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GROUNDWATER RESOURCES OF THE PILBARA REGION, WESTERN AUSTRALIA

by

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PREFACE

This summary report is based exclusively on the Water and Rivers Commission Hydrogeological Report No 35

Groundwater resources of major catchments in the Pilbara Region, Western Australia

By

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INTRODUCTION

The Pilbara Region is considered by the State to be one of the main areas for Australia's economic recovery. The economic potential of the Pilbara is based primarily on its mineral resources, in particular iron ore and gas / petroleum. Other industries include agriculture, fishing and tourism. Water is recognised as an essential requirement for future development. Groundwater represents an important source of water in the region and currently provides sustainable water supplies to towns, mining centres, industry and agriculture. It is also essential for the maintenance of the environmental ecosystems associated with springs and permanent pools within the drainage systems of the region.

Since 1960, and with the development of the iron ore industry, there has been substantial groundwater resource drilling throughout the Pilbara Region. However, most of the data from this drilling have only been locally assessed and there is a need for a regional groundwater resource appraisal. As a reconnaissance appraisal of the groundwater resources, the Water Authority of Western Australia (Water Authority) requested the Geological Survey of Western Australia (GSWA) to assess and evaluate the available data and make recommendations for future investigations including exploratory drilling and regional hydrogeological mapping, particularly those areas with potential for large groundwater supplies, but for which little data are available. This assessment, commenced by the GSWA, has been carried out by the Groundwater Investigation Branch of the Water and Rivers Commission (WRC) and resulted in a technical report by Skidmore (1996) entitled "Groundwater resources of major catchments in the Pilbara Region , Western Australia". This summary report is based exclusively on that work and includes some verbatim parts of the Skidmore report.

LOCATION

The Pilbara Region lies in the northwest of Western Australia. The study area covered by Skidmore (1996) covers about 230 000 km^2 and includes the Australian Water Resources Catchment (AWRC) Drainage Basins 706 to 710 and the northwestern portion of the Great Sandy Desert (Fig. 1). The major coastal towns are Port Hedland, Karratha, Dampier and Onslow, and inland towns include Pannawonica, Tom Price, Newman, Paraburdoo, Nullagine and Marble Bar.

CURRENT WATER SUPPLY

Water for most of the towns in the Pilbara Region, other than those owned and operated by large mining companies, is supplied by the Water Corporation. Large quantities of water for water supply, processing and dewatering are consumed by the many mines throughout the region. The locations of the major water supply schemes are shown in Figure 2 and the more important groundwater supply schemes listed in

Table 1. Apart from the Harding Dam / Millstream aquifer scheme and the Ophthalmia Dam Groundwater Recharge Scheme, all other schemes are supplied solely from groundwater sources. There are 92 licensed groundwater users in the Pilbara Region and current licensed abstraction quotas range from 400 m^3/year to about 15 x10^6 m^3/year. Most allocations are for mining activities, but some smaller quotas are allocated for pastoral station use. Details of groundwater licenses are held by the WRC.

Table 1 : The major groundwater supply schemes in the Pilbara Region.

Town / Mine	Wellfield	Usage (x 10^6 m^3/yr)	Potential (x 10^6 m^3 /yr)
West Pilbara WSS	Millstream *	4.9	10.7
Onslow	Cane River *	0.35	0.35
Tom Price	Fortescue River	0.7	
	Hardey River	0.7	6.9
	Mt. Lionel	1.3	
Paraburdoo	Town	0.6	4.3
	Mine		
Pannawonica	Eastern Deepdale	0.6	0.7
Port Hedland	Yule River *	2.6	12.0
	De Grey River *	3.3	
Marble Bar	Town *	0.14	0.2
	Coongan River *		
Nullagine	Nullagine River *	0.05	0.08
	MRD well area *		
Wittenoom	Joffre Creek (to be shut down)	0.09	0.1
Newman	Ophthalmia	5.3	10.0
Goldsworthy	DeGrey River (shut down)	0.1	1.5

* managed by Water Corporation .

A recent water resource review (WRC ,1996) indicated that there are sufficient water resources in the Region to satisfy future industrial development. Pilbara town water supply sources are capable of meeting unrestricted demand under normal climatic conditions. However , during extended dry periods some towns could experience restrictions. The inland towns supplied by groundwater have sufficient surplus capacity available in the local aquifers to allow for expansion of existing borefields. The coastal centres of Karratha and Port Hedland, which are expected to receive substantial industrial growth will, however, require additional water from further afield. This will involve establishing additional regional groundwater supply schemes.

PREVIOUS INVESTIGATIONS

The 1996 Skidmore study represents the first comprehensive , quantitative assessment of the groundwater resources of the Pilbara Region. Prior to this, Balleau (1973) briefly described the hydrogeology and groundwater resources of the region. Resources data were presented for selected superficial units, but a quantitative assessment of the groundwater resources of the basement rocks was not undertaken. A hydrogeological reconnaissance survey of basement rocks and superficial units of the Pilbara Region was undertaken by Davidson (1975). The region was divided into 22 drainage catchments and the groundwater salinity, recharge and potential bore yields of the various aquifers were discussed.

In 1992 , the Kimberley Water Development Office commissioned the GSWA to undertake a review of the major groundwater resources in Western Australia (Allen et al., 1992). The review included the Pilbara Region and its principal objective was to identify renewable groundwater resources of more than $10 \times 10^6\ m^3$/year of fresh to marginal salinity (0-1500 mg/L TDS)[#] . Alluvial aquifers beneath the coastal plains associated with the Robe, Fortescue, Yule and DeGrey Rivers, as well as aquifers within superficial units overlying fractured rocks at Millstream and along the upper reaches of the Oakover River were identified. Groundwater resource estimates of other aquifers in the Pilbara Region were not included in the review.

