed for years. Accordingly, the granting of irrigation allocations has been pegged, however, the demand for water continues to increase.

Consultants (SMEC) are currently investigating ways to improve the reliability of the water supply arrangements in Carnarvon. This consultancy will:

- Prepare a feasibility study of options to augment the water supply available to the Carnarvon irrigators by up to 4.0 GL/annum,
- Analyse options for future management of the irrigation area, and
- Provide an evaluation of the financial and funding options.

A draft water management strategy (1994) indicates that efficient and sustainable use of the Carnarvon groundwater resource is the underlying strategic aim and this is coupled with a concern for the long term financial viability of the scheme. It is anticipated that the work currently being undertaken by SMEC will facilitate completion of the strategy.

5.4 Environmental Issues

5.4.1 Groundwater Management

In recent times, the level of awareness of the key role which groundwater usage has in influencing a broad range of environmental features has increased considerably. Impacts on wetlands, vegetation, surface waters and other aspects of the environment are generally appreciated. A broad range of specific issues are identified and are as follows:

The need for the groundwater resource to remain useable through a specified climatic range,

- Prevention of sea water intrusion,
- Land and water salination due to disturbance of recharge/discharge patterns,
- The need to protect mound springs,
- Consideration of Aboriginal sites of significance, and
- Effects of land management practice (eg waste discharges) on groundwater resources.

In the future, development of land and water will be constrained by the intra aquifer environment. Environmental requirements for groundwater need to be addressed. Internationally research/protection of the groundwater biota is becoming an issue. Certainly the impact on the abundance and diversity of aquifer biota can be starkly seen when nutrients are added as contaminants to the groundwater system.

It is highly likely that the impact of groundwater usage on the environment, especially interference with surface waters and river base flows, will become a major issue in the future and conscious decisions will need to be made by the community concerning the relative priorities and impacts of groundwater licensing. Consequently, there is a clear need for more public education about the interaction between groundwater and the environment.

5.4.2 Salt Water Intrusion

The chief threat to sustainable use of the river bed sand and older alluvium aquifers, which supply Carnarvon and Gascoyne Junction, is salt water intrusion caused by over extraction. The river bed sand aquifers are recharged by river flow and extraction at rates greater than recharge will result in movement of the salt water interface towards the river.

The hydrological characteristics of the river bed sand aquifers vary, which means the nature and likelihood of salt intrusion varies throughout the aquifer system, making monitoring difficult. When salinity levels reach 1,000 mg/L TDS, extraction is stopped until the salt water is displaced by fresh water inflows.

The Water Corporation monitors salt intrusion and salinity changes. Private bores and Water Corporation bores are sampled frequently to provide early warning of changes in groundwater salinity.

Salt water intrusion is a major problem at Exmouth as the fresh water supplying the town is extracted from a thin fresh water lens aquifer overlying saline water. The inland extent of the salt water wedge appears to be controlled by the presence of highly transmissive karstic features which increases the potential for salt water to move upwards or inland to wells drawing from the thin lens of fresh water.

The water levels in the aquifer respond to variations in abstraction and recharge. Saline upconing is sensitive to relatively small changes in water levels due to the thin nature and flat hydraulic gradient of the aquifer. To alleviate the problem, a bore rationalisation plan has been proposed which involves a combination of redrilling and re-equipping low salinity bores and abandoning higher salinity bores.

5.4.3 Floodplain Management

The town of Carnarvon and the surrounding plantation areas are flood prone, which is a constraint on both production activity and town growth. In August 1980, Sinclair Knight and Partners Pty Ltd, were engaged to appraise the flood situation and put forward guidelines for resolution of these issues. Following the publication of a feasibility report, Sinclair Knight and Partners were commissioned to develop a floodplain management strategy for the Gascoyne River.

The recommended strategy involved the construction of a number of levees to protect the existing floodprone residences and part of the commercial area. Flood mitigation work on the Gascoyne River at Carnarvon has progressed since the strategy was recommended and further flood mitigation works are proposed for the future.

5.4.4 Climate Variability

Australian rainfall is the most variable in the world. The duration and frequency of drought sequences is extreme and interspersed with sequences of above average rainfall (Fleming, 1995). However, it has been shown that the last 20 years have not been interspersed with sequences of above average rainfall.

These sequences of above average rainfall provide most of the recharge to groundwater and when individual events are large, significant surface runoff occurs. Thus rainfall is transformed into surface runoff and groundwater recharge by a residual process. Australian streamflow shows an amplified variability, particularly in the sub-humid to semi-arid zones and the variability increases with catchment size (Fleming, 1995).

As a result, streamflows and groundwater recharge events are extremely variable. Most years will either be very wet or very dry. The "average" water year will occur very rarely. The average year is more likely to be drought or flood.

5.4.5 Climate Change

Global climate change, according to current scientific understanding, is very likely to occur in the next few decades as a result of increasing levels of greenhouse gasses in the earth's atmosphere, particularly carbon dioxide and methane. Global warming is the result of an increase in the amount of the sun's energy retained in the atmosphere due to the accumulation of greenhouse gasses. Accurate predictions of future climate change are not yet possible. The potential impact of the 'Greenhouse Effect' on the State's climate by the middle of next century cannot be ignored. According to Chittleborough (1985), the south - western portion of the State will become drier.

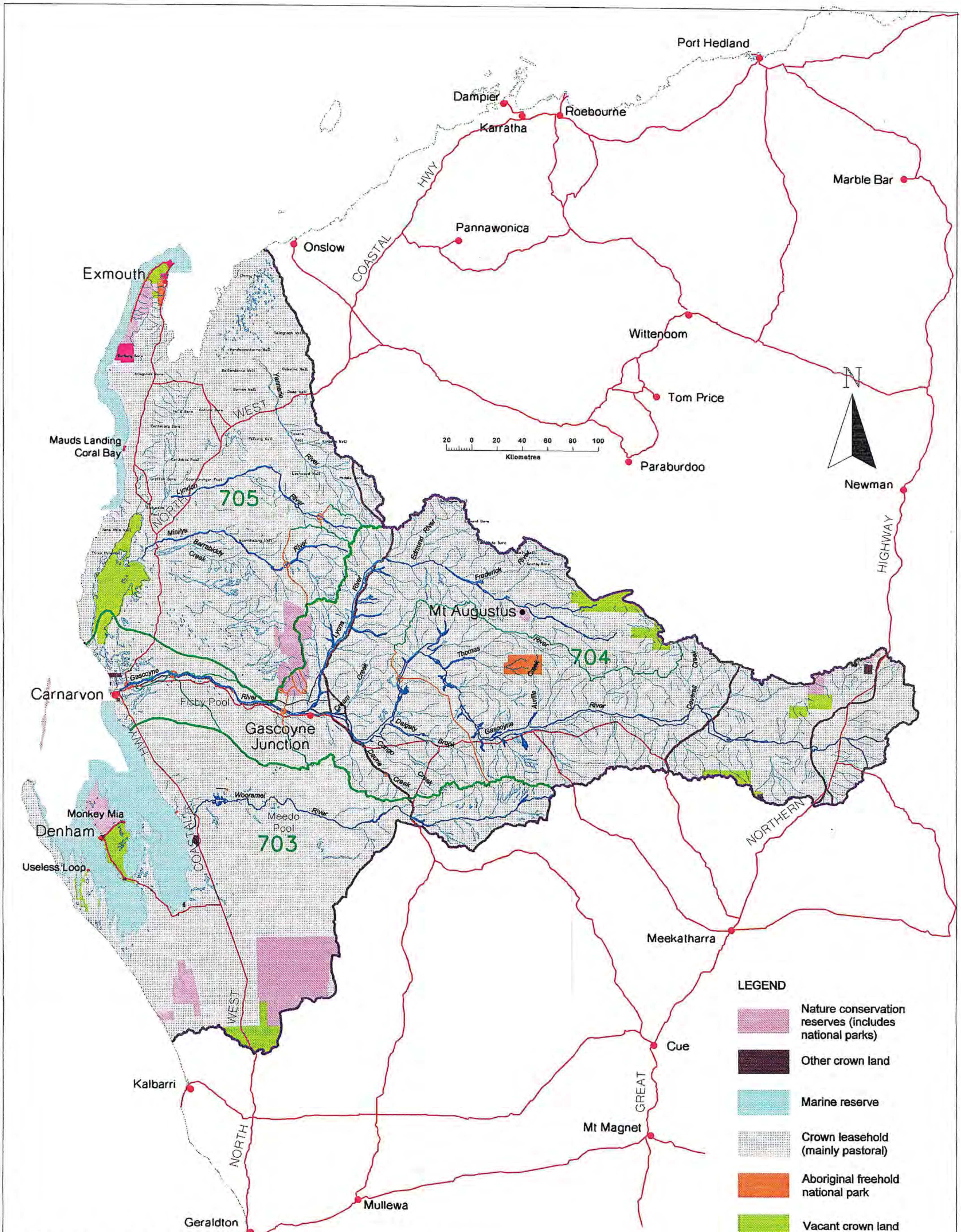
Climate change scenarios have been developed for the Australian region by the Climate Impact Group (1992), CSIRO Division of Atmospheric Research. They are continuously updated as new information becomes available. Global Climate Models are used to estimate global changes. However, uncertainty in future greenhouse gas emissions and deficiencies in existing climate models make it difficult to translate global estimates into regional estimates. Consequently, it is not yet possible to make detailed predictions of changes in climate at a regional level.

The Climate Impact Group have investigated various scenarios of global warming for Australia up to 2070 AD. However the summary of their findings below, relative to 1990, for the North West region, only goes up to 2030 AD.

Temperature change	
Northern Coast	0.0 to +1.5°C
Inland (> 200 km from coast)	+0.5 to +2.5°C
Rainfall	
Summer (Nov to April)	0 to +20 per cent
Winter (May to Oct)	0 to +10 per cent
Evaporation	
Northern Coast	0 to +6 per cent
Inland (> 200 km from coast)	+1 to +10 per cent

It is anticipated that there will be a general increase in rainfall intensity, and in the occurrence of heavy rainfall events. Extreme events will become more likely and current research suggests more very hot days, fewer frosts, more floods and dry spells. It is possible that this will result in greater recharge for both surface and ground water sources. However, this might be offset by the fact that sources would need greater storage to provide water for the longer dry spells.

The Water and Rivers Commission will continue to monitor the implications of climatic change research and incorporate them into planning for water resources development in the region.



Gascoyne Region Water Resource Review

CONSERVATION RESERVES-SURFACE WATER CATCHMENTS

Figure 5.1

6. Environmental/Social and Cultural Values

6.1 General

The condition of the region's water resources in all aspects can be regarded as a measure of the state of the environment as a whole and must therefore be a key element in planning strategies. Increasing pressure on water bodies and their environments, from activities such as clearing and agriculture has resulted in a noticeable, and often serious, deterioration of water quality.

Proposals for intensifying land use must be assessed against the existing environment to determine the level of environmental, social and cultural impact. For a regional planning exercise, it is crucial to consider the larger environmental issues such as the conservation of biological diversity, ecological sustainable development and the protection of major rivers and waterways.

This section details the environmental, social and cultural values of the individual basins. It also identifies issues which may threaten the environmental, social or cultural value of the region.

Environmental water usage is an important consideration and is used as a precautionary principle when maintaining the environmental value of the region. However, no studies have been undertaken to determine the amount of water required for the maintenance of environmental ecosystems in the Gascoyne Region. Until better estimates become available, the environmental water usage has been set at 25 to 30 per cent of the available renewable water resources. This water is required to prevent salt water intrusion, maintain aquifer levels and maintain flora and fauna.

Appendix E details the inter-relationships between land use and water supply schemes. This broad assessment is made for surface water and shallow groundwater and for forested, rural and urban land uses.

6.2 Environmental Values

6.2.1 Wooramel River Basin (703)

Table 6.1: Environmental Values of Wooramel River Basin

Environmental Value	Comments
Total Area	40500km^2
Conservation Park	5km^2
National Park	529km^2
Nature Reserve	3959km^2
State Forest	0km^2
Waterways	Primary catchment: Wooramel River
Wetlands	Wetlands include all creeks, rivers, lakes, floodplains and sumplands, which are permanently or seasonally inundated with water. Examples include: Wooramel River, Toodacaraddy Pool.
Water Reserves	Denham Water Reserve
Miscellaneous Reserves	5km^2
Marine Reserve	0km^2
Coastal Environment	1155km of coastline
CALM Leasehold	0km^2
CALM Freehold	0km^2
Section 5(g) Reserves	94km^2
Area Cleared	No significant clearing

6.2.2 Gascoyne River Basin (704)

Table 6.2 Environmental Values of Gascoyne River Basin

Environmental Value	Comments
Total Area	77600km^2
Conservation Park	0km^2
National Park	893km^2
Nature Reserve	4km^2
State Forest	0km^2
Waterways	Primary catchment: Gascoyne River
Wetlands	Wetlands include all creeks, rivers, lakes, floodplains and sumplands, which are permanently or seasonally inundated with water. Examples include: Rocky Pool, Chinaman's Pool
Water Reserves	Carnarvon Water Reserve
Miscellaneous Reserves	0km^2
Marine Reserve	0km^2
Coastal Environment	105km of coastline
CALM Leasehold	0km^2
CALM Freehold	0km^2
Section 5(g) Reserves	0km^2
Area Cleared	No significant clearing

6.2.3 Lyndon-Minilya River Basin (705)

Table 6.3 Environmental Values of Lyndon -Minilya River Basin

Environmental Value	Comments
Total Area	48300km^2
Conservation Park	0km^2
National Park	1410km^2
Nature Reserve	12km^2
State Forest	0km^2
Waterways	Primary catchment: Lyndon - Minilya River
Wetlands	Wetlands include all creeks, rivers, lakes, floodplains and sumplands, which are permanently or seasonally inundated with water. Examples include: Lake MacLeod, tidal flats south and east of Exmouth Gulf.
Water Reserves	Exmouth Water Reserve
Miscellaneous Reserves	15km^2
Marine Reserve	5km^2
Coastal Environment	674km of coastline
CALM Leasehold	0km^2
CALM Freehold	$<$1km^2
Section 5(g) Reserves	$<$1km^2
Area Cleared	No significant clearing

6.3 Environmental Issues

6.3.1 Existing Degradation

Environmental impacts are already evident throughout the region. Increases in developments and visitors will exacerbate this situation, unless proper planning and management measures are introduced.

6.3.2 Protection of Subterranean Fauna in Cape Range

The subterranean fauna occupying underground caves and fissures of the Cape Range landscape represent rare and unique species of worldwide scientific significance. Troglobites and stygofauna, which inhabit saturated caverns and fissures in the limestone of the coastal plain, are sensitive to hydrological changes. The use of groundwater, limestone excavation and other activities which may potentially disrupt the existing hydrological regime may impact upon subterranean fauna.

Any major building projects, mining and extractive industries or groundwater extraction proposals which involve possible contamination or changes in groundwater levels should include in their proposal:

- An account of the species diversity and richness of subterranean fauna within the development site and any other areas which would have an impact from the development,
- An assessment of the regional significance of any potentially affected populations, and
- An indication of the potential impact on the subterranean fauna, which should not jeopardise the survival of the species or future research initiatives.

Protection of the stygofauna may be included into the Exmouth Town Planning Scheme if studies indicate that this level of commitment is necessary for the long term well-being of this fauna.

The EPA recently commissioned a study into the value of the subterranean fauna (stygofauna) of the Cape Range to recommend measures which should be taken to provide them with appropriate levels of protection. This report has not yet been released but reinforces the position taken by Humphries (1994) that the stygofauna at the Cape Range has international significance and should be protected.