Numerous smaller investigations involving drilling and testing have been undertaken throughout the Pilbara Region for town and mining water supplies. Many published and unpublished reports on subsequent investigations are available from the WRC, where a library of Commission and private consultant's reports is maintained. Figure 3 indicates the area covered by these reports.

BORE DATA

The Groundwater Investigation Branch of the Water and Rivers Commission is the State custodian of all bore data which is stored in a digital groundwater database (AQWABASE) and on a card index system. The bore data for each 1: 250 000 Geological Series sheet were obtained from the database and these formed the basis of the groundwater resources assessment. Figure 2 gives an indication of where these bores are located. Bore data that have not been recorded on AQWABASE may be available in unpublished consultant's reports held by the WRC. A special appeal for any other additional bore data was made to those mining companies operating in the region in order to include the many bores drilled during exploration programs and ongoing inhouse groundwater monitoring in this assessment . Unfortunately, many of the mineral exploration bore logs contain little hydrogeological data and are therefore of limited value to this study.

More than 6000 bores, wells, mine shafts, soaks and river pools provide water data of the region. Town and mining water supply bores, supplying the larger centres, are concentrated in wellfields along some of the major rivers on the coastal plains, along the Fortescue River near Millstream and within some of the larger valleys in the Hamersley Range close to the iron ore mining centres. Other bores are mainly concentrated around mining centres within the rugged greenstone terrain. Detailed data, including the hydraulic parameters of the various aquifers intersected, as determined from aquifer testing, are available from many of these bores.

[#] Note TDS (total dissolved solids)

Fresh	0 - 500 mg/L	Marginal	501 - 1500 mg/L
Brackish	1501 - 3000 mg/L	Saline	> 3000 mg/L

Many pastoral bores and wells have been drilled or dug on the coastal plain and inland on the high plain country, mostly underlain by granitic rocks. Pastoral bores are sparse in the rugged areas less suited to pastoral activity. The construction details of many pastoral bores and wells are often not available and it is not possible to determine which aquifers are being utilised. Many bores are not operating due to collapsed walls, decreased yields or contamination. Figure 2 indicates those bores from which the data may be reliable.

Recorded bore yields have been determined using a variety of methods including, bailing, airlifting, pumping or estimated artesian flow, but the precise method employed is not always known. Low yielding bores are often considered as dry and are abandoned and data from these not always recorded , while other bores are operated below capacity. Groundwater levels and salinity vary seasonally depending on rainfall and the recorded bore data have not necessarily been recorded during the same time of the year providing further inconsistency. As a result, data used in this assessment are not synoptic and may obscure the true potential of aquifers. More detailed investigations are required to adequately assess the groundwater resources of many areas in the region.

PHYSIOGRAPHY

CLIMATE

The Pilbara Region has an arid climate with hot summers and mild to warm winters. Average annual rainfall ranges from 200 to 350 mm and is greater close to the northern coast and over the Hamersley Range (Fig. 1). Rainfall results from summer thunderstorms and cyclones, and winter frontal systems, but the influence of winter fronts decreases from south to north across the region. The annual rainfall is not consistent and a number of years can pass with little rainfall or many times the average may fall with the passage of one cyclone.

Average potential evaporation exceeds rainfall in each month of the year and can be ten times greater than rainfall annually.

TOPOGRAPHY

The landscape is variable and shaped by the structure of the underlying geology and imposed weathering processes. The Pilbara has moderately high relief with a number of ranges, river valleys and peneplains which in the north fall away to form a gently sloping coastal plain. The centrally located Hamersley Range is the highest range in the State, Mt Meharry reaching a height of 1235 m AHD (Australian Height Datum). The Hamersley and Chichester Ranges divide the region into three major river systems : the Ashburton , Fortescue , and DeGrey Rivers (Fig. 4). All rivers are ephemeral, indicating the erratic nature of rainfall and flow only after heavy rain. Pools and springs are often present in the river beds long after the rivers cease to flow. The rivers mostly flow through single well defined channels, but the channels often become braided on the coastal plains where the rivers cross extensive flood plains. Channels are often poorly defined near the coast , and most river flows dissipate in tidal creeks and on tidal flats. The mid reaches of the Ashburton River are commonly braided.

The Hamersley Range is a major topographic feature separating the Fortescue River and Ashburton River valleys. It mostly comprises folded sedimentary and volcanic rocks, but granite-greenstone inliers form domal structures in places along the southern flanks of the range. The landscape is mostly rugged with prominent strike ridges and hills of outcropping rock separating deep valleys in which thick sequences of infill have locally accumulated. Drainages are well developed along zones of weakness in the underlying rocks, and run along strike paralleling the valleys or across strike where they cut deep gorges through the outstanding ridges to form trellis drainage patterns.

The Chichester Range lies to the north of the Fortescue River valley and forms the watershed dividing the Fortescue River catchment to the south from the Port Hedland coast and DeGrey River catchments to the north. The range extends adjacent to the entire length of the Fortescue River valley and at its eastern extent, trends northward to wrap around the northern river catchments. A narrow, gently undulating plateau, up to 7 km wide and with local relief to 50 m, lies at the top of the range and slopes gently up to the catchment boundary. Along the northern side of the eastern and western margins of the range, the plateau is often deeply incised by drainages to form steep sided gorges and very rugged scarps with local relief up to 100 m. The scarps represent the dissected plateau and are steep along the northern side, but slope more gently toward the north at the eastern end of the range and to the west at the western end of the range. In places where the plateau has been completely eroded, the top of the scarps form the catchment boundary.

The Ashburton River catchment lies to the south of the Hamersley Range and is characterised by broad shallow valleys and low subdued hills and mesas, separated in the south by long, narrow prominent ranges. The ranges comprise more resistant lithologies and form prominent strike ridges and scarps, while the valleys indicate the position of less resistant rocks. The larger ranges rise to 200 m above the surrounding plain, but local relief is mostly less than 100 m. A parallel to trellis drainage pattern is well developed in the range country and steep sided gorges may exist where drainages cut through prominent ridges. The Ashburton River flows approximately east to west over the length of the valley. Drainage is mostly moderately well developed on the lower lying areas, but zones of poor drainage marked by claypan and are present.

The Fortescue River flows within a broad valley separating the Hamersley and Chichester Ranges. The valley occupies most of the Fortescue River catchment and extends over 400 km from the southeast to the northwest of the catchment. It is up to 60 km wide in the east and less than 10 km wide in the west. The northern valleyside is defined by eroded and dissected volcanic and metasedimentary rocks dipping gently to the south, off the margin of the granite-greenstone terrain of the Pilbara Craton. Relatively flat lying metasedimentary basement rocks are extensively eroded, south of the Chichester Range, to form the broad floor of the Fortescue River valley. The southern side of the Fortescue River valley is defined mostly by metasedimentary basement rocks which are extensively folded into the Hamersley Range.

The Fortescue River valley was once occupied by the Robe River, but the present Fortescue River captured the Robe River near Millstream where the Fortescue River now leaves the ancient valley to flow northwest toward the coast. Extensive outwash fans as well as scree and talus slopes emerge from the bordering ranges, but small hills, mesas or cuestas of outcropping rocks can also occur at the base of the valleysides. Tributaries of the river discharge into the Fortescue River valley over outwash fans along the valleysides. The drainages leaving the Hamersley Range are longer and drain larger areas than those of the Chichester Range. Drainages either cross the valley floor to join the Fortescue River or dissipate within the scree and talus slopes along the valleysides. It is estimated that the upper catchment (east of the Great Northern Highway) only flows into the lower catchment once every hundred years, causing widespread flooding.

The area to the north of the Chichester Range (the northern catchments) consists of broad sandplains and gently sloping valleys which drain into the De Grey River. A well defined dendritic drainage pattern has developed over most of the granitic terrain , but areas of poor drainage also exist. Archaean greenstone rocks rise above the sandplains to form long arcuate strike ridges and areas of very rugged, prominent hills, which rise up to 200 m above the plains. Drainages in the greenstone terrain are well developed and run mostly along narrow valleys between strike ridges, but broader valleys, through which the larger rivers flow, also exist and are developed over less resistant greenstone units. Where drainages cross geological strike they often erode steep sided gorges into the basement rocks.

The Oakover River valley occupies the northeastern part of the Pilbara Region where the Oakover River and its tributaries have eroded a broad , deep valley into clastic and carbonate sedimentary rocks. Gently undulating areas, over sediments of fluvioglacial origin, occur on the valley floor along with calcrete and chert breccia which form mesas and valleyside benches. The eastern side of the valley is bound by deformed volcanic and metasedimentary rocks that form a well dissected, rugged terrain mostly at elevations between 300 and 350 m AHD with local peaks to 449 m AHD. In the south , the valley terminates on the western edge of the Little Sandy Desert.

A gently sloping coastal plain has developed in the north and west of the Pilbara Region. The Port Hedland coastal plain lies in the north and overlies eroded basement rocks and, in the west, the Onslow coastal plain overlies a thick sedimentary sequence. The plains rise gradually from sea level to about 50 m AHD and are around 20 to 60 km wide over most of the area. However, a broad alluvial plain, associated with the DeGrey, Coongan, Shaw and Strelley Rivers merges with the coastal plain about 40 km south of the mouth of the DeGrey River. The alluvial plain extends about 80 km further inland from the coastal plain and is up to 120 km wide. For the purpose of this report, the alluvial plain is considered to be part of the Port Hedland coastal plain. The surface of the coastal plains are mostly monotonous, but seif dunes up to 15 m high have developed over much of the southwest area of the Onslow coastal plain. The main drainages, on entering the coastal plain, flow in well defined channels, but become poorly defined in a network of braided tidal creeks and salt flats at the coast. Distant from the influence of the main drainages, the coastal plains are mostly poorly drained by small creeks in local catchments.

An eolian sandplain occurs in the northeast of the study area and represents the westernmost extension of the Great Sandy Desert (Hickman and Gibson, 1982 ; Hickman et al., 1983). The surface of the plain is characterised by east to southeast trending seif dunes, rare rocky outcrops and occasional low breakaways. The dunes have been stabilised by scrub and grass and the plain slopes gently towards the coast over most of its area, but in the southeast it slopes southward into the Oakover River valley. Surface drainages are absent over most of the plain.

VEGETATION

Vegetation is variable throughout the Pilbara Region as a result of differences in soils, topography, rainfall and the availability of groundwater for plant growth. A detailed description of the vegetation of the Pilbara Region is given by Beard (1975) and summarised by Ruprecht and Ivanescu (1995).

The coastal plains are covered mostly by shrub savanna with grasses and spinifex. Dense mangrove stands line tidal creeks and halophytes grow around tidal salt flats. Tree, shrub, dwarf-scrub, and low woodland vegetation grow throughout the region, inland of the coastal plains, but large bare patches also exist. Large eucalypts line the main drainages in the vicinity of deep permanent and semi-permanent pools and tree savanna with salt bush, forming marshes, occur in groundwater discharge zones in the upper reaches of the Fortescue River.

GEOLOGY

The Pilbara Region has undergone a long geological evolution over a period of about 3500 million years (Trendall, 1990). Pre-Cambrian basement rocks, generated during phases of sedimentation, intrusion and volcanism, were deformed and metamorphosed due to movements in the earths crust. These rocks occupy most of the Pilbara Region and have been cut by intrusive dykes and veins. Later, sea level changes and subsidence led to the deposition of large Phanerozoic sedimentary basins that onlap the west and northeast margins of the region over small areas (Fig. 5). Erosion of the basement rocks and transportation of sediments by drainages has lead to the deposition of Cainozoic superficial units which now cover much of both the basement rocks and the Phanerozoic sedimentary basins.