6.4 Parks and Reserves

The Gascoyne Region contains a World Heritage Area and a number of national parks, marine parks and conservation reserves. Additionally, there are a number of proposed extensions to these parks and reserves. The location of parks and reserves in the region are shown in Figure 5-1.

6.4.1 Shark Bay World Heritage Area

Shark Bay became a World Heritage listed area in 1991 and is one of only 11 sites on the World Heritage List to meet all four natural criteria for listing. A strategic plan for the protection and management of the World Heritage values is being prepared by CALM. This is known as the World Heritage Area Strategic Plan.

6.4.2 Cape Range National Park

CALM is currently seeking to extend the Cape Range National Park to the east as proposed in its management plan (CALM, 1987). The extension would include some of the most scenic areas of the region, complete catchments of most watercourses and a physiographic unit which is highly fossiliferous and of considerable scientific importance.

The Gascoyne Coast Regional Strategy (1996) recommends the extension of the Cape Range National Park to the east in the short term, as proposed by CALM's management plan, and in the medium to long term, the southern extension of the park to include the Ningaloo pastoral lease, as described in the North West Cape Tourism Development Study (1993).

6.4.3 Mount Augustus National Park

Mount Augustus, the world's largest monocline, is the most significant feature in the Mount Augustus National Park and is located approximately 460 km east of Carnarvon. The National Park is rich in Aboriginal heritage and has examples of Aboriginal rock paintings and engravings. A wealth of animal and bird life inhabit the area, the most prolific being the wedge tailed eagle.

6.4.4 Kennedy Range National Park

The Kennedy Ranges, extending approximately 195 km in length and up to 30 km in width, are the remains of an old erosional landform. Erosion has created ridges and isolated mesas with steep stony slopes and restricted plains. The Kennedy Ranges are the main feature of the Kennedy Range National Park which is located approximately 160 km east of Carnarvon.

6.5 Social and Cultural Issues

6.5.1 Aboriginal Issues

The Gascoyne Region is rich in Aboriginal history (Ministry for Planning, 1996). The vast majority of the recorded sites comprising middens (shell and bone fragments) and artefacts (stone tools and utensils) are of archaeological significance. There are also a number of recorded ethnographical sites, which have strong spiritual links with sectors of the present Aboriginal community due to their association with ceremonial, mythological or burial activities.

The limited information on the extent, significance and location of Aboriginal sites presents difficulties with regard to planning and management. More detailed information is required to enable definitive action and resolve potential land use conflicts.

At the strategic level, it is appropriate to recognise the protective status of aboriginal sites and ensure that known sites are preserved. Any development or change in land use will require site specific surveys to determine the extent of recorded sites and possibility of other sites potentially affected.

6.5.2 Native Title

Native title is presumed to exist over land which is the subject of Crown tenure, unless the Crown has extinguished native title by some past action. *The Native Title Act 1993* validates all past acts of the Commonwealth and allows the State to do the same in accordance with the provisions of the Act. Western Australia has enacted a State *Titles Validation Act 1995* in conformity with the federal legislation to validate land titles issued prior to 1 January 1994. The effect of this validation process is the extinguishment of native title by some validly granted land titles such as commercial, agricultural, pastoral or residential leases, and public works in existence on 1 January 1994.

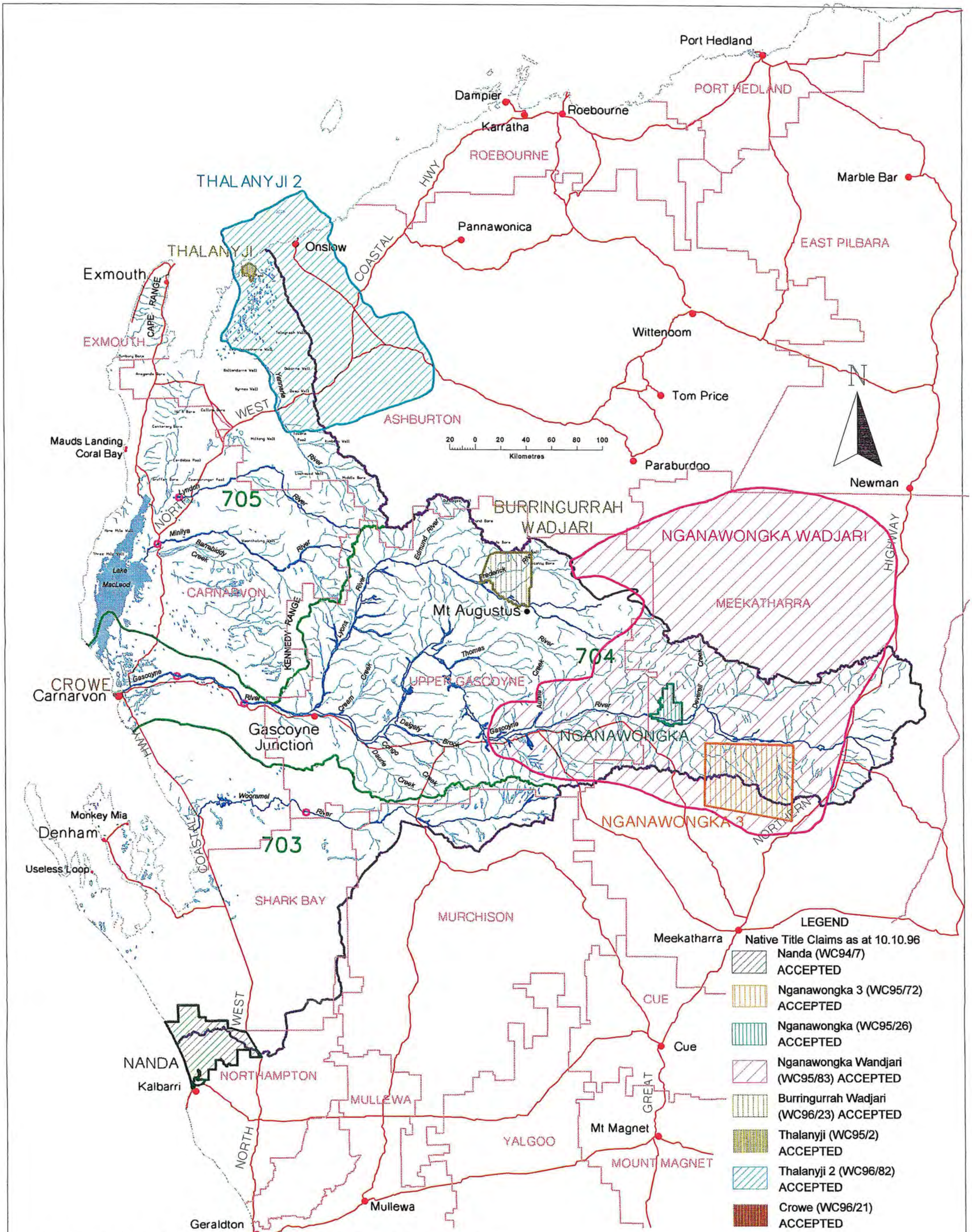
Of strategic planning concern is how the *Native Title Act 1993* will affect future government infrastructure activities and the expansion of some towns which are surrounded by land potentially subject to native title.

For future development of towns in more remote parts of the Gascoyne, the *Native Title Act 1993* may influence the speed of urban growth through the need to provide the "right to negotiate" to any registered native title claimants. In the Gascoyne, the future planning for land use needs, which may require the resumption of native title, must acknowledge the lead time necessary for the completion of the process. This may involve forward planning up to 5 years in advance of the need, as the resumption and "right to negotiate" process can take up to 2 years under the *Native Title Act 1993*. Government bodies will also need to address the question of compensation for any native title rights and interest affected by resumption.

Several native title claims in the Gascoyne Region are currently lodged with the National Native Title Tribunal. These are shown in Figure 6.1. Documentation of areas of aboriginal significance, in addition to the qualification of possible claims under the Native Title legislation, are considered necessary.

6.5.3 European Heritage

There are numerous sites of importance to the Gascoyne's European heritage which include sites of European discovery dating back hundreds of years. Also significant are sites of early settlement and early industrial activity which represent the character and development of the region.



Gascoyne Region Water Resource Review

NATIVE TITLE CLAIMS

Figure 6.1

7. Existing Water Supplies

7.1 Towns / Settlements In Wooramel River Basin (703)

7.1.1 Denham Town Water Supply Scheme

The Denham town water supply is drawn from two production wells. These wells are located approximately 900 m from one another on the south-eastern side of the town and are screened in the Birdrong Sandstone, an artesian aquifer of the Carnarvon Basin. The town has a dual water supply system which provides saline water for general use and a restricted supply of fresh (desalinated) water. The desalinated water is subject to a price surcharge as it is expensive to produce.

The groundwater salinity has remained relatively consistent and ranges from about 4,000 to 4,500 mg/L TDS. However, there has been an apparent decline in the pressure and flow rate of bores in the region. This may be attributed to the large number of uncontrolled flowing artesian pastoral wells in the region. It could be attributed to mutal interference with the Shire bores which are located several hundred metres away.

All groundwater abstracted for the town water supply is cooled, aerated and then filtered to remove iron. The desalinated supply is further treated by aeration, filtration and reverse osmosis. All chemical components of the desalinated supply are within the current NH&MRC drinking water guidelines.

Wellfield production from the two town water supply wells in 1995/96 totalled approximately 149 ML (Appendix F). One of the town water supply wells is highly calcified and has experienced low yields in recent years. The Water Corporation proposes to drill a replacement well in the near future to ensure a continued supply to the town.

Additional supplies could be obtained in future by drilling additional wells into the Birdrong Sandstone. However, each well should be sited at least 500 m from existing wells in order to minimise mutual interference caused by pumping.

7.1.2 Monkey Mia Water Supply Scheme

The Monkey Mia settlement is a popular holiday and recreation destination located approximately 20 km north east of Denham on the Peron Peninsula in Shark Bay.

The water supply for Monkey Mia is drawn from a privately operated bore screened in the Birdrong Sandstone.

The groundwater salinity is approximately 4,500 mg/L TDS. Landscaping has been possible with the saline water as salt tolerant lawn, plants and trees have been introduced. However, the water requires desalination to enable it to be used for potable purposes. Desalination is achieved by reverse osmosis.

Additional water supplies could be obtained in future by drilling additional wells into the Birdrong Sandstone. However, the efficient use of existing water supplies and water sensitive design incorporated into developments, landscaping and other initiatives could minimise the demand for further extraction.

7.1.3 Useless Loop Water Supply Scheme

Useless Loop is a closed mining town built exclusively for the staff of Shark Bay Salt. It is located on the Heirisson Prong in Shark Bay.

The water supply for Useless Loop is drawn from a privately operated bore screened in the Birdrong Sandstone.

The groundwater salinity is approximately 4,500 mg/L TDS. The water requires desalination to enable it to be used for potable purposes and this is achieved by reverse osmosis. Due to the high reverse osmosis costs, the water is rationed and residents (staff and families) are expected to keep within the annual allocation limit set by the company.

There are proposals to increase production of salt by about 50 per cent. This is expected to require a 30 per cent increase in staff numbers to meet production which will result in a 30 per cent increase in water consumption.

7.2 Towns / Settlements In Gascoyne River Basin (704)

7.2.1 Carnarvon Irrigation and Town Water Supply Scheme

The Carnarvon irrigation and town water supplies are drawn from the river bed sand aquifers and deeper older alluvium aquifers immediately adjacent to the main channel of the Gascoyne River. The area currently in use extends for some 55 km from the river mouth and is divided into management basins which reflect their use and hydrogeological characteristics (Figure 11-3).

Basins B to L extend approximately 20 to 55 km from the river mouth and are used solely by the Water Corporation to supply water for irrigation and community use. Basin A, occupying the 20 km section of the Gascoyne River from the river mouth to the Basin B boundary, is used primarily by growers and the water is extracted under licenses issued by the Water and Rivers Commission.

Groundwater abstracted from the water supply bores (Basins B to L) is pumped via collector mains into the trunk supply main. The supply main delivers water to storage tanks at Brickhouse pumping station from where it is pumped directly to growers and the community via the irrigation and town distribution mains.

Approximately 5,533 ML was delivered to the growers and the town in 1992/93 from the scheme wells in Basins B to L. Of this, approximately 3,816 ML was used by the growers and the remaining 1,537 ML was used by the town. It is believed that up to 1,590 ML was lost from the scheme in 1992/93. In comparison, approximately 4,697 ML was used by the growers from private wells in Basin A.

Water rest levels in all basins fluctuate considerably as a result of variations in demand and recharge from sporadic river flow events. Groundwater salinity of the aquifers also fluctuate considerably and this is attributed to variations in demand and recharge from sporadic river flow events. Salinity values may range from 400 mg/L TDS after a good river flow to 1,000 mg/L TDS after a significant period with little or no river flow.

All chemical components of the water supply are within the current NH&MRC drinking water guidelines. When the salinity in any well reaches 1,000 mg/L TDS, abstraction is stopped until the salt water is displaced by fresh water. This principle also applies to private wells in Basin A.

Limited additional groundwater supplies could be obtained in future by drilling additional wells into the river bed aquifers and deeper older alluvium aquifers of the Gascoyne River.

7.2.2 Gascoyne Junction Town Water Supply Scheme

The Gascoyne Junction town water supply is drawn from two shallow production wells. These wells are located just north of the town site and are screened in the alluvial coarse sands and gravels of the Gascoyne River bed. Recharge of the surficial aquifer occurs irregularly and results from river flows associated with tropical cyclone activity or occasional winter rains.

There is insufficient data to establish any trends in the water levels. Although, it is anticipated that the water rest levels will fluctuate considerably as a result of variations in demand and recharge from sporadic river flow events. Groundwater salinity of the aquifer fluctuates considerably and this is also attributed to variations in demand and recharge from sporadic river flow events. The salinity values may range from 400 mg/L TDS after a good river flow to more than 1,000 mg/L TDS after a significant period with little or no river flow.

Groundwater quality, with the possible exception of salinity during long dry spells, is within the current NH&MRC drinking water guidelines. Wellfield production from the two town water supply wells in 1992/93 totalled approximately 30 ML (Appendix F).

Additional groundwater supplies could be obtained in future by drilling additional wells into the alluvial sands and gravels of the Gascoyne River bed.

7.2.3 Burringurrah Aboriginal Community Water Supply Scheme

The Burringurrah Aboriginal Community is located about 25 km north of Mount James (and is approximately 40 km south of Mount Augustus). It is sometimes referred to as Mount James.

The water supply for Burringurrah is drawn from two shallow bores in a fractured rock aquifer. Groundwater in the area occurs mainly in the weathered profile of the granite bedrock or in fractures and joints. The depth to the water table in the area ranges from 5 to 15 m below the natural surface and the groundwater salinity varies from 700 mg/L to 2000 mg/L TDS.

7.3 Towns/Settlements In Lyndon-Minilya Rivers Basin (705)

7.3.1 Exmouth Town Water Supply Scheme

The Exmouth town water supplies are drawn from wells intersecting the Tulki and Trealla Limestone formations of the Cape Range Group in the Carnarvon Basin. These low yielding wells are located to the west and south of the town and extend for a distance of about 8 km along the eastern side of Cape Range.

Salt water underlies a thin layer of fresh water in the aquifer and extends inland for about 5 km. However, the inland extent of the salt water wedge appears to coincide with, and be controlled by, the presence of highly transmissive karstic features such as solution cavities and channels below the water table. These features increase the potential for salt water to move upwards or inland to wells drawing from the thin lens of fresh water.

Wellfield production from the town wells in 1992/93 totalled approximately 715 ML (Appendix F). Delivery to the town has decreased by more than 100 ML from the previous year due to the departure of the US Naval Base personnel from the town. Water quality is within NH&MRC drinking water guidelines, except for salinity in some wells. Salinity at the reticulation point is within the guidelines due to the mixing effect of water from different bores.

A substantial number of wells produce water with salinity greater than 1000 mg/L TDS and these wells may experience moderate or occasional usage to cater for demand. There is a trend of increasing salinities from east to west across the wellfield which may be attributed to the shallower depth to the salt water interface as the freshwater lens thins. There are generally higher salinities in the northern part of the wellfield and this is likely to be due to significant private abstractions and possible interference from the Harold E Holt Naval Base wellfield located to the north.

Most wells have experienced fluctuations in the water levels which are significant in comparison to the very flat gradient of the water table. The water levels respond to variations in abstraction and variations in recharge which are brought about by variations in rainfall. A slight declining trend in water levels in the wellfield is apparent during periods of below average rainfall. Saline upconing is sensitive to relatively small changes in water levels due to the flat water table.

A bore rationalisation and replacement programme has been proposed for the wellfield. The plan involves a combination of redrilling and re-equipping low salinity bores and decommissioning (abandoning) higher salinity bores. Also included in the plan are the replacement of collector mains and power aerials.

Limited additional groundwater supplies could be obtained in future by drilling additional wells into the Tulki and Trealla Limestone formations of the Cape Range Group.

Abstraction from the existing borefield currently exceeds the maximum allowable abstraction rate (sustainable yield) of the borefield. Therefore, to ensure reliability of supply, an extension to the Exmouth borefield has been proposed and this is expected to result in a reduction in the drawdown of the existing borefield and possibly some restoration of the fresh water lens.

The southward extension of the borefield involves the equipping of four bores along 'Leg 6'. These bores have already been drilled. Progression on the project is at a stand-still, as significant cave fauna, known as stygofauna, have been discovered within the borefield area. These cave fauna are dependent on the influx of water to the caves and interruption of the flow of water may adversely impact on the fauna. Consequently, the extension of borefield will not progress until a resolution on the stygofauna issue has been reached.

7.3.2 Coral Bay (Maud's Landing) Water Supply Scheme

The Coral Bay settlement is a popular holiday and recreation destination located approximately 160 km south of Exmouth. It is the southern portion of the Maud's Landing townsite. The northern part of the Maud's Landing townsite is currently vacant Crown land.

The water supply for the Coral Bay settlement is drawn from two privately operated bores screened in the Birdrong Sandstone.

The groundwater salinity is approximately 5,000 mg/L TDS. Landscaping has been possible with the saline water as salt tolerant lawn, plants and trees have been introduced. However, the water requires desalination to enable it to be used for potable purposes. Desalination is achieved by reverse osmosis. The water also needs to be cooled from the 60°C extraction temperature.

Additional water supplies could be obtained in future by drilling additional wells into the Birdrong Sandstone. However, the efficient use of existing water supplies and water sensitive design incorporated into developments, landscaping and other initiatives could minimise the demand for further extraction.

The provision of services and infrastructure in the settlement is expensive due to its isolation. To reduce costs, the developers could implement a combined water and sewerage system. This system would enable bores to be shared, thus providing desalinated water for potable purposes and more saline water and treated water from the effluent disposal system for landscaping and providing a back up in the event of bore failure.

The Gascoyne Coast Regional Strategy has pointed to the inadequacy of the existing servicing situation at Coral Bay, caused by the lack of Government utility involvement and the uncoordinated establishment of essential services. This has led to the appointment of the Coral Bay Infrastructure Task Force, which is required to provide Cabinet with advice on the infrastructure development needs for the settlement.

There are proposals to significantly increase the magnitude of the Maud's Landing townsite by incorporating a marina to allow access for boating to the adjacent Ningaloo Reef and other attractions, tourist and commercial facilities including a club resort, resort hotel, country club, caravan park, backpackers, associated commercial centre and community services together with some single and similar residential units.

The development is expected to be implemented in stages over 15 to 20 years and when complete is expected to require up to 1,890 kL of potable water per day. Although, the proposed development will have a separate water supply system to that supplying the existing Coral Bay area, it is expected that water will also be obtained from bores screened in the Birdrong Sandstone. It is doubtful that this amount of water can be readily obtained from the Birdrong Sandstone in the vicinity of Maud's Landing.

7.3.3 Harold E Holt Naval Base

The Naval Base draws water from a wellfield located to the west of the base and to the north of the Exmouth Town Water Supply Scheme. Water in this part of the aquifer ranges from 2000mg/L TDS and is desalinated to supply the Base's needs. Recently, the Naval Base supplied desalinated water to Wapet, however, this arrangement has ceased. The Navy is looking for further opportunities to sell its surplus desalinated water.

The Naval Base draws water from approximately 10 bores and heavy abstraction from these bores leads to saline water upconing. Careful managment of the wellfield is therefore required to maintain the aquifer at a sustainable level.

The desalination plant is an Electro-Dialysis Reverse cycle (EDR) plant with a capacity of 760kL/day. The Base does not produce desalinated water at the full capacity of the plant. Therefore, desalinated water may be available to supplement the Exmouth town water supply scheme.

8. Future Water Source Options

8.1 General

There are limited fresh groundwater sources available in the Gascoyne Region. These resources are described in more detail in Chapter 4. The potential for traditional surface water sources such as dams and pipehead dams are also limited due to the poor topographical characteristics of the identified sites which may lead to salinity failure or storage failure. The potential dam sites and yields are described in Chapter 3. This chapter addresses alternative water supply options which may be available for development in the Gascoyne Region.

8.2 Wooramel River Basin (703)

(Denham Town Water Supply Scheme, Monkey Mia, Shark Bay Salt and other minor schemes)

8.2.1 Desalination

Desalination is a technique currently used in the Wooramel River Basin to produce fresh water supplies for the town of Denham and other areas of Shark Bay. Major desalination operations in the area include the Water Corporation, Monkey Mia Resort and Shark Bay Salt reverse osmosis plants.

Groundwater drawn from the Birdrong Sandstone aquifer is generally brackish and has limited potential for usage unless it is desalinated. Desalinated water is currently used for in-house purposes such as drinking and bathing. Current uses of the brackish groundwater include stock watering and irrigation of salt tolerant gardens.

The use of water in the basin is expected to increase and this is likely to be due to future increases in tourism at Shark Bay. Residential population at Denham is also likely to increase. It is expected that the demand for fresh water will increase in tune with increases in residential population and tourist numbers in the area.

Expansion of the existing Water Corporation reverse osmosis plant may be necessary to cater for the demand in fresh water requirements at Denham, as part of the town water supply scheme. However, fresh water requirements in other areas may need to be provided by developers as an integral part of their developments.

Fresh groundwater resources have been identified to occur in limited quantities in the Wooramel River Basin at Wooramel and Meedo. Thus, it is considered that potential development and diversification in the basin will be largely dependent on the use of desalination practices.

8.3 Gascoyne River Basin (704)

(Carnarvon Town Water Supply Scheme and Irrigation Scheme)

It is anticipated that positive steps will be taken in the immediate future to address the water supply situation at Carnarvon.

The initiative to address the above has been brought about by recent restructuring and reform within the water industry, a commitment by the current government to allocate funds to the area and the opportunity to collaborate resources with the Main Roads Department who are also proposing work in the area. A consultant has been employed to investigate options to address the water supply situation at Carnarvon.

Considerable investigation has been undertaken in the Gascoyne River Basin in past years to determine alternative sources to augment the water supplies to Carnarvon. The following options were considered. Desalination may also be a viable option.

8.3.1 Gated Weir across Gascoyne River

This proposal involves the building of a barrage or weir with gates which collapse when overtopped by a flood. It was originally proposed by a plantation owner named Veen and is also known locally as the "Veen Barrage". A proposed site is located near the Nine Mile Bridge. In operation, the first flows in the river would be allowed to pass as this contains saline water and debris. The gates would then be lowered into place and the storage allowed to build up. Stored water would be used first, then the groundwater.

Increases in groundwater recharge from the storage would be small, as water can only be stored behind the barrage when the groundwater system is full. Once the surface storage has been used, the remaining groundwater storage is not much greater than if the supply had been from the groundwater alone. The increase in yield benefit is estimated to be approximately 1 GL per year (Wark and Ventriss, 1986). However, data available since their work suggests that the yield benefit may be slightly higher.

This option is currently being reviewed by SMEC as part of their study into the augmentation options for the Carnarvon Irrigation district. SMEC are also investigating an option for a low-level fixed weir (causeway) at Bibbawarra Crossing to provide additional storage. Two and three metre high causeways are being investigated. SMEC's preliminary findings are that neither of these proposals are economically viable.

Preliminary indications are that the three metre high causeway exceeds the southern bank level which means that a causeway of this height is not possible without building additional levee banks to contain the flow. The two metre causeway also exceeds the southern bank level, however, this height is considered unfeasible for use as an additional storage area as the annual pan evaporation exceeds 2 m.

8.3.2 Major Dams

Investigations for major dam sites were conducted in the early 1970's. The work included field testing programmes, survey work and topographic mapping leading to the preparation of preliminary design concepts. The work indicated that major dams would not be feasible as the sole source because of the poor storage basin shape, irregular flows in the Gascoyne and high evaporation.

A dam would have to be operated under the principle of conjunctive use with the groundwater scheme to produce the most acceptable form of supply. However, if water was retained in storage to provide a drought reserve, the loss of water due to the high evaporation rate would reduce the storage and increase the salinity so that the water would not be useable. Alternatively, if the water was used before a salinity failure occurred, there would be insufficient water available to carry the system through a prolonged drought and a supply failure would occur.

The dam sites at Rocky Pool and Kennedy Range were investigated and it was determined that the added yields which could be achieved from these dams were approximately 12 GL from Rocky Pool and 60 GL from Kennedy Range (Wark and Ventriss, 1986). Benefits from flood mitigation are considered to be small at Rocky Pool, although, they are more significant at the Kennedy Range site.

8.3.3 Major Off-stream Storages

The system involves multiple tanks constructed of local earthen materials. These would be filled by pumping from the river during river flows. Evaporation losses would be controlled by building deep storages (approximately 15 to 20 m deep) and by transferring water between tanks to minimise the surface area. Covers could also be used to control evaporation.

The system would be operated conjunctively with the groundwater scheme, both shallow and deeper aquifers, to provide the most benefit. Water would be taken from the system having the greatest evaporation losses. The deeper aquifer would provide the drought reserve.

It has been proposed that the offstream storages could be located approximately 15 km upstream of the Nine Mile Bridge. The additional yields which may be achieved from the storages are shown in Table 8.1, (Wark and Ventriss, 1986). Large pumps would be required to fill the storages and the effect of this demand on the Carnarvon power supply would need to be evaluated.

Table 8.1: Additional yields achieved from the offstream storages

Storage Volume (m^3)	Added Average Yield (m^3/year)
10×10^6	2.1×10^6
15×10^6	3.2×10^6
20×10^6	4.4×10^6
30×10^6	6.2×10^6

8.3.3.1 Yandoo Creek Scheme

Two proposals were investigated for this scheme in 1984. The first part of the scheme consists of two dams across water courses north of the Gascoyne River and one of these is Yandoo (Cardabia) Creek. Runoff from local rainfall would be stored behind the dams and then is diverted via two channels to the Gascoyne River to recharge the groundwater system in basins A and B as required.

A further development of the scheme includes the diversion of water from the Gascoyne River to the Yandoo Creek storages via a diversion channel at Rocky Pool. The option is considered uneconomical as the additional yields generated are small.

The overall increase in available yield depends upon a number of variables, including reservoir seepage, evaporation losses, uncertainty in the flow estimates and transfer and distribution losses. Gauging of the site between 1983 and 1991 indicated that the average annual flow was 3.94 GL. An acceptable estimate of the water yielded from this scheme is considered to be between 1.0 and 2.5 GL (Wark and Ventriss, 1986).

The water has high turbidity and there are concerns regarding the extent to which turbidity would contribute to the clogging of the aquifer during recharge.

8.3.3.2 Nichol Bay Flats Storage

Suggestions have been made that the area behind Brown Range known as Nichol Bay Flats could be used as a storage to supply irrigation needs. Water collects in the basin during relatively large flow events on the Gascoyne River and run off from local rainfall events which on occasion partially fills the basin.

The additional yield made available by the natural filling of the basin would be very small. This is due to the infrequency of events and the fact that river flows that are sufficiently large to fill the Nichol Bay Flats, recharge the groundwater basin at the same time. The flat storage shape and high evaporation rates combine to render the reservoir ineffective in providing long term storage.

The basin was analysed as a conventional offstream storage scheme which pumped water into the storage when the Gascoyne River flowed. The yields were determined to be approximately 0.5 GL, thus rendering this scheme largely ineffective (Wark and Ventriss, 1986). A hydrographic review of the area indicates that the volume of local run off is not large and is not worthy of further consideration.

8.3.4 On-farm Storages

The effectiveness of storages on individual properties is limited by operational efficiencies. For example, if a storage basin of the order of 100,000 kL was constructed, the probable yield would be approximately 15,000 to 30,000 kL/year (Wark and Ventriss, 1986), depending on the method of construction and the type of evaporation control. This has been based on the assumption that water would be drawn from farm storages until they are drained and that losses due to evaporation would be occurring from the groundwater system in the meantime.

8.3.5 Clay Barriers

This concept involves the installation of a clay barrier or barriers across the width of the river to act as an impediment to the downvalley flow of groundwater within the shallow river bed sand aquifers. It is based on the assumption that the groundwater within the shallow aquifer is free flowing and that during extended no flow period, significant quantities of groundwater may be lost from the system through discharge to the ocean at the river mouth.

It has been determined that the downvalley flow within the shallow aquifer is approximately 7,000 kL/year (Wark and Ventriss, 1986) and is considered to be negligible when compared with the other components of the water balance such as recharge, abstraction, evapotranspiration and deep infiltration.

A clay barrier, constructed in 1956 to a maximum depth of 8.5 m, was positioned approximately 3 km downstream from the Nine Mile Bridge. The condition of this barrier is unknown, however, it is suspected that the barrier was not completely finished when river flows occurred and scouring apparently occurred in floods during the 1960's. From the experiment, it was decided that clay barriers should not be considered further as a source of water.

8.3.6 Upstream Extension beyond Rocky Pool

The Gascoyne River upstream of Rocky Pool has potential to be used as a source of water. Groundwater in the area occurs in unconfined aquifers within the river bed sand and older alluvium and is recharged by the Gascoyne River flows.

Drilling in 1971 extended some 23 km upstream of Rocky Pool. A recent assessment of data by Panasiewicz (1995) reveals that the maximum sustainable yield of the aquifer is approximately 8.0 GL/year, based on the water balance in the area. This estimate allows for a non river flow period of 3 years due to the intermittent nature of the river flows. Further investigations should be carried out to improve the estimates of the groundwater resource.

The costs to deliver this water to the existing irrigation area may be in excess of $10 million. However, the availability of suitable soils and climate in the Rocky Pool area makes it possible to establish new plantations in the area which would make better use of both water and land resources of the Rocky Pool area.