A comprehensive description of the geology of the Pilbara Region is given in Memoir 3 (Geological Survey of Western Australia, 1990) and detailed descriptions of the geology are contained in the respective Western Australian Geological Survey 1:250 000 Geological Series Explanatory Notes.

PRE - CAMBRIAN BASEMENT ROCKS

The basement rocks can be broadly divided into the Archaean and Proterozoic Pilbara Craton in the north and the Early and Middle Proterozoic orogens and basins in the south and east (Fig. 5).

Pilbara Craton

The Pilbara Craton contains the oldest rocks in the region and is subdivided into the Archaean granite-greenstone terrain in the north and the Archaean and Proterozoic Hamersley Basin in the south (Fig. 5). The Hamersley Basin onlaps the granite-greenstone terrain and numerous inliers of the granite-greenstone terrain occur within the Hamersley Basin. Outliers of Hamersley Basin sediments also occur in the granite-greenstone terrain.

Granite-Greenstone Terrain

The greenstone sequences of the Pilbara Craton cover approximately 40 % of the granite-greenstone terrain (Trendall, 1990). They comprise metasedimentary and volcanic rocks up to 3500 million years old and have been intruded by significant volumes of granitoid over an extended period ending about 2500 million years ago (Trendall, 1990). A complex history of multiple deformation and metamorphism is preserved within the sequence and the rocks are often exposed and steeply dipping. The sequence has a maximum thickness of about 15 km (Trendall, 1990). The granitic rocks occupy approximately 60 % of the granite-greenstone terrain and form ovoid bodies or domes up to 120 km across (Trendall, 1990). They contain a range of deformed and metamorphosed granitic phases with complex relationships and are intruded by younger veins and dykes. The rocks of the complexes are exposed in the eastern Pilbara Region, but are less well exposed in the west.

Hamersley Basin

The Hamersley Basin forms a relatively undisturbed cover over the older granite-greenstone terrain and is nowhere thicker than 10 km (Trendall, 1990a). Its southern boundary is a complex arcuate zone of tectonic disturbance, convex to the south and which curves continuously to the north along both the eastern and western sides of the basin. Its northern boundary is marked by narrow northward-extending apophyses of Hamersley Basin rocks, and a number of outliers occur further north in the granite-greenstone terrain (Trendall, 1990a).

The basin comprises a sequence of rocks including mafic and felsic volcanic and intrusive rocks, shale, siltstone, sandstone and conglomerate as well as dolomite and banded iron rocks. The sequence was extensively deformed between 1600 and 2000 million years ago during the Capricorn Orogeny (Myers, 1990), a period of intense tectonic activity centred south of the Pilbara Craton, and the rocks are faulted and folded. The folding was much more intense in the south and is largely preserved in the Hamersley Range where strata in the limbs of the folds are mostly steeply dipping and dip direction is variable. The rocks have undergone low grade burial metamorphism and the metamorphic grade decreases from south to north across the basin.

Early and Middle Proterozoic Orogens and Basins

The Capricorn Orogen broadly coincides with the southern margin of the Pilbara Region and separates the Pilbara Craton from the Yilgarn Craton to the south. In the study area it comprises Proterozoic rocks of the Gascoyne Complex and Ashburton Basin which are overlain in places by the smaller Mount Minnie and Blair Basins. The Paterson Orogen broadly coincides with the northeastern margin of the Pilbara Region, separates the Pilbara Craton from the Canning Basin to the east, and in the study area, comprises rocks of the Yeneena Basin. The Bresnahan and Bangemall Basins are younger Proterozoic basins that overlie parts of the Capricorn Orogen and the Savory Basin overlies parts of both the Capricorn and Paterson Orogens (Fig. 5).

A variety of rocks are present in these orogens and basins including granitic and high grade metamorphic rocks, mudstone, siltstone, sandstone, conglomerate, dolomite, banded iron and chert as well as mafic and felsic volcanics. The strata are commonly faulted, folded and metamorphosed, and are mostly gently to steeply dipping.

Intrusive Veins and Dykes

At least ten separate mafic dyke swarms have intruded the basement rocks in a variety of trend directions (Tyler, 1990). All dykes are doleritic in composition and were intruded over a period extending from before deformation of the greenstone sequences to after the Capricorn Orogeny (Tyler, 1990). The Black Range dyke swarm is the most prominent in the Pilbara with individual dykes extending up to 100 km. Hickman (1983) reported that the Cajuput dyke reaches 1 km in width. Dykes within swarms that post date the maximum development of the Hamersley Basin range from 1 to 10 m in width (Tyler, 1990).

Felsic dykes and veins also intrude the Archaean and Proterozoic rocks of the Pilbara Region, but they are less common and smaller than the mafic dykes and no detailed descriptions of their occurrence are available.

PHANEROZOIC SEDIMENTARY BASINS

Around the northern, eastern and western margins of the Pilbara Craton are sedimentary basins containing relatively unconsolidated and gently dipping Phanerozoic sediments. The sediments were deposited in intercratonic or marginal basins developed in response to the evolutionary history and breakup of the Gondwana supercontinent.

Canning Basin

The southwestern part of the Canning Basin onlaps the northeastern margin of the Pilbara Craton (Fig. 5). The sediments are deposited on basement rocks of the Anketell Shelf which runs southeast from the coast for about 200 km. The shelf also extends into the Pilbara Craton along a narrowing trench that coincides with the position of the Oakover Valley. The western Canning Basin sequence comprises Permian, Jurassic and Cretaceous sediments, more than 700 m thick, overlying Archaean and Proterozoic basement rocks. A veneer of Cainozoic deposits overlies the sequence. The West Canning Basin contains glacial sediments, sandstones and shales. The main geological units are summarised in Table 2. The sediments are not deformed and occur mostly in the sub-surface, but small isolated outcrops appear throughout the Cainozoic cover of the eolian sandplain and in the Oakover River valley.

Table 2 : Stratigraphy of the Canning Basin within the Pilbara Region .

Age	Unit	Thickness	Lithology
Cretaceous	Parda Formation	<20 m	mudstone: with fine sandstone lenses
Cretaceous/Jurassic	Broome Sandstone	<70 m	sand, sandstone & conglomerate
Jurassic	Jarlemai Siltstone	<95 m	silty clay & mudstone
Jurassic	Wallal Sandstone	<200 m	sandstone: minor siltstone & conglomerate
Permian	Paterson Formation	<500 m	claystone & siltstone
Permian	Grant Group		siltstone, claystone & sandstone

Carnarvon Basin

The Carnarvon Basin onlaps the western margin of the Pilbara Craton and Capricorn Orogen (Fig. 5). The sediments are deposited on Proterozoic basement rocks forming the Peedumullah Shelf which runs along the Onslow coast and extends inland for up to 60 km. The sequence comprises Late Devonian to Early Permian and Cretaceous sandstones, shales and limestones (Table 3). The sequence is mostly less than 500 m thick, but increases to 700 m in the southwest. The trend is modified along the coastal plain near the Robe River where the sequence can be greater than 1000 m thick within a structural depression called the Robe River embayment.

Table 3 : Stratigraphy of the Carnarvon Basin within the Pilbara Region

Age	Unit	Thickness	Lithology
Tertiary	Trealla Limestone	15 m	limestone, clay & marl
	Pisolite limonite	<40 m	limonite, gravel & goethite
Late Cretaceous	Toolonga Calcilutite	<100 m	calcilutite & marly limestone
	Muderong Shale, Windalia Radiolarite, Gearle Siltstone	150 m	claystone, shale, siltstone & radiolarite
Early Cretaceous	Yarraloola Conglomerate (Nanutarra Fm & Birdrong Sst)	<300 m	conglomerate, sandstone & siltstone
Late Devonian	Lyons Group	>280 m	limestone, dolomite, claystone, shale, siltstone & sandstone

CAINOZOIC DEPOSITS

Eluvium and Colluvium

Eluvium comprises in situ residual weathered material developed to various depths over underlying basement rocks. Colluvial material of scree and talus is present over much of the Pilbara Region and obscures the basement geology. It comprises poorly sorted clay, silt, sand and gravel that has been transported by gravity over short distances.

Alluvium

Rivers traverse the coastal plains and deposit large amounts of alluvial material. The alluvium overlies older sediments of the Carnarvon Basin or Proterozoic basement rocks on the Onslow coastal plain, but on the Port Hedland coastal plain, the alluvium overlies weathered Archaean basement rocks. It comprises clay, silt, sand and gravel defining a complex, three dimensional, pattern of present and prior stream deposition. It can be greater than 50 m thick close to major drainages, but decreases in thickness with increasing distance from the major drainages, where it merges with colluvial and eluvial material, and in these areas it is mostly less than 20 m thick. The sediments gradually become finer with increasing distance from the rivers and with distance downstream, but palaeochannels containing bed-load deposits of sand and gravel can occur away from the present positions of the rivers. Thick sections of alluvium, possibly representing palaeochannels, have been intersected by drilling some distance away from the Ashburton, Maitland, Yule and DeGrey Rivers. The alluvium is occasionally cemented by calcium carbonate into calcrete. The calcrete zones are developed at various depths and formed by hydrochemical activity in the zone of watertable fluctuation.

Inland of the coastal plains, the alluvium is of variable, lateral extent and thickness and mostly occupies channels of the present drainages. However, it can also occur as sheet wash deposits on adjacent floodplains. It is mostly less than 1 km wide, but along some sections of the main rivers the alluvium can be up to 10 km wide. Most deposits are generally less than 10 m thick and often cemented into calcrete. However, deposits greater than 30 m thick occur and are common in the valleys of the Hamersley Range.

Chemical Precipitates

Deposits of calcrete and dolomite, impure, earthy limestone and minor silcrete occur throughout the Pilbara Region and the locations of the larger deposits are shown on Figure 6. They lie mostly in or adjacent to drainage channels, where they occur in outcrop, or in the sub-surface below alluvial and colluvial material. The deposits mostly comprise carbonate cemented clay, silt, sand and gravel and are developed by re-precipitation of carbonate material derived from basement rocks. Solution cavities up to 0.5 m in diameter have been developed in places in calcrete, but it can also be massive and hard. Deposits in some of the main drainage channels, or larger valleys, may be up to 65 m thick and outcrops may be up to 20 km wide. They are often strongly dissected and form a dissected plateau of scarps, mesas and buttes (Williams, 1989). Outcrops outside the main drainages are mostly thin and cover only small areas. Deposits of calcrete under alluvium and colluvium in the Fortescue River valley and the valleys of the Hamersley Range may be up to 54 m thick, but are mostly between 20 and 40 m thick.

Coastal Deposits

Calcareous clay, silt, and sand with gypsum, algal mats and salt crusts have been deposited along the coast in tidal and supratidal flats as well as mangrove creeks and swamps. Unconsolidated and variably carbonate-cemented calcarenite with beach and dune sand is also deposited in places along the coast. These coastal deposits occur mostly within 5 km of the coast, but extend up to 10 km inland in places.

Seif Dunes

Sief and network sand dunes up to 15 m high, frequently occur on the coastal plain around the Ashburton River, and minor development of dunes occur in the upper reaches of the Fortescue River valley where the valley floor is widest. Southeast trending seif dunes up to 6 m high have also developed on the eolian sandplain overlying the Canning Basin.