8.3.7 Artificial Recharge of Management Basin G

Artificial recharge to management basin G has been proposed because a major portion of this basin's storage is not located under the present river bed. The storage is located under the south bank, adjacent to the river, where a deposit of river sand up to 16 m deep exists. The low flow channel is located along the northern bank through this reach.

This basin does not recharge to the same extent as shallow storages occurring under the river bed, particularly in the case of low flows confined to the low flow channel. Previous work has indicated that recharge to this basin may be enhanced through artificial means, thus increasing the overall system yield.

An open pit recharge scheme, involving the pumping of low flows into the pits, enables infiltration of water into the shallow groundwater basin below. The added yield from this scheme is approximately 0.3 GL/year (Wark and Ventriss, 1986). While this may appear small, some benefits occur through reductions in demand from the older alluvium aquifers. This basin also has good prospects for low sand barrages, gravity wells and canals to recharge the younger alluvium under the south bank.

8.3.8 Increased Use of Deep Aquifer System

In 1987, investigations were carried out to determine the extent of the water resources in the older alluvium of the Carnarvon irrigation scheme area. Recharge was estimated to be approximately 11.8 GL/year (Martin, 1990).

Groundwater available for abstraction from the older alluvium will depend on the management strategy adopted for the scheme. Potential problems from over-abstraction may include the loss of the existing level of supply security in the event of limited river flows.

Detailed modelling of the system is considered necessary to accurately estimate the increase in abstraction that can be practically achieved. Salinity implications should also be addressed.

8.3.9 Artificial Recharge of Prior Channels and Deeper "Second Aquifer"

Recharge of prior stream channels has not been investigated since the early 1970's, after it was reported that borehole injection was not viable due to the limited areal extent of these aquifers and their relatively low permeability.

Two reinjection experiments conducted at the Agricultural Research Station in 1966 and 1970 were unsuccessful. This was due primarily to the high suspended solids and dissolved oxygen content of the reinjection waters, which led to diminishing injection rates and significantly reduced the aquifer capacity.

This option is the most likely augmentation recommendation from the augmentation study with the option of "wick" drains, recharge wells and gravel trenches through the clay layer. In their study, SMEC concludes that such groundwater recharge options are the only augmentation options for the Carnarvon Irrigation District which can be justified on economic grounds.

8.3.10 Desalination

Desalination may be used to produce fresh water resources for the Gascoyne River Basin. Desalination techniques have been used with success in the Wooramel and Lyndon-Minilya River Basins. The majority of the groundwater resources in the basin are brackish, except for the limited fresh groundwater resources situated along the Gascoyne River.

8.4 Lyndon-Minilya Rivers Basin (705)

(Exmouth Town Water Supply Scheme, Coral Bay, Harold E Holt Naval Base, Learmonth Airport and other minor schemes)

8.4.1 Exmouth Town Water Supply Scheme

Exmouth obtains its water from a wellfield located to the west and south of the town. There are two problems with the system and they are:

- The wellfield capacity is limited and this is due to the geology of the area and the upconing effects of saline water from below the fresh water lens, and
- The system is aging. Some of the infrastructure has been in place for over 30 years and is showing signs of wear with pipe bursts occurring regularly.

8.4.1.1 Extend Existing Wellfield

The Exmouth wellfield extends south to Mowbowra Creek, which is a significant physical barrier to the southward extension of the wellfield infrastructure. In order to extend the wellfield further south, access, collector mains and power must be extended across Mowbowra Creek.

The preferred way to achieve this is to extend the existing collector main and access road along the edge of the coastal flat with westerly legs stretching into the foothills. Wells should be placed roughly in line with the existing wells to the north of Mowbowra Creek. The wellfield could be extended as far south as Learmonth or beyond if necessary or economically feasible.

Production per well is estimated to be 20,000 kL/year. Production from 4 wells could be used to satisfy existing demand and assist in correcting the over-abstraction of the aquifer from the northern section of the wellfield.

8.4.1.2 Purchase Desalinated Water from Naval Base

The Naval Base draws water from a wellfield located to the west of the base and to the north of the Exmouth Town Water Supply Scheme. Water in this part of the aquifer ranges from 2000 mg/L to 3000 mg/L TDS and is desalinated to supply the Base's needs. Recently, the Naval Base supplied desalinated water to Wapet, however, this arrangement has ceased.

The desalination plant is an Electro-Dialysis Reverse cycle (EDR) plant with a capacity of 760 kL/day which is approximatley 400kL/day more than current consumption.

It would be relatively simple and inexpensive to augment the existing TWS source by about 400 kL/day. The water would be available immediately and the only infrastructure needed would be a pipe connecting the northern end of the TWS reticulation system to the southern end of the Naval Base water reticulation system. This would provide an infusion of excellent quality water into the northern end of the reticulation system which now receives the worst quality water in the scheme.

8.4.1.3 Desalination

Desalination is a technique currently used in the Lyndon-Minilya Rivers Basin to produce fresh water supplies for Coral Bay and the Naval Base at Exmouth. Groundwater in the basin is generally brackish, however, fresh groundwater does exist in limited quantities in the Cape Range area.

Two desalination options could be used to provide water for the area. They are:

- Desalination of brackish water from wells in the northern part of the Exmouth wellfield, and
- Desalination of sea water from wells near the coast.

A number of wells in the northern part of the wellfield could be disconnected from the main wellfield piping and re-equipped for higher duties. The water would then be piped to a small reverse osmosis (RO) or EDR plant. The plant could deliver up to 500 kL/day of desalinated water. The plant could be designed for easy transport and reused elsewhere if it is no longer required.

Sea water could be obtained from wells along the coast and would be piped to a reverse osmosis or vapour compression plant. The reverse osmosis plant could deliver up to 500 kL/day of desalinated water and be expanded by adding 500kL/day modules. The plant could be designed for easy transport so that it may be used elsewhere if required.

It is proposed that desalination techniques are used when the cost of extending the wellfield exceeds the cost of desalination. This may occur in 2004.

9. Town Population and Water Supply Projections

9.1 General

To plan for future growth of the region it is important to identify future population levels. In order to support an increasing population, infrastructure such as water supply, must be provided.

The following projections are sourced from Ministry for Planning Reports coupled with data provided from the Australian Bureau of Statistics (ABS). Two population growth scenarios have been developed - 'Medium' and 'High'. Population growth rates are based on historical evidence with consideration given to major driving forces of each of the scenarios.

Population projections produced by the Ministry for Planning have been used as a basis for the Medium scenario. The High scenario is based on the increased migration as incorporated by the ABS modelling process. This has been referred to as the 'feasible population' and is used to demonstrate the likely maximum needs in the respective areas.

It is difficult to incorporate speculative developments into population projections and hence these have not been addressed.

This section details the projected population and water supply demand growth of the individual shires located in each of the drainage basins, and the major towns which influence the region's development.

The projections were primarily conducted on a shire basis, whereby the population was projected for each individual shire and the major centre within each of the shires. However, it must be noted that these projection figures are approximate calculations which reflect the intentions of the two scenarios. Therefore, the figures must be taken as indicative only and an expression of certain assumptions.

It is difficult to anticipate the growth and impact of tourism within the region. Regarding the water supply, there can only be as many visitors as the accommodation permits. While guest arrival figures for off-peak periods would exactly equate to demand, it is difficult to assess how many people during the peak season miss out on visiting the region in a particular year as a result of the lack of accommodation. However, it has been demonstrated that the seasonal influx of tourists during the peak season results in at least a doubling of the towns population.

Historical water delivery and consumption figures for the years 1981 to 1996 were obtained from the Water Corporation. This data is presented in Appendix F.

It has been assumed that the resident to tourist ratio remains constant. Hence, the resident projections reflects the trend of the tourist growth. In addition, the recorded delivery figures incorporate current tourist usage, hence, the projected delivery figures also account for tourist supply.

Growth scenario projections, incorporating population and water demand to the year 2026 for each shire are presented graphically below. Included are projections for each of the major towns and an overall projection for the region.

9.2 Gascoyne Region

In the past, the distance from Perth, high construction costs and climatic factors have discouraged population growth in the Gascoyne Region. However, a number of factors have been identified that indicate the growth in the region may accelerate:

- The steady growth of service sector employment, particularly in the tourism industry will continue in regional centres.
- Exmouth and Shark Bay provide superb scenic features upon which a thriving tourist industry could develop.
- The development of mining opportunities.
- Marina developments.
- Significant improvements in transport and communication infrastructure, the upgrading and expansion of air transport and improved road linkages will enhance access to regional centres.
- The petroleum industry provides good prospects for growth into the future.

The past population growth rates for the Gascoyne Region provide a cautionary message for the accuracy of any predictions for future growth. In the past, population growth rates for the region have been highly erratic, while the projections for the future are based on relatively stable growth year after year. Much of the erratic nature of these past patterns can be attributed to the region's small resident population and the effect of the region experiencing a significant one-off decline such as a result of the withdrawal of the US Navy from Exmouth which is unlikely to be replicated. Major future development could provide similar dramatic swings in the positive direction.

The instability of the region's population makes projections difficult and it is possible that the region could experience higher levels of growth than is currently predicted. However, for the population of the region to vary significantly from the following projections continuing growth in the tourism industry, further development of the horticulture sector, increasing mineral development and development of emerging industries such as aquaculture and possible floriculture is required.

9.3 Development

Over the next three years $8.5 million will be spent to provide additional residential and light industrial land across the region. $1 million will be spent in Denham to provide residential land, $3.1 million in Exmouth for residential land and $250,000 will be spent providing residential land in Gascoyne Junction. In addition, $1.5 million will be spent developing light industrial land in Exmouth and a further $600,000 in Carnarvon (GDC, 1996).

The Gascoyne Region is likely to see the development of a range of new initiatives over the next three years across a range of industry sectors. The following projects have or are about to commence and will contribute to the growth of the region's economy, providing new jobs, attracting new residents and tourists and providing additional wealth:

- Lake MacLeod Gypsum Project
- Carnarvon Fascine Development
- Exmouth Boat Harbour

In addition, a number of major projects are under consideration which are envisaged to take place within the next five years:

- Limestone Mining Project
- Learmonth Airport upgrade
- Exmouth Boat Harbour Development
- Mauds Landing Tourist and Residential Development
- Rocky Pool Horticulture Development
- Coral Bay Infrastructure Development
- Monkey Mia Dolphin Resort Expansion
- Aquaculture Initiatives

(Further information on any of the above projects can be obtained from the Gascoyne Development Commission).

9.4 Shire of Carnarvon

Carnarvon is the largest town in the region and the main administrative service centre and horticultural district. Its role as a tourist stopover and destination is growing and has the potential for further development.

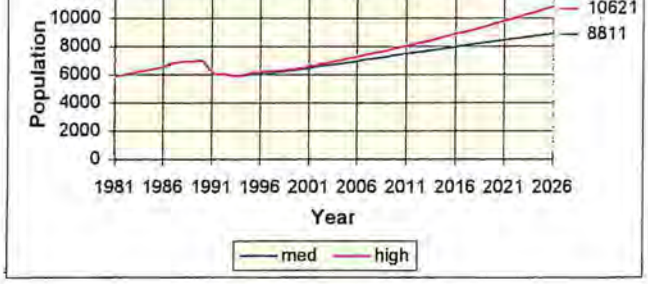
Landcorp is proposing a waterside residential estate for Carnarvon. Dredging of Carnarvon's Fascine between the ocean and the historic Tramway Bridge will pave the way for the new residential, tourism and recreation facilities.

Recently, the Town of Carnarvon has experienced some fluctuation in resident population. Despite rising strongly in the mid 1980's, the towns population has now returned to approximately the same level that existed in the early 1980's. The movement of Aboriginal people into and out of the region and the closure of some government services are possible reasons for the past fluctuations.

The population projections for Carnarvon Regional Centre, without consideration for tourism result in total populations of 8,811 and 10,621 in the year 2026 for each growth scenario respectively (Figure 9-1).

The Gascoyne Coast Regional Strategy Steering Committee recently published population projection figures for Carnarvon which were much higher than these projections and indeed for those of the Gascoyne Region. The figures are based on the presumed success of the Fascine Residential Development.

Figure 9-1: Population Projections - Carnarvon Town

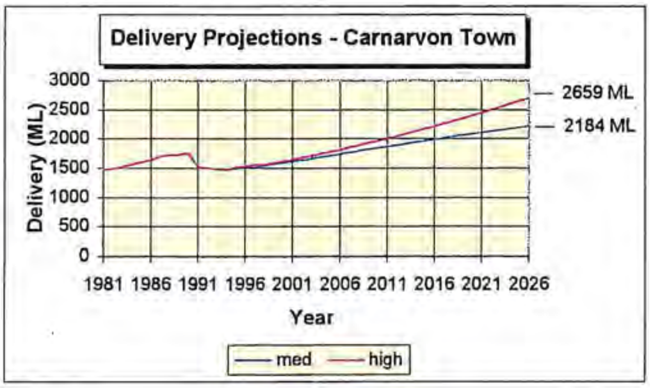


There are currently 1,956 services supplied in the town of Carnarvon. Of these services, approximately 1,575 are residential. During the 1994/95 financial year, the total consumption for the town was 1433 ML.

The total average annual delivery per person applied for the Shire projection was 245 kL/person. This annual delivery per person is based on annual delivery figures to the town and hence, incorporates the seasonal usage by the tourist population (Appendix F details the town water supply statistics). Assuming a constant resident to tourist ratio of approximately 1:4 the delivery projection adequately incorporates the tourist water usage.

The total annual water requirement as a result of the population increase is 2,184 ML and 2,659 ML respectively for each growth scenario (Figure 9-2).

Figure 9-2 : Delivery Projections - Carnarvon Town



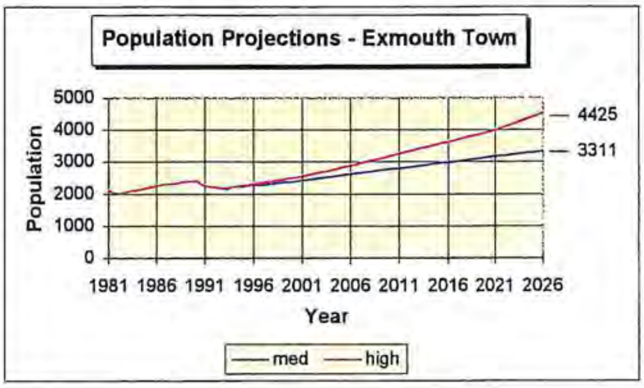
9.5 Shire of Exmouth

Exmouth Town is the sub-regional centre serving the northern part of the region. In recent years it has demonstrated its potential to grow despite the loss of the US navy personnel. Exmouth is currently diversifying its role to become a tourist destination and service centre. The current development of a marina facility at Exmouth will promote tourism development and provide opportunities for other industry in addition to providing the potential for residential growth.

The population projections for the Exmouth Town, without consideration for tourism, result in total populations of 3,311 and 4,425 in the year 2026 for each growth scenario, respectively (Figure 9-3).

The Gascoyne Coast Regional Strategy Steering Committee recently published population figures for Exmouth which are higher than these projections. Although a similar annual growth process was applied for the projections, the Strategy projections were based on slightly higher historical figures and not ABS statistics.

Figure 9-3 : Population Projections - Exmouth Town

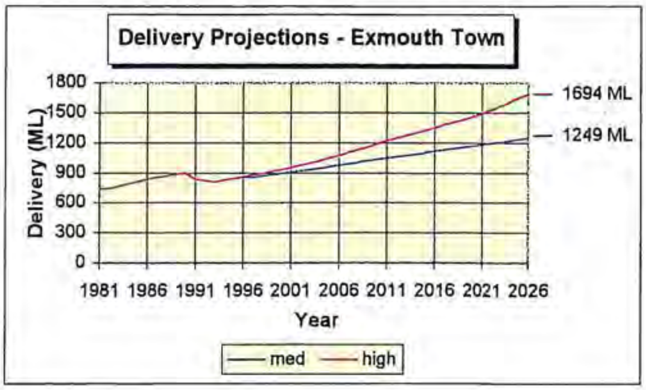


There are currently 866 services supplied in Exmouth. Of these services approximately 690 are residential. During the 1994/95 financial year, the total consumption was approximately 599 ML.

The total average annual delivery per person applied for the town projection was 373 kL/person. This annual delivery per person is based on annual delivery figures to the town and hence, incorporates the seasonal usage by the tourist population (Appendix F details the town water supply statistics). Assuming a constant resident to tourist ratio of approximately 1:4 the delivery projection adequately incorporates the tourist water usage.

The total annual water requirement as a result of the population increase is 1,249 ML and 1,694 ML respectively for each growth scenario (Figure 9-4).

Figure 9-4 : Delivery Projections - Exmouth Town



9.6 Shire of Shark Bay

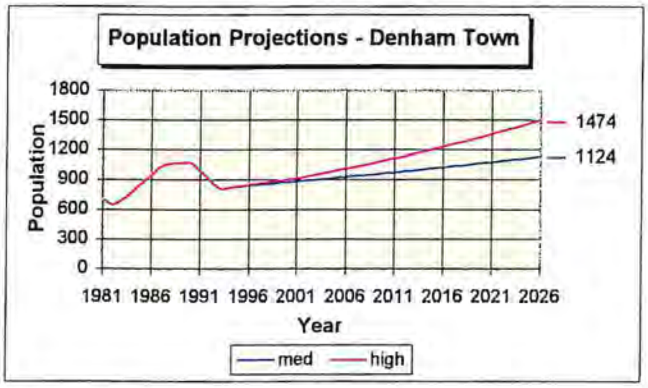
Denham, as the regional centre of the Shark Bay Shire, provides a desirable location for the focus of future development in the region. The following opportunities exist for further development and activity linked to the central role of Denham:

- Francois Peron National Park - improved use and access to tourism and recreation sites.
- Monkey Mia - expansion of the resort area and identification of an aquaculture precinct.
- South Peron Multiple Use Area.
- Nanga Homestead Project.

(Shark Bay Regional Strategy, 1996)

The population projections for the regional centre of Denham, without consideration for tourism, results in total populations of 1,124 and 1,474 in the year 2026 for each growth scenario respectively (Figure 9-5).

Figure 9-5 : Population Projections - Denham Town

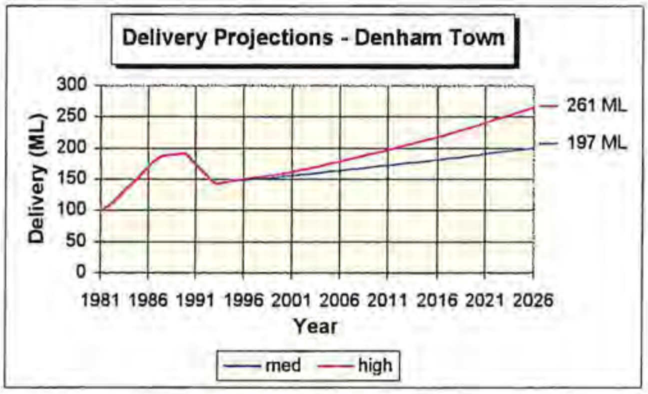


There are currently 346 services supplied in Denham. Of these services approximately 259 are residential. During the 1994/95 financial year, the total consumption was approximately 99 ML.

The total average annual delivery per person applied for the town projection was 245 kL/person. This annual delivery per person is based on annual delivery figures to the town and hence, incorporates the seasonal usage by the tourist population (Appendix F details the town water supply statistics). Assuming a constant resident to tourist ratio of approximately 1:4 the delivery projection adequately incorporates the tourist water usage.

The total annual water requirement as a result of the population increase is 197 ML and 261 ML respectively for each growth scenario (Figure 9-6).

Figure 9-6 : Delivery Projections - Denham Town

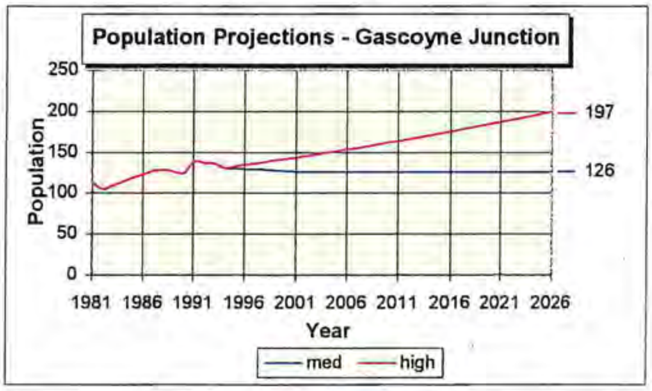


9.7 Shire of Upper Gascoyne

Gascoyne Junction is a small pastoral centre within the Upper Gascoyne Shire. Past trends indicate a decline in the resident population. Hence, the medium scenario has been modified to reflect the past decline with a stabilising beyond the year 2000.

The population projections for regional centre of Gascoyne Junction, without consideration for tourism, result in total populations of 126 and 197 in the year 2026 for each growth scenario, respectively (Figure 9-7).

Figure 9-7: Population Projections - Gascoyne Junction

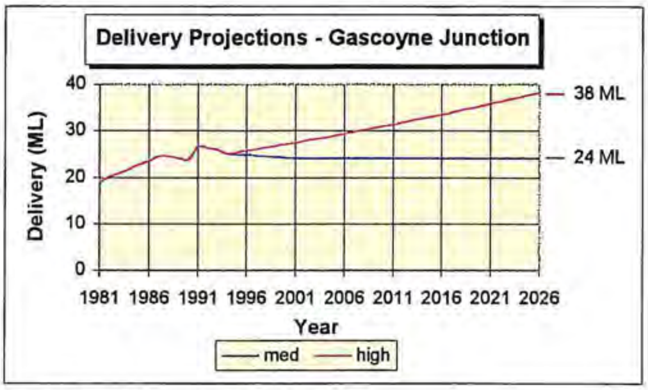


There are currently 17 services supplied in Gascoyne Junction. Of these services approximately 9 are residential. During the 1994/95 financial year, the total consumption was approximately 19 ML.

The total average annual delivery per person applied for the town projection was 190 kL/person. This annual delivery per person is based on annual delivery figures to the town and hence, incorporates the seasonal usage by the tourist population (Appendix F details the town water supply statistics). Assuming a constant resident to tourist ratio of approximately 1:4 the delivery projection adequately incorporates the tourist water usage.

The total annual water requirement as a result of the population increase is 24 ML and 38 ML respectively for each growth scenario (Figure 9-8).

Figure 9-8 : Delivery Projections - Gascoyne Junction

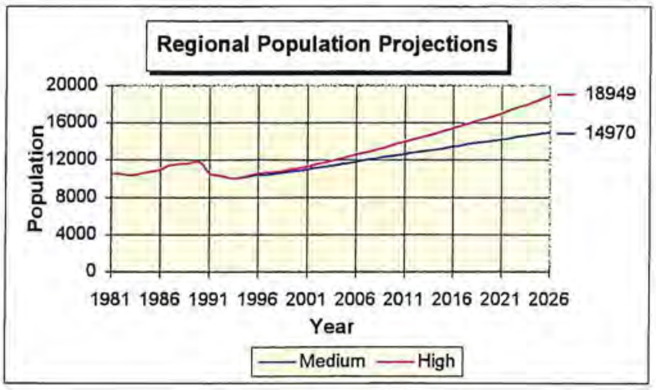


9.8 Regional Projection

A regional projection was conducted incorporating the major towns and shire developments within the region. The shire populations were projected individually and combined to provide a regional figure. The Medium Projection envisages a population of 14,970 in the year 2026. The high scenario projects a population of 18,949 in the year 2026 (Figure 9-9).

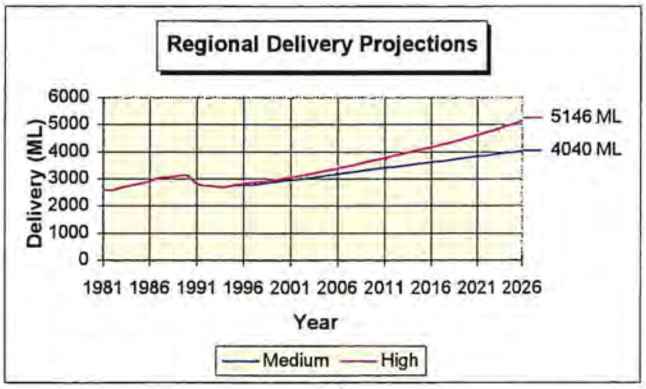
The WA 2029 study's Business as Usual Scenario projected a population of 12,000 people and their Quantum Expansion Scenario projected 14,700 in the year 2026. These projections did not incorporate the shires individually, hence local developments may not have been considered. In addition, the modelling process was based on the state rather than being regionally focussed.

Figure 9-9 : Population Projections - Gascoyne Region



These projections equate to an annual water demand of 4,040 ML and 5,146 ML for the two scenarios (Figure 9-10).

Figure 9-10 : Delivery Projections - Gascoyne Region



It is recommended that monitoring of the population and delivery figures be regularly reviewed as the above analysis is dependent on the proposed developments proceeding. These figures do not take agricultural, tourism and industrial growth into account. These are considered in Sections 11 and 12 respectively.

10. Tourism Development and Growth Potential

The growth of the tourism industry will have an impact on the natural resources, existing infrastructure and utilities, such as power and water supply. Additional information development of tourism in the Gascoyne Region is contained in Appendix G.

Increased tourist numbers and a general increase in the number of permanent residents will mean an increased demand on water resources. Periods of high water consumption during the peak holiday seasons may place pressure on existing water sources and promote the need for the development of new sources.

The development of new sources is restricted by the climate and geology of the region. Despite the presence of large rivers, surface water resources are unreliable and difficult to develop because of the large variation in rainfall and high evaporation rates. Groundwater occurs throughout the region. However, in response to the varied geology and climatic factors, the groundwater varies widely in the amount available and its salinity. Considerations to the availability and quality of water resources must be made in planning for the future development of the tourism industry.

The quality of water resources may also be affected by tourism development within the Gascoyne Region. Developments that may potentially impact on water resources, including water reserves, should be referred to the Water and Rivers Commission for advice.

Competition for water resources may arise when existing sources cannot supply demand. The tourism industry is only one growing industry in the Gascoyne Region in which future water requirements is an important issue related to its development. Other areas of growth include mining and horticulture. Competition for water resources may occur when existing sources can no longer sustain demand. If future sources are not allocated sustainably, water resources may become exhausted under the pressure of competition.

The availability and quality of water resources in the Gascoyne Region are limited. It is important that the planning of the tourism industry in the future allows for the related increases in the demand for water to ensure the safekeeping of sustainable resources.

The planning of developments related to the tourism industry should consider the impact they may have on existing and future water resources in the Gascoyne Region. This includes the sustainable allocation of resources as well as the consideration of potential pollutants.

In the future, other water source options may have to extend further than the potential resources within the region. These may include desalination of sea water or brackish water or the piping of water from other regions of the State, which at present are considered uneconomical. As the water resources in the region become fully allocated and technology is improved, the economic viability of these options will become more favourable.

11. Agricultural Development and Growth Potential

11.1 General

Primary industries have historically been the mainstay of the Gascoyne regional economy. Activities such as pastoral production and horticulture have contributed much to the prosperity of the region through the years.

Two distinct types of agricultural activities take place in the Gascoyne. Horticulture takes place along the banks of the Gascoyne River between 5 and 18 km from its mouth, and pastoral activity occurs extensively throughout the region.

Additional information on the development of agriculture in the Gascoyne Region is contained in Appendix H.

11.2 Pastoral Industry

The pastoral industry is the main user of the artesian aquifers. The annual abstraction from artesian bores is estimated to be approximately 45 GL (Allen, 1986). This estimate may be high, however, even if it was conservatively estimated, it would still exceed the total recharge of 27.9 GL per annum to the aquifer of which only 17.3 GL per annum is recharged to the most heavily exploited part of the aquifer. The groundwater salinity generally ranges from 3,000 to 6,000 mg/L TDS.

The Gascoyne Region currently supports an estimated 725,000 sheep and 33,000 cattle. In this region, one DSE (Dry Sheep Equivalent) can be expected to consume 1.5kL of water per year. This equates to a demand of about 2 GL per year. The current usage of 45GL per year (mostly from uncontrolled artesian bores?) would appear to be a serious misuse of a regionally valuable resource.

The effect of allowing artesian bores to flow has probably extended to the recharge areas in the southern part of the basin. However, the apparent continued decline in flow rates indicates there has been no large compensating recharge. Furthermore, it is unlikely that there has been any improvement in groundwater salinity as the unconfined groundwater in alluvium overlying the intake areas to the Birdrong Sandstone is generally brackish.

The main effect of controlling artesian flows would be to maintain artesian pressures over a relatively large area for an indefinite period. This would reduce the necessity for windmills or pumps in some areas and thus reduce operating costs to some station owners. A secondary effect of controlling artesian flows is to conserve groundwater.

By the year 2026, it is anticipated that groundwater usage from the artesian pastoral bores will be reduced to the sustainable yield of the aquifer, which is estimated to be approximately 20 GL per annum.

It is anticipated that the impacts of future pastoral development on the surficial groundwater resources of the region will be minimal (because they are localised). This is due to the remoteness of the pastoral stations from other developments, the lack of competition for the groundwater resources and the limited amount of water that is drawn from bores for stock usage.

11.3 Horticultural Industry

Existing groundwater supplies in the current horticultural area are already fully committed. Currently 8.5 GL of water is utilised for horticultural practices. In order for the horticultural industry to develop, the identification and utilisation of potential water resources needs to be addressed. Groundwater resources are known to exist at Rocky Pool, Mooka, Meedo and Wooramel. These water resources could be used for horticultural development.

In the Rocky Pool area, the renewable groundwater resource is estimated to be 8.0 GL/annum with salinity less than 1,000 mg/L TDS. The estimation of the sustainable yield is based on inferred limits derived from groundwater information. Abstraction quotas, therefore should progress gradually from about 5.0 GL/annum to about 8.0 GL/annum, at which time the maximum vertical hydraulic gradient will be induced (Panasiewicz, 1995).

The extent of horticultural development at Rocky Pool will be constrained by the availability of suitable water resources. Although, firm decisions have not been made on the management and allocation of water in this area, it is expected that the criteria will be similar to that for the existing horticultural area. The water infrastructure is likely to be privately developed.

It is expected that the use of water at Rocky Pool will be managed in a way which will minimise the adverse effects on water availability in the existing horticultural area at Carnarvon. This could be achieved by limiting the amount of water which may be drawn from the Gascoyne River when it is flowing. Small flows at Rocky Pool would be required to pass unhindered and work is in process to determine the level at which water may be drawn from the river at Rocky Pool without affecting recharge to the aquifers downstream in the Carnarvon horticultural area.

Currently SMEC consultants are investigating the future management and augmentation of the Carnarvon Irrigation area. The consultants are undertaking a detailed feasibility study of options to augment water available to Carnarvon irrigators by approximately 3.5 to 4.0 GL/annum.