HYDROGEOLOGY

Groundwater occurs throughout the Pilbara Region in the Precambrian basement rocks, Phanerozoic sedimentary basins and Cainozoic deposits. It originates from direct rainfall recharge over outcropping basement rocks and from infiltration of rainfall and runnoff through Cainozoic deposits. The amount of groundwater that can be obtained from a particular area depends on the rock type. Rock formations which yield economic supplies of groundwater are termed aquifers and may be divided into four broad types : unconsolidated sediment aquifers; chemically deposited rock aquifers; sedimentary rock aquifers; and fractured rock aquifers. A further distinction that can be made is whether the aquifer is confined or unconfined. This often dictates the development and management strategy chosen for the aquifer.

All the geological formations of the Pilbara Region contain some groundwater, but not all are aquifers. The quantity and quality of the groundwater held in the different aquifers varies considerably and some aquifers are therefore considered of greater significance than others. The aquifers in the Pilbara Region have therefore been grouped into four types as illustrated in Table 4 and Figure 6.

Table 4 : Aquifers of the Pilbara Region

Aquifer Type	Aquifer	Geological Unit	Major Occurrence	Resource * potential
Unconsolidated sediment aquifer	Alluvial	Alluvium	Coastal plain	Major
	Valleyfill	Colluvium	Inland drainage channels	
		Eluvium		
Chemically deposited rock aquifer	Calcrete	Calcrete	Inland drainages	Intermediate
	Pisolitic limonite	Robe Pisolite	Inland drainages	
Sedimentary rock aquifer		Carnarvon Basin		Major
	Yarraloola Conglomerate	Trealla Limestone	Onslow coastal plain	
		Yarraloola Conglomerate	Onslow coastal plain	
	Lyons Group	Lyons Group	Onslow coastal plain	
		Canning Basin		
	Broome Sandstone	Broome Sandstone	Eolian sandplain	
	Wallal Sandstone	Wallal Sandstone	Eolian sandplain	
	Paterson Formation	Paterson Formation	Oakover River valley	
Fractured rock aquifer	Fractured sedimentary	Hamersley Basin	Hamersley Range	Intermediate
	BIF	Brockman Iron Formation	Hamersley Range	
		Marra Mamba Iron Formation	Hamersley Range	
	Dolomitic	Wittenoom Dolomite	Hamersley Range	
		Carawine Dolomite	Fortescue River valley	
	Sandstone	Hardey Sandstone	Hamersley Range	
		Cliff Springs Formation	Northern catchments	
	Undifferentiated sediments	Bangemall Basin	Ashburton River valley	Minor
		Ashburton Basin	Ashburton River valley	
	Metamorphic			
	Weathered rock	Morrissey Metamorphic Suite	Lower Ashburton River	
		Mosquito Creek Formation	Northern catchments	
	Igneous			
	Weathered rock	Mafic & Felsic Volcanics	Chichester Range	
	Intrusive rock	Granites	Hamersley Range	
		Greenstones	Northern catchments	

* Aquifer potential is based on expected individual bore yields (see Table 5)

The most significant and exploited groundwater resources of the Pilbara Region are contained within the alluvial aquifers on the coastal plains and the valleyfill aquifers within the Fortescue River valley and valleys of the Hamersley Range. Minor calcrete and alluvial aquifers in the upland areas are important for the provision of small quantities of groundwater for pastoral supply and also provide water for some small towns. Groundwater resources in basement rocks are exploited locally for mining and town supply as well as for miscellaneous infrastructure development. The major groundwater users are indicated in Figure 2.

The groundwater resources of the aquifers in the Pilbara Region are considered in terms of storage and recharge and have been estimated by Skidmore (1996) using the limited data available. In this report they are summarised for the major aquifers (Tables 5 and 6) as well as for the AWRC catchments (Appendix A). For fractured rock aquifers it has been assumed that secondary porosity and permeability is developed over only 20 % (sedimentary rocks) and 5 % (metamorphic & igneous rocks) of the total area of each of the aquifers.

Table 5 : Summary of groundwater resources of the Pilbara Region aquifers.

Aquifer Type	Aquifer	Saturated thickness (m)	Total Area (km^2)	Storage (x 10^6 m^3)	Recharge (x $10^6 m^3$) per year	Bore Yield (m^3 / day)	Aquifer Potential
Unconsolidated sediment aquifer	Alluvial	15	16580	12480	106	<1 000	Maj
	Valleyfill	30	19740	43568	291	<1500	Maj
					397		
Chemically deposited rock aquifer	Calcrete	15	4646	11658	46	5000	Maj
	Pisolitic limonite	10	1419	1127		1500	Maj
					>46		
Sedimentary rock aquifer	Carnarvon Basin						
	Yarraloola Conglo.	25	6345	18550	-	<1 000	Maj
	Lyons Group	60	550	3300	-	<1 000	Maj
	Canning Basin						
	Broome Sandstone	20	2925	3290	29	<1 000	Maj
	Wallal Sandstone	90	2100	5500	21	<2 000	Maj
	Paterson Formation	100	2560	2560	13	<500	Int
					>63		
Fractured rock aquifer	Fractured sedimentary						
	BIF	20	23070	4015	30	<500	Int
	Dolomitic	25	18290	9150	26	2 000	Maj
	Sandstone	30	4610	420	6	<250	Int
	Undifferentiated	20	75530	6040	53	<150	Int
	Metamorphic	20	3680	40	1	<100	Min
	Igneous						
	Felsic volcanic	30	3160	240	1	<100	Min
	Mafic volcanic	10	31170	780	21	<100	Min
	Granitic	35	32490	2840	15	<100	Min
	Greenstone	30	11880	710	5	<100	Min
					157		

Aquifer potential (based on individual bore yields)

Major	> 500 m^3/day
Intermediate	100-500 m^3/day
Minor	< 100 m^3/day

Each aquifer type is considered in terms of its potential for town, horticultural and pastoral groundwater supply. Where possible, recommendations are made concerning the best target zones.