The resources of the Mooka and Meedo areas are unknown and have been omitted in the planning process until information concerning the resources is available. Rockwater (1996) estimated the groundwater resources of the Wooramel River basin to be 2.2 GL/annum.

Two scenarios for the horticultural projections for the region were developed based on the above available water resources. Both scenarios assume the augmentation study is successful, consequently 4.0 GL/annum is available.

Scenario 1, assumes the development of all possible resources to their maximum potential. This incorporates developing the resource at Rocky Pool in two stages; firstly developing, 5.0 GL/annum then, secondly progressing to the maximum 8.0 GL/annum.

Scenario 2 assumes that only the first stage of Rocky Pool will eventuate and that the Wooramel resource is constrained to provide only 1.1 GL/annum.

Water projections indicate water requirements in the year 2010 of 17.5 GL for the two scenarios and the year 2026 of 22.7 GL and 18.6 GL for scenario 1 and 2 respectively.

Year	Scenario 1 (1 x $10^6 m^3$/annum)	Scenario 2 (1 x $10^6 m^3$/annum)
2010	17.5	17.5
2026	22.7	18.6

Figure 11.1: Horticultural Projection Scenario 1

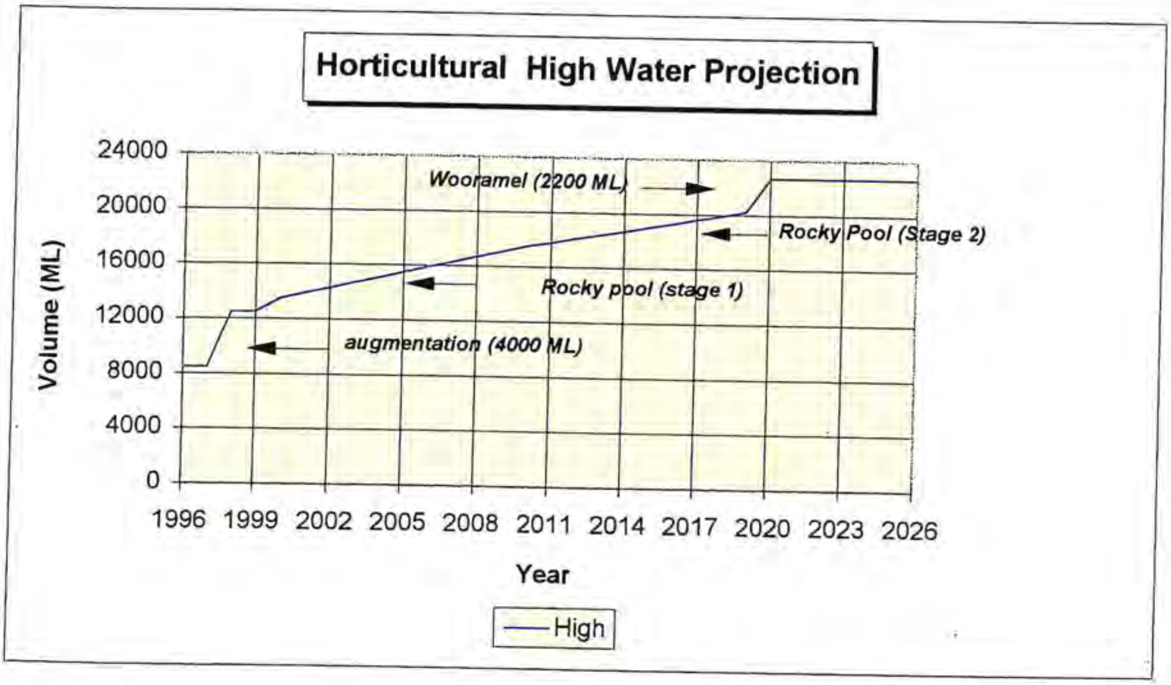
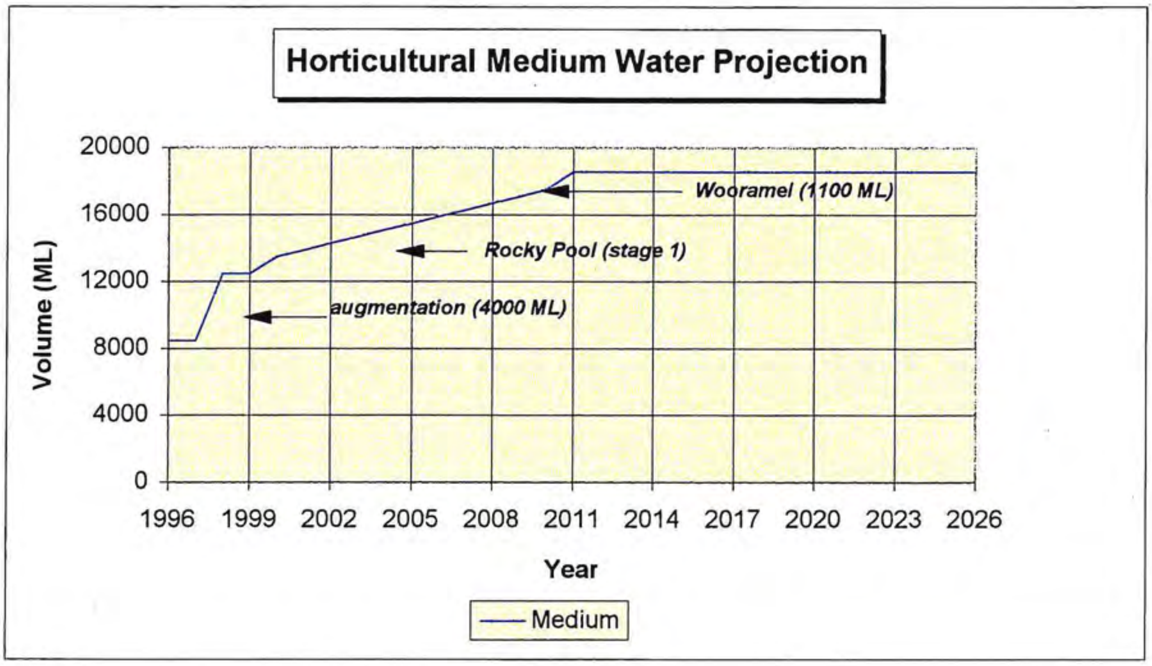


Figure 11.2: Horticultural Projection Scenario 2



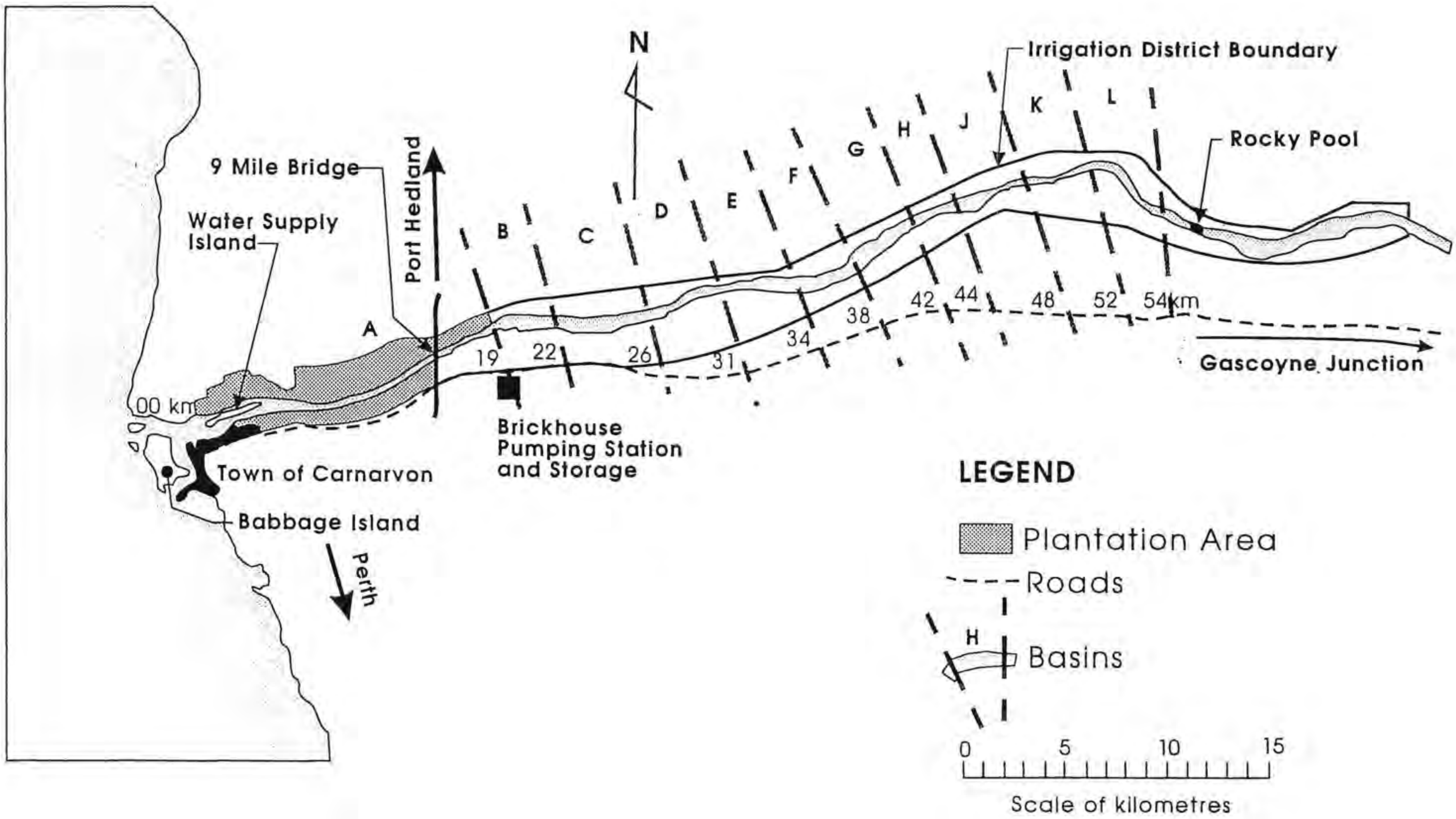


Figure 11-3 : Carnarvon Irrigation District and wellfield basins (A -L)

12. Industrial Development and Growth Potential

The region's economic activity is diverse and relatively well balanced. Almost all of the product from the region is directed to either the Perth metropolitan domestic market or to export markets. While the region has the smallest economy in total, it has one of the broadest with important contributions being made to economic activity and employment by a variety of sectors.

The economic return from tourism and mining are likely to expand in the medium term. In the longer term, growth may also be expected from the fishing, aquaculture and horticultural industries.

The prospect of strategic industrial development is also strong, particularly in the North West Cape, where development associated with quality limestone resources are proposed and consideration is being given to the Cape as a site for natural gas related initiatives.

The region's mining sector makes an important contribution to the region in both economic and employment terms. However, the lack of diversity from this sector is of concern to the region and efforts are being made to enhance the role played by this sector in the region's economy. Production from the region is almost entirely attributable to salt mining.

The region's fishing sector provides a rich variety of seafood to the domestic and international market. Fishing in the Gascoyne is based on prawns, scallops and varieties of fish such as snapper, tuna, shark and mackerel. The catch is also processed in the region and this is the region's principal manufacturing activity.

Infrastructure such as the proposed new boat harbour at Exmouth will provide improved facilities for the growing number of recreational fishers who visit the area. It will also benefit the Exmouth Gulf fishing industry through the provision of servicing facilities and safe anchorage in cyclonic conditions. The upgrading of the airport terminal at Learmonth will enable the provision of improved export and cold storage facilities to industries.

Additional information on the development of industry in the Gascoyne Region is contained in Appendix I.

Currently, 1,445 ML of water is utilised in the region for industrial purposes and includes the mining, fishing and manufacturing sectors. The water demand for the industrial sector has been projected and considers only the known large scale developments which are expected to require water within the next 5 to 10 years. This assessment includes the water requirements associated with the expansion of the salt, gypsum, limestone and fishing/fish processing industries. The water usage from the Naval Base is expected to increase as industries take advantage of the water and infrastructure available at the base.

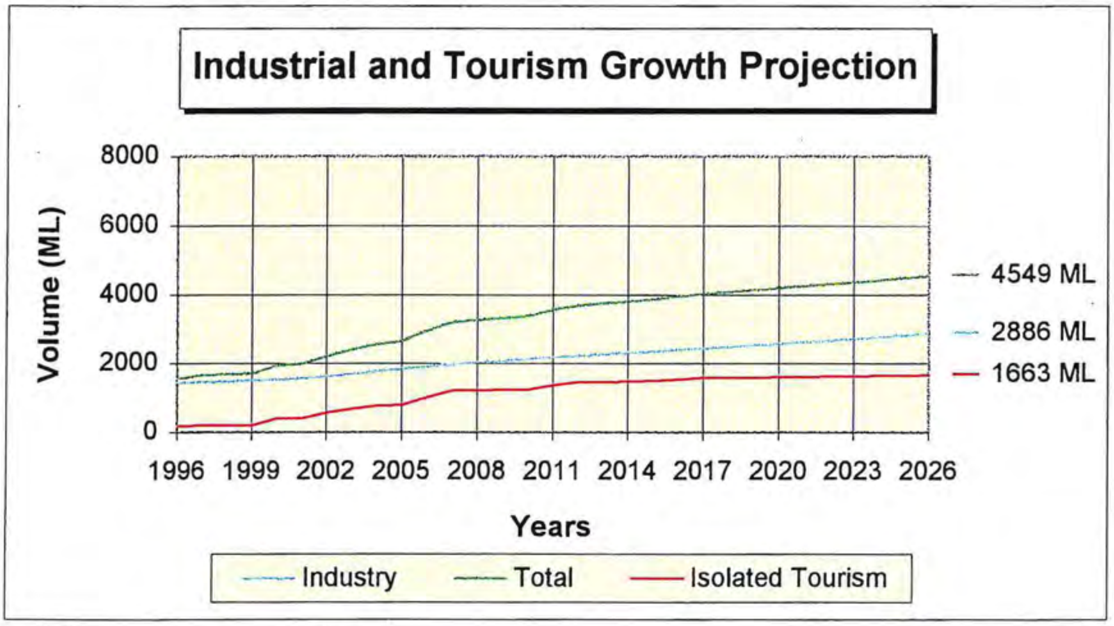
The water projections indicate that in 2026 the industrial water requirements are likely to be about 2,886 ML. This is an estimate based on the best available knowledge and may need to be reviewed in the next 5 to 10 years.

Approximately, 191 ML is believed to be used by the tourism industry in areas remote from the major towns in the region. The water demand for the tourism industry (remote from towns) has been projected and considers only the known large scale developments which are expected to require water within the next 5 to 10 years. This assessment includes the water requirements associated with the expansion of the tourism industry at Coral Bay, Monkey Mia, Nanga and the North West Cape.

The water projections indicate that in 2026 the tourism water requirements are likely to be about 1,663 ML. This is an estimate based on the best available knowledge and may need to be reviewed in the next 5 to 10 years.

In 2026, the combined industrial and tourism water requirements are believed to be approximately 4,549 ML.

Figure 12-1 : Tourism and Industrial Projection



13. Water Resource Development Plans

13.1 General

The following section outlines the potential development of water resources in the study area for future town water supply, industrial and agricultural use. The various population centres described and the potential surface water development sites are shown in Figure 1-1 and Figure 3-1 respectively. Figure 4-3, Figure 4-4 and Figure 4-5 show the locations of the major groundwater aquifers in the region and these are grouped according to river basins.