UNCONSOLIDATED SEDIMENT AQUIFERS

The unconsolidated sediment aquifers include both coastal alluvial and valleyfill Quaternary deposits. Groundwater in the Quaternary deposits of the coastal plain is mostly contained in alluvial, unconfined aquifers in which regional flow systems may be defined. Coastal calcarenite and sand dunes, as well as seif dunes form local unconfined aquifers and are not of regional significance. The Quaternary deposits developed over the Canning Basin cover only small areas, are thin and not suitable for the development of large supplies (Leech, 1979).

Groundwater in the Quaternary deposits in the upland areas is mostly contained in valleyfill in the Fortescue River valley and the valleys within the Hamersley Range. The valleyfill which consists of colluvium and alluvium often overlies pisolitic limonite and calcrete and can be over 100 m thick. It forms local confined aquifers with artesian pressures occurring at some localities, but the aquifers are unconfined where recharge occurs. Groundwater is also contained in unconfined alluvial and calcrete aquifers along the present drainages, other than those within the Fortescue River valley and valleys within the Hamersley Range, but these mostly cover small areas and are thin and not suitable for the development of large supplies.

Groundwater recharge to the coastal plain alluvial aquifers and valleyfill aquifers in the upland areas, occurs mostly by leakage from the drainages during surface water flows, and to a lesser extent by direct infiltration of rainfall over the surface. Davidson (1973) estimated that river recharge accounted for 98 % of the total recharge to the alluvial aquifer along the DeGrey River, with direct infiltration through the surface accounting for 2 %. Minor recharge may also occur by lateral groundwater flow from the basement rock aquifers where they are in hydraulic connection with the Quaternary deposit aquifers. A groundwater mound develops in the aquifers, along the drainages or below outwash fans in the major valleys, as hydraulic head builds up, due to infiltration of water during surface flow.

The volume of water recharged to the aquifers annually is variable and dependant on the frequency, flow volume and duration of surface water flows, as well as on the permeability of the aquifers. Estimates range from 150 000 to 1 350 000 m^3/year/km length of river, and these provide the basis for estimated annual recharged volumes to the alluvial aquifers (Table 6). Estimates of quantities of recharge in the valleyfill aquifers range from 90 000 to 17 000 000 m^3/year/km length of valley and provide the basis for groundwater resource calculations for the Valleyfill aquifers. Minor, additional recharge may occur from the underlying aquifers of the Carnarvon Basin by upward leakage where upward hydraulic heads exist.

Groundwater flows away from the recharge areas. Flow in the alluvial aquifers of the coastal plains is outward from the rivers and toward the coast. Bedrock topography is largely responsible for determining groundwater flow directions in the valleyfill aquifers. Flow in these aquifers moves away from the recharge areas, along the valley sides or centres, and then moves down gradient, usually in the direction of surface water flow. Flow converges where bedrock highs cause narrow channels and reduced cross sectional area of valleyfill deposit.

Table 6 : A summary of groundwater resources of the coastal alluvial aquifer
(Salinity < 1 000 mg/L TDS)

River *	Saturated thickness (m)	~ Area ** (x 10^6 m^2)	Storage ** (x 10^6 m^3)	Recharge (x 10^6 m^3) per year	Bore Yield (m^3 / day)	Potential
Ashburton River	12	151 (2527)	272 (1050)	15	500-1000	major
Cane River	10	215 (1798)	108 (697)	4	<500	inter.
Warramboo Creek	5	31 (761)	8 (190)	1	<50	minor
Robe River	12	132 (494)	240 (442)	15	1000-1500	major
Peter Creek	6	200 (2539)	60 (762)	5	<100	minor
Fortescue River	19	190 (461)	357 (514)	16	500-1000	major
				56		
Pewah-Harding River	4	(720)	(230)	7	<500	minor
Yule River	17	361 (929)	1008 (1282)	14	1000-2000	major
Turner River	12	182 (488)	232 (380)	3	500-1000	inter.
Tabba Tabba Creek	4	79 (457)	16 (92)	1	<100	minor
Shaw River	15	1140 (2148)	1926 (2295)	12	<1000	major
DeGrey River	30	1030 (3259)	2084 (4547)	13	1000-2000	major
				50		

* Location shown in Figure 7 ** Figure in brackets denotes total irrespective of salinity

Groundwater storage in the aquifers has been estimated by multiplying the area over which the aquifers occur by the estimated specific yield, and by the average thickness, as determined from bore data. On this basis, the groundwater storage is :

12 367 x 10^6 m^3 in the alluvial aquifers of the coastal plains, and
28 548 x 10^6 m^3 in the valleyfill aquifers.

Groundwater discharge occurs by outflow to river springs and pools, evapotranspiration from vegetation and evaporation through the unsaturated zone where the watertable is shallow, and by abstraction from groundwater bores. Discharge will occur to underlying aquifers where downward hydraulic gradients occur and discharge to the Indian Ocean will occur from the aquifers of the coastal plains. The quantity of groundwater discharge into river pools can be quite large, especially if calcrete is present. At Millstream, for example, discharge into the pools from the valleyfill aquifer has been estimated to be 15 x 10^6 m^3/year.