No attempt has been made to identify specific environmental/social issues related to the individual potential developments. Environmental/social water requirements will be determined by the environmental impact assessment process through which each source development proposal must pass before being approved.

13.2 Town / Settlement Water Supplies in the Wooramel River Basin (703)

13.2.1 Denham Town Water Supply Scheme

The Denham town water supply scheme obtains its water from groundwater in the Birdrong Sandstone, an extensive aquifer of the Carnarvon Basin. The groundwater is brackish and has a salinity of approximately 4,500 mg/L TDS. The town has a dual water supply system which provides saline water for general use and a restricted supply of fresh (desalinated) water for potable purposes. The desalinated water is subject to a price surcharge as it is costly to produce.

Population projections indicate a high growth scenario water demand of 261 ML from the water supply scheme in the year 2026. This exceeds the current groundwater license of 200 ML by 61 ML and a new license would have to be obtained from the Water and Rivers Commission at the appropriate time.

It is expected that the additional groundwater supplies required to meet this projected demand will be sourced from the Birdrong Sandstone. However, each well should be sited at least 500 m from existing wells in order to minimise mutual interference caused by pumping. The Water Corporation proposes to drill a replacement well in the near future to improve the wellfield yields, thus increasing the reliability of supply to the town. Additional or replacement wells would need to be covered by a groundwater license obtained from the Water and Rivers Commission.

There is currently an apparent interference between bores used by the Shire (for watering parks and gardens) and bores used by the Water Corporation. Any replacement bores constructed by the Water Corporation should be sited to minimise such interference.

Monitoring indicates that there is an apparent decline in the pressure and flow rate of bores in the region. This is likely to be due to the large number of uncontrolled flowing artesian pastoral bores in the region. This decline in pressure and flow rate should not significantly impact the expansion of the Denham water supply.

A schematic diagram of the existing town water supply scheme is shown in Appendix J.

13.2.2 Monkey Mia Water Supply Scheme

The Monkey Mia settlement is a popular holiday and recreation destination located approximately 20km north east of Denham on the Peron Peninsula in Shark Bay. Monkey Mia obtains its water from groundwater in the Birdrong Sandstone. The groundwater salinity is approximately 4,500mg/L TDS. The groundwater is desalinated to enable it to be used for potable purposes, although, landscaping has been possible with the saline water.

There are proposals to double the carrying capacity of the tourist settlement and projections indicate a water demand of 106 ML in the year 2026. This would exceed the current groundwater license of 100 ML by 6 ML and a new license would have to be obtained from the Water and Rivers Commission at the appropriate time.

Additional supplies could be obtained in future by drilling additional wells into the Birdrong Sandstone. However, the efficient use of existing water supplies and water sensitive design incorporated into developments, landscaping and other initiatives could minimise the demand for further extraction.

13.2.3 Useless Loop Water Supply Scheme

Useless Loop is a closed mining town built exclusively for the staff of Shark Bay Salt. It is located on the Heirisson Prong in Shark Bay. Useless Loop obtains its water from groundwater in the Birdrong Sandstone, an extensive artesian aquifer occurring throughout most of the Carnarvon Basin.The groundwater salinity is approximately 4,500 mg/L TDS. The groundwater is desalinated to enable it to be used for potable purposes and the water is rationed due to the high desalination costs. Landscaping has been possible with the saline water.

There are proposals to increase production of salt by about 50 per cent. This is expected to require a 30 per cent increase in staff numbers to meet production which will result in a 30 per cent increase in water consumption. Projections indicate a water demand of 167 ML in the year 2026 which is covered by the current groundwater license of 200 ML.

13.3 Town / Settlement Water Supplies in the Gascoyne River Basin (704)

13.3.1 Carnarvon Irrigation and Town Water Supply Scheme

The Carnarvon irrigation and town water supplies are drawn from the river bed sands and the deeper older alluvium aquifers in and immediately adjacent to the main channel of the Gascoyne River. The area in use extends approximately 55km from the river mouth and is divided into management basins which reflect their use and hydrogeological characteristics. Basins B to L extend approximately 20 to 55km from the river mouth and are used exclusively by the Water Corporation to supply water for irrigation and community use. Basin A occupies the 20km of river from the mouth of the river to the Basin B boundary and is licensed for use by approximately 160 plantations.

The groundwater is generally fresh, although, the salinity varies considerably in response to variations in demand and recharge from sporadic river flow events. The water rest levels also fluctuate considerably in response to the variations in demand and recharge. Saline water ingress from more saline parts of the aquifer may occur if the water rest levels beneath the river bed fall significantly.

Population projections for the town indicate a high growth scenario water demand of 2,659 ML from the water supply scheme in the year 2026. This reflects a growth of 37 ML per year which exceeds the part of the license related to the town supply. A new license would have to be obtained from the Water and Rivers Commission at the appropriate time.

It is assumed that the area of plantation properties in the Carnarvon area will remain constant until 2026, as the limited supply of water should prevent any extension of the plantation area. However, fluctuations in water demand from year to year are likely to occur depending upon the crop water requirements. Water efficiency techniques may aid in keeping water consumption down and ongoing education of the need for water efficiency is considered essential. The Water Corporation's irrigation supply totalled approximately 3,815 ML in 1993, although, over the last 10 years the demand has fluctuated and has averaged approximately 4,250 ML. Based on the above, it is anticipated that demand from the Water Corporation's irrigation supply will total approximately 4,250 ML in the year 2026.

The combined total for the irrigation and town supply demand is estimated at 6,909 ML in the year 2026. This exceeds the current groundwater license of 6,800 ML by 109 ML.

Limited additional groundwater supplies for irrigation and community purposes could be obtained in future by drilling additional wells into the river bed sand aquifers and the deeper older alluvium aquifers of the Gascoyne River. This may pose some difficulties due to the large number of bores in Basins B to L and the expense involved in extending the irrigation area upstream beyond Basin L. In addition, the groundwater occurring upstream is likely to be used for irrigation of the proposed Rocky Pool horticultural area.

The Carnarvon Irrigation Augmentation Steering Committee's Consultant SMEC is currently investigating options to address the water supply situation in Carnarvon. It is expected that a resolution will be reached in the next few months on ways to improve the reliability of water supply to the entire existing Carnarvon irrigation area (Basins A to L). Preliminary indications suggest that the most economic way to improve the reliability of supply to the Carnarvon Irrigation District will be by induced groundwater recharge.

A schematic diagram of the existing town water supply scheme is shown in Appendix J.

The groundwater license should differentiate between the irrigation and town water supplies.

13.3.2 Proposed Rocky Pool Horticultural Area Water Supply Scheme

Water for the proposed Rocky Pool horticultural area is expected to be obtained from the alluvial aquifers of the Gascoyne River, in the vicinity of Rocky Pool upstream of Basin L. The renewable fresh groundwater resource is estimated to be 8.0GL per year, although, it is recommended that development of the resource be restricted to 5.0GL per year until the yield of the resource can be proven. As is the case for the existing Carnarvon horticultural area, the extent of horticultural development at Rocky Pool will be constrained by the limited availability of suitable water resources.

The Water and Rivers Commission policy for groundwater well licensing at the Rocky Pool horticultural area will be one of self management, where irrigators take responsibility for managing the quantity and quality of groundwater they draw. This responsibility will be delegated to the irrigators by provisions in the groundwater well license.

Groundwater well license applicants may initially be granted an exploratory groundwater well license which will enable formal assessment of the potential for the groundwater resource to cater for the proposed development. Results of the aquifer investigation should be prepared by a competent hydrogeologist and submitted to the Water and Rivers Commission in the form of a hydrogeological report.

It is envisaged that groups of adjacent proponents may form an association to perform the necessary hydrogeological assessments. This would serve to reduce the expense of the individual licensees from aquifer investigations and hydrogeological reporting.

13.3.3 Gascoyne Junction Town Water Supply Scheme

The Gascoyne Junction town water supplies are drawn from the alluvial coarse sands and gravel of the Gascoyne River bed. The groundwater is generally fresh, although, the salinity varies considerably in response to variations in demand and recharge from sporadic river flow events. The water rest levels also fluctuate considerably in response to the variations in demand and recharge. Saline water ingress from more saline parts of the aquifer may occur if the water rest levels beneath the river bed fall significantly.

Population projections indicate a high growth scenario water demand of 38 ML from the water supply scheme in the year 2026. This amount is covered by the current groundwater license of 40 ML.

Additional groundwater supplies could be obtained in future by drilling wells into the alluvial sands and gravels of the Gascoyne River bed. Additional groundwater supplies would need to be covered by a groundwater license obtained from the Water and Rivers Commission.

A schematic diagram of the existing town water supply scheme is shown in Appendix J.

13.3.4 Burringurrah Aboriginal Community Water Supply Scheme

The Burringurrah Aboriginal Community is located about 25 km north of Mount James (and is approximately 40 km south of Mount Augustus). It is sometimes referred to as Mount James. Burringurrah obtains its water from groundwater occurring in the weathered profile of the granite bedrock or in fractures and joints. The groundwater salinity varies from 700 mg/L to 2000 mg/L TDS.

No projections have been determined for the community due to the lack of available data. Currently, investigations are being conducted to ascertain the groundwater prospects of the area and this depends on the occurrence of fracture zones within the granite bedrock. Exploratory bores may be required and pumping tests are expected to be carried out on several new and existing bores. The target water requirement is 300 kL per day.

13.4 Town / Settlement Water Supplies in the Lyndon-Minilya Rivers Basin (705)

13.4.1 Exmouth Town Water Supply Scheme

The Exmouth town water supplies are drawn from the karstic Tulki and Trealla Limestone formations of the Cape Range Group, in the Carnarvon Basin. The groundwater is generally fresh, although, it is limited. Salt water underlies the thin layer of fresh water in the aquifer. The inland extent of the salt water wedge appears to coincide with, and be controlled by the presence of highly transmissive karstic features such as solution cavities and channels below the water table. These features increase the potential for salt water to move upwards or inland to wells which draw from the thin lens of fresh water.

Population projections indicate a high growth scenario water demand of 1,694 ML from the water supply scheme in the year 2026. This exceeds the current groundwater license of 800 ML by 894 ML and a new license would have to be obtained from the Water and Rivers Commission at the appropriate time.

Abstraction from the current borefield currently exceeds the sustainable yield of the borefield. To ensure reliability of supply, an extension to the Exmouth borefield has been proposed by the Water Corporation. Progression on the project is at a stand-still, as significant cave fauna known as stygofauna have been discovered within the borefield area. Extension of the borefield is pending EPA approval and this is unlikely to occur until a resolution on the stygofauna issue has been reached.

This southern extension of the borefield involves the equipping of four existing bores along 'Leg 6'. The maximum allowable yield from this 'leg' of bores is 160 ML per year. Two further borefield extension 'legs' have also been identified. The yield from these two legs is estimated to be 305 ML. The total yield from all eight legs of the Exmouth borefield (when fully commissioned) is expected to reach a maximum of 1,095 ML. This is inadequate when considering the projected water requirements for 2026. A shortfall of 600 ML is apparent and this would need to be obtained from another source.

Possibilities for meeting this shortfall include:

- Extending the borefield further beyond the eight 'legs'. However, judgement would need to based on economics as further borefield extension is likely to exceed the cost of alternative sources. The bore yields for further extensions are unknown and would need to be evaluated by drilling and bore pump testing to ascertain the sustainable yields.
- Purchasing desalinated water from the Naval Base. Up to 400 ML of desalinated water could be purchased, however, this would need to be subject to mutual agreement between the Naval Base and the purchaser (Water Corporation). Water drawn from the aquifer to meet this demand should be drawn sustainably to prevent ingress of the saline water interface.
- Desalination of sea water or brackish water (from the Tulki and Trealla Limestone or Birdrong Sandstone). It is expected that a small reverse osmosis desalination plant could deliver up to 500 kL per day of desalinated water. However, this would need to be subject to environmental impact assessment.

Strong competition for the limited water resources on the North West Cape is likely to occur between the requirements for the town water supply and the needs for water to service the tourism and industry sectors.

A schematic diagram of the existing town water supply scheme is shown in Appendix J.

13.4.2 Coral Bay Water Supply Scheme

The Coral Bay settlement is a popular holiday and recreation destination located approximately 160km south of Exmouth. It is the southern portion of the Maud's Landing townsite. Coral Bay obtains its water from groundwater in the Birdrong Sandstone. The groundwater salinity is approximately 5,000 mg/L TDS. The groundwater is desalinated to enable it to be used for potable purposes, although, landscaping has been possible with the saline water.

There are proposals to develop a new boat launching facility, with associated services. This is likely to provide for additional tourist related development in the Coral Bay area. Additional water supplies could be obtained in future by drilling additional wells into the Birdrong Sandstone.

The provision of services and infrastructure in the settlement is expensive due to its isolation. To reduce costs, the developers could implement a combined water and sewerage system. This system would enable bores to be shared, thus providing desalinated water for potable purposes and more saline water and treated water from the effluent disposal system for landscaping and providing a back up in the event of bore failure.

If the proposed Maud's Landing Project goes ahead, it may prove to be cost-effective to integrate the Coral Bay supply with that of Maud's Landing.

The Gascoyne Coast Regional Strategy has pointed to the inadequacy of the existing servicing situation at Coral Bay. This has led to the appointment of the Coral Bay Infrastructure Task Force, which is required to provide Cabinet with advice on the infrastructure development needs for the settlement. It is likely that improvements will be recommended to the water, sewerage and power infrastructure.

13.4.3 Proposed Maud's Landing Water Supply Scheme

The northern part of the Maud's Landing townsite (also referred to as Maud's Landing) is currently vacant Crown land. It is located approximately 3km north of the existing Coral Bay tourist area.

There are proposals to significantly increase the magnitude of the Maud's Landing townsite by incorporating a marina to allow access for boating to the adjacent Ningaloo Reef and other attractions, tourist and commercial facilities including a club resort, resort hotel, country club, caravan park, backpackers, associated commercial centre and community services together with some single and similar residential units.

The development is expected to be implemented in stages over 15 to 20 years and when complete is expected to require up to 1,890 kL of potable water per day. The efficient use of existing water supplies and water sensitive design incorporated into developments, landscaping and other initiatives could minimise the demand for further extraction.

Although, the proposed development will probably have a separate water supply system to that supplying the existing Coral Bay area, it is expected that water will also be obtained from bores screened in the Birdrong Sandstone. It is doubtful that this amount of water can be readily obtained from the Birdrong Sandstone in the vicinity of Maud's Landing. A hydrogeological assessment should be conducted to ascertain the sustainable yield of the aquifer in this area.

In terms of the development of the tourism industry, the marina and resort elements of the proposed development at Maud's Landing are probably not economically sustainable without a predominant housing component. The proposal should therefore consider the effect of the combined tourist and residential populations on the water resources in the area and should ensure that demand at peak times is consistent with the sustainable management of the resources in the area.

13.4.4 Harold E Holt Naval Base

The Harold E Holt Naval Base draws water from a wellfield located to the west of the base and to the north of the Exmouth Town Water Supply Scheme. Water in this part of the aquifer ranges from 2000 mg/L to 3000 mg/L TDS and is desalinated to supply the Base's needs. Recently, the Naval Base supplied desalinated water to Wapet, however, this arrangement has ceased.

The Naval Base draws water from approximately 10 bores and heavy abstraction from these bores leads to saline water upconing. Careful management of the wellfield is therefore required to maintain the aquifer at a sustainable level.

The desalination plant is an Electro-Dialysis Reverse cycle (EDR) plant with a capacity of 760 kL/day. The Base does not produce desalinated water at the full capacity of the plant. Therefore, desalinated water may be made available to the Exmouth town water supply scheme.

Approximately 400 kL per day of desalinated water could be augmented to the Exmouth town water supply scheme which is expected to have a water supply shortfall of approximately 600 ML in the year 2026. This would be subject to mutual agreement between the Naval Base and the Water Corporation.

A pipe connecting the northern end of the Exmouth TWS reticulation system to the southern end of the Naval Base water reticulation system would provide an infusion of excellent quality water into the northern end of the Exmouth reticulation system which currently receives the worst quality water in the scheme.

14. Conclusions and Recommendations

14.1 Introduction

The prime focus of the study was:

- to provide an inventory of the divertible water resources of the region;
- to assess the current water requirements of existing developments;
- to predict the future water requirements of existing and potential developments.

14.2 Conclusions

14.2.1 Surface Water Resources

Currently, no water is obtained from surface water storages in the Gascoyne Region.

Extensive hydrological analyses of potential surface water sources were undertaken. Only limited information relating to each site has been presented in this report and can be used for preliminary design and planning purposes. The presented information is based on dam and pipehead specifications that are the most feasible. Complete analyses, contained in spreadsheets, for each site have been archived and are available from the Hydrologic Services section of the WRC. This information should be used when planning specific schemes. Reduction in rainfall brought about by potential climate change has not been taken into account in the hydrological analysis and should be applied where and when deemed necessary.

Surface water resources in the Gascoyne Region are notoriously unreliable. In addition, high evaporation rates make surface water storages less attractive. The most cost - effective way to use surface water resources in the region is conjunctively with groundwater resources i.e. when there is surface water available, it is used in preference over groundwater, "resting" the groundwater resources. When surface water sources become unavailable either because of salinity or lack of storage, then groundwater sources should be used.

Table 14-1 below indicates the total potential divertible surface water resources within each basin.

Table 14-1: Surface Water Resources.

Basin	Resources (ML)
703	0
704	382,110*
705	4,900
All	387,010**

* This is a summation of the divertible yields from all dam sites in this basin. In reality, the divertible yields from a combination of any or all the sites would be much less. Conjunctive use of surface water resources with groundwater resources would increase available yields.

**This total is directly affected by*.

Development of the surface water resources are subject to constraints and these outweigh the yield benefits which may be obtained. Major constraints at most sites include: poor topographic characteristics, sporadic river flows and high salinity and/or storage failures.

14.2.2 Groundwater Resources

The Gascoyne Region is an arid to semi-arid region which comprises about 6 per cent of Western Australia. Despite the presence of large rivers, surface-water resources are unreliable and difficult to develop because of the large variation in rainfall and high evaporation rates.

Groundwater occurs throughout the region. However, in response to the varied geology and climatic factors, the groundwater varies widely in the amount available and its salinity.

The fresh renewable groundwater resources (<1,000 mg/L TDS) are small (about 90 GL/year) and limited to a few areas and aquifers where favourable recharge conditions exist. In contrast, brackish and saline groundwater resources are widespread and are fairly readily available. Nine possible sources of fresh groundwater capable of yielding 0.5 GL/yr or more have been identified. The largest apparent resources are in the alluvium along the Lower Gascoyne River, at Cape Range, and possibly in the Birdrong Sandstone. Several other small actual or potential sources have also been identified.

No new drilling was undertaken to determine the extent of groundwater resources in the Gascoyne Region. The appraisal of the groundwater resources undertaken in this report considered existing information obtained from previously recorded bore logs and hydrogeological assessments. The resources include fresh and brackish water supplies.

It is important to note that the groundwater resources which have been determined to exist in the region are indicative only and it is recommended that the proponent of any proposed development conduct a thorough appraisal of the groundwater resources in the area before proceeding with the development.

Table 14-2 below indicates the potential groundwater supply and likely demand within each basin.

Table 14.2: Groundwater Supply and Demand Scenarios

Basin	**703**		**704**		**705**	
Year	**1996**	***2026***	**1996**	***2026***	**1996**	***2026***
Total Resources (ML)	44,600	*44,600*	95,200	*95,200*	49,000	*49,000*
TWS(ML)	149	*261*	1,561	*2,697*	815	*1,694*
Industry (ML)	690	*1,314*	250	*1,190*	696	*2,045*
Agriculture (ML)	39,000#	*15,000**	10,500	*24,700*	4,000	*3,000**
Total Demand (ML)	**39,839**	***16,575***	**12,311**	***28,587***	**5,511**	***6,739***
Reserved for Enviro (ML)	11,150	*11,150*	23,800	*23,800*	12,250	*12,250*
Surplus Available (ML)	**-6,389****	***16,875***	**59,089**	***42,813***	**31,239**	***30,011***
% Used	114%	*62%*	38%	*55%*	36%	*39%*

This figure is high due to the wastage of water from uncontrolled flowing artesian bores.

* The reduction in agricultural usage as shown is based on the assumption that currently uncontrolled artesian bores will be capped as recommended thus limiting wastage of groundwater from uncontrolled flowing bores.

** The fact that this figure is negative reflects that groundwater is being drawn at an unsustainable level because of uncontrolled flowing artesian bores.

14.3 Recommendations

The data and projects assessed in this study should be reviewed in approximately 5 years so that information remains as up to date as possible.

14.3.1 Surface Water Resources

Although, recently performed hydrological analyses and streamflow simulations have been used to determine the potential divertible yields for the various dam sites, comparisons with earlier simulations has indicated serious discrepancies.

The earlier simulations, produced in 1978, have been used to determine the yields of the alternative sources in the 1986 study "Review of Alternative Sources to Augment Water Supplies to Carnarvon" by Wark and Ventriss. While these simulations may be inaccurate, they provide the only available data on the likely yields of alternative sources.

More accurate results would be possible if more detailed modelling was undertaken to include the additional 20 years of streamflow record now available.

14.3.2 Groundwater Resources

(1) Exploratory drilling to define the availability and extent of groundwater resources is recommended to be undertaken at the following localities, if additional fresh groundwater is to be developed:

- Yannarie River - alluvium
- Rocky Pool-Fishy Pool - alluvium
- Wooramel-Meedo - alluvium
- Kennedy Range - Birdrong Sandstone
- Coastal (Mooka Area) - Birdrong Sandstone
- Coastal (Meedo Area) - Birdrong Sandstone

(2) Groundwater from potential sources should be analysed for trace elements, in particular boron, fluoride, selenium and nitrate, which may affect their usefulness for irrigation, or for domestic water supply.

(3) Consideration should be given to relining, plugging, or replacing artesian bores in the western Carnarvon Basin which are currently flowing uncontrolled.

(4) A recommendation from the Carnarvon Irrigation Augmentation Consultancy is that investigation and modelling of the Gascoyne River alluvium aquifers should be undertaken in order to develop a better understanding of that crucial resource. This recommendation is endorsed by this study.

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15.2 Abbreviations

AHD	Australian Height Datum
ANCOLD	Australian National Committee On Large dams
AWRC	Australian Water Resources Council
CALM	Department of Conservation and Land Management
CER	Consultative Environmental Review
DEP	Department of Environmental Protection
EIA	Environmental Impact Assessment
EMP	Environmental Management Plan
EPA	Environmental Protection Authority
ERMP	Environmental Review and Management Programme
G & AWS	Goldfields and Agricultural Water Supply Scheme
g/w or GW	groundwater
GL	Gigalitres (one million kilolitres)
GSTWS	Great Southern Towns Water Supply Scheme
GWA	Groundwater Area
ha	hectares
km	kilometres
m	metres
MAF	Mean Annual Flow
mg/L	milligrams per litre
Mt/a	megatons per annum
MWS	Metropolitan Water Supply Scheme
N/A	not applicable
NH&MRC	National Health and Medical Research Council

OWR	Office of Water Regulation
PER	Public Environmental Review
PWF	Perth's Water Future Study
PWSA	Public Water Supply
Res.	reservoir
Spec. rural	Special rural
sq. km	square kilometres
SWIRT	South West Irrigation Review Taskforce
TSS	Total Soluble Salts
TWE	Transferable Water Entitlements
WAWA	Water Authority of Western Australia
WAWRC	Western Australian Water Resources Council
WC	Water Corporation
WR	Water reserve
WRC	Water and Rivers Commission

15.3 Glossary

Aquifer	A geological formation or group of formations capable of receiving, storing and transmitting significant quantities of water.
Artesian aquifer	See confined aquifer.
Beneficial use	The current or future uses for a water resource which have priority over other potential uses because of their regional significance to the community. Beneficial use designations provide guidance in determining the management and protection of the quality and quantity of the resource.
Bore	See well.
Brackish water	Water of salinity 1000 - 3000 mg/L TSS.
Catchment	The surface area from which run-off flows to a river or a collecting reservoir such as a lake or dampland.
Chemical	Harmful alteration of the chemical properties of the environment, eg. the pollution water resource.
Confined aquifer	A permeable geological formation saturated with water under pressure and underlying a relatively impervious layer.
Criteria	Principles or standards by which a thing is judged.
Cubic metre	The volume occupied by a cube measuring one metre along each edge. On cubic metre contains one kilolitre of water.
Dam	A structure constructed across a river valley to store stream flow and allow it to be diverted for water supply use and for release in a controlled manner for downstream use.
Demand	The amount of water required from the water supply system.
Desalination	The process of removing salts from water to produce fresh water.
Diversion	Development of a water resource to harvest some or all of its divertible water.
Divertible water	The average annual volume of water which could be removed from developed or potential sources on a sustainable basis.
Effluent	The liquid, solid or gaseous products discharged by a process, treated or untreated.
Evaluation	The process of analysis to describe using decision factors and criteria, the implications of an thereby to help to determine the acceptability of, an option relative to a set of objectives.
Factors	Circumstance, fact or influence which contributes to a result.

Filtering	A more refined screening process of evaluating options and deciding whether the option should be considered for more detailed analysis at the next stage.
Fresh water	Water of salinity less than 500 mg/L TSS.
Gigalitre	1000 Megalitres.
Groundwater	Water which occupies the pores and crevices or rock or soil.
Groundwater area	An area proclaimed under the Rights in water and Irrigation Act 1911 in which private groundwater abstraction is licensed.
Kilolitre	1000 litres (see also cubic metre).
Land use	Land use which is sufficiently significant to prevent an incompatible constraint development of a divertible water resource.
Marginal water	Water of salinity 500 - 1000 mg/L TSS.
Megalitre	1000 Kilolitres.
Nutrients	Materials conveying, serving as or providing nourishment to some organisms.
Options	Alternative ways of meeting the objectives. In this case sources of water or water efficiency measures.
Pesticides	Collective name for a variety of insecticide, fungicides, herbicides, fumigants and rodenticides.
Pipehead	A small dam allowing some of the water flowing in a stream to be diverted into a pipe for water supply use.
Pollution	Any direct or indirect alteration of the physical, chemical, thermal, biological, or radioactive properties of any part of the environment by discharging, emitting or depositing wastes or substances so as to affect any beneficial use adversely, to cause a condition which is hazardous or potentially hazardous to public health, safety or welfare, or to animals or plants.
Potable water	Fresh and marginal water generally considered suitable for human consumption.
Pumpback	A pipehead dam diverting some streamflow by pumping through a pipeline into a storage dam.
Recharge	Water arriving at the water-table.
Recharge area	An area allowing water to percolate to the water-table. An unconfined aquifer is recharged by rainfall throughout its distribution. Confined aquifers are recharged in specific areas, where water leaks from overlying aquifers, or where the aquifer rises to meet the surface. Recharge of confined aquifers is often at some distance 'upflow' from points of extraction.
River basin	The catchment of river(s) as defined by the Australian Water Resources Council for presenting hydrological data.
Runoff	The discharge of water through surface streams into larger water courses.
Saline water	Water resources of salinity greater\ than 3000 mg/L TSS.
Salinity	The measure of the total soluble (or dissolved) salt, ie. mineral constituents in water. Water resources are classified on the basis of that salinity in terms of milligrams per litre Total Soluble Salts (mg/L TSS).
Saltwater	The interface between a layer of fresh groundwater and underlying saltwater.

Saltwater intrusion	The inland or upward intrusion of saltwater into a layer of fresh groundwater.
Scheme supply	Water diverted from a source (or sources) by a water authority or private company and supplied via a distribution network to customers for urban, industrial or irrigation use.
Scheme	A conceptual design or operating procedure to supply water from a source (see source).
Self supply	Water diverted from a source by a private individual, company or public body for their own individual requirements.
Service reservoir	A reservoir built near consumers to receive bulk supplies of water from major sources prior to final distribution to services.
Sewage	Domestic wastewater
Source	An actual water source such as a new dam, expansion of existing dams or development of groundwater which will contribute to meeting water needs (see scheme).
Storage reservoir	A major reservoir of water created in a river valley by constructing a dam.
Stormwater	Rain water which has runoff roads etc., and is usually disposed of by drains.
Strategy	A set of policies or means aimed at a set of objectives designed to bring various actions under unified direction in order that the organisation's or community's objectives may be effectively served. It may consist of one or more source options, water efficiency policies, as well as a commitment to research and develop "environmentally friendly" options.
Surface water	Water flowing or held in streams, rivers and other wetlands in the landscape.
Sustainable yield	The rate of water extraction from a source that can be sustained on a long-term basis without exceeding the rate of replenishment. Sustainable groundwater use limits extraction to no more than the recharge rate and requires sufficient throughflow to prevent ocean water intrusion into aquifers.
System yield	The maximum demand that the water supply system can sustain under specified expectation of restrictions (currently restrictions are expected in 10 per cent of years).
Transpiration	The process by which plants take up water from the soil and release water vapour through the leaves.
Treatment	Application of techniques such as settlement, filtration, chlorination, to render water suitable for drinking purposes.
Turbidity	Clouding of water due to suspended material in the water causing a reduction in the transmission of light.
Unconfined aquifer	An aquifer which has its upper boundary at the earth's surface (the upper surface of the groundwater within the aquifer is called the water-table).
Upper dam	A major reservoir on a river upstream of a main dam.
Wastewater	Water which has been used for some purpose and would normally be discarded. Wastewater usually contains significant quantities of pollutant (see Pollution).
Water Reserve	An area proclaimed under the metropolitan water Supply Sewerage and Drainage Act or Country Areas water Supply Act to allow the use of water on or under land for public water supplies.

Water Resources	Water in the landscape (above and below ground) with current or potential value to the community and the environment.
Water-table	The surface of the unconfined groundwater, which may be above ground as swamps or lakes in low-lying areas. Measured as the level to which water rises in a well tapping an unconfined aquifer.
Well	A hole dug or drilled (bore) from the ground surface into a groundwater aquifer to monitor or to withdraw water. Household wells are commonly termed bores.
Wellfield	A grouping of wells to extract large volumes of groundwater, generally for scheme supply.
Wetland	Area of seasonally, intermittently or permanently waterlogged soils or inundated land, whether natural or otherwise, fresh or saline.
Yield benefit	The increase in system yield which occurs when a new source is added to the water supply system.

15.4 Computer Files

Most of the work in this study has been stored in Microsoft Word (Version 6), Microsoft Excel (Version 5) and MicroStation (Version5) files. All this information is stored on floppy disks which are contained in the relevant file (Gascoyne Water Resource Review - 1996), housed in the Development Planning Section of the WRC. These files, especially the Excel files containing the projections and additional information, could be a useful source of information when undertaking projects within the region.