Groundwater salinity is generally fresh close to areas of recharge. Salinity increases in the direction of groundwater flow, in areas of low permeability, and with increasing depth, as salt is concentrated in groundwater by evapotranspiration and by dissolution of salt stored in the strata through which the groundwater flows. Salts may also be concentrated in groundwater in discharge areas by evaporation from the watertable through the unsaturated zone. Higher salinities may also be encountered where saline groundwater from the basement rocks discharges into the overlying aquifers. Groundwater salinity also varies seasonally. Groundwater in the alluvial aquifers of the coastal plains is freshest close to the drainages and increases toward the aquifer margins and the coast (Fig. 7). It is fresh to saline and measured groundwater salinities range from 90 to 35 000 mg/L TDS . Groundwater in the valleyfill aquifers is mostly fresh to marginal with most salinities in the range 200 to 1000 mg/L TDS .

However, brackish to saline groundwater also occurs and salinities of up to 6500 mg/L TDS have been recorded.

Coastal alluvial aquifer . The alluvial aquifers of the Port Hedland coastal plain are in hydraulic connection with weathered fractured rock aquifers and are bounded to the north by the Indian Ocean, to the south and west by outcropping basement rocks and to the east by the Canning Basin. On the Onslow coastal plain the alluvial aquifers are in hydraulic connection with the confined aquifers of the underlying Carnarvon Basin sediments. The aquifers are bounded to the east and north by basement rocks, to the west by the Indian Ocean and arbitrarily to the south by the southern boundary of the Ashburton River catchment.

The coastal alluvial aquifers have been exploited for many years for pastoral supply. Figure 2 gives some indication of the bore density on the coastal plain. Most of these bores are shallow and the bore data often unreliable. The most important areas with regard to groundwater resources, are where the river drainages cross the coastal plain. These areas are clearly defined by groundwater salinity (Fig. 7). Palaeochannels and abandoned channels related to these rivers represent prime exploration targets. Table 6 provides a summary of the most relevant resource data for the different rivers and the potential for further exploitation is as follows :

Ashburton River. There is potential for large supplies of groundwater for town and horticultural supplies from the alluvium close to the Ashburton River and large supplies of saline groundwater may be available from palaeochannels of the Ashburton River to the southwest of the present channel. There is good potential for small supplies of brackish to saline water for pastoral purposes throughout the subcatchment, but fresh supplies are likely only to be located along the drainages. However, bore data are few and further investigations are required to adequately assess the groundwater resources of the alluvium in the Ashburton River catchment.

Cane River. The alluvial aquifer , in conjunction with the underlying Trealla Limestone formation, supplies about 300 000 m^3/year of groundwater from the Cane River wellfield, for Onslow town supply. The potential for further development exists upstream of the wellfield. Any further investigations to adequately define the resource should be linked to water supply needs and form part of the wellfield development. There is good potential for small pastoral supplies of brackish to saline groundwater throughout the catchment.

Warramboo Creek. The alluvium has no potential for town or horticultural groundwater supplies due to its poor recharge and low bore yields. There is good potential for supplies of brackish to saline water, for stock, from low yielding bores and small quantities of groundwater for domestic supplies may be located close to the drainages in the east of the catchment.

Robe River. The alluvium has good potential for town, horticultural and pastoral groundwater supplies. An investigation by Commander (1994a) identified a possible Lower Robe Wellfield site. Further drilling and test pumping is required to determine the effectiveness of river flow recharge to the aquifer under stressed conditions of groundwater abstraction.

Peter Creek. The alluvium in Peter Creek catchment has no potential for town and horticultural groundwater supply due to high salinity, as well as low yields and recharge. The alluvium has good potential for small supplies of brackish and saline groundwater for stock, but domestic water supplies will be located only close to the drainages.

Fortescue River. The alluvium has good potential for town and horticultural groundwater supplies close to the Fortescue River where groundwater is fresh. Commandeer (1994) identified a potential wellfield to the west of the Great North Western Highway. There is good potential for pastoral bores over most of the coastal plain, but domestic supplies will only be available close to drainages. Further drilling and test pumping is required to determine the effectiveness of river flow recharge to the aquifer under stressed conditions of groundwater abstraction.

Pewah, Sherlock, George and Harding Rivers. The alluvium has good potential for small pastoral supplies of brackish to saline groundwater, but domestic requirements will only be obtainable from along the drainages. There may be poor potential for town and horticultural groundwater supplies along the rivers close to where they enter the coastal plain, but these areas have not been explored. Investigations are required to adequately assess the groundwater resources of the alluvium in these areas. In particular the possible presence of palaeochannels. Initial indications are, however, not encouraging and any further field work should be of low priority.

Yule River. The Yule River wellfield currently supplies Port Hedland with 3×10^6 m^3/year of groundwater and there may be potential for further development upstream of the wellfield. However, aquifer storage is not known to the south of the coastal plain and further investigations are required to adequately assess the groundwater resources of the alluvium along the Yule River. There is good potential for small pastoral supplies of brackish to saline groundwater, but fresh groundwater will be located only in the vicinity of the river.

Turner River. The Turner River alluvium has been utilised to augment supplies to Port Hedland, but the wellfield is no longer operated. There is potential for groundwater supplies from within the existing wellfield as well as upstream of the wellfield. However, the storage of the alluvium is not known in this area and should be determined by drilling. A reassessment of the aquifer using long term monitoring data should precede any drilling. There is good potential for pastoral supplies of brackish to saline groundwater throughout the subcatchment, but fresh groundwater will only be located close to the river.

Tabba Tabba Creek. There is no potential for town or horticultural groundwater supplies from the Tabba Tabba Creek alluvium due to low yields and low recharge. There is good potential for pastoral supplies of fresh to saline groundwater, but domestic requirements will only be met close to the drainages.

Shaw River. There is no proven potential for town or horticultural groundwater supplies from the alluvium. There is good potential for small supplies of brackish to saline groundwater throughout the subcatchment. However , the alluvium in the subcatchment is mostly unexplored and further investigations are required to adequately assess its groundwater resources. Fresh groundwater occurs along the river and the possible presence of palaeochannels and abandoned channels should be investigated.

DeGrey River. The alluvium is currently utilised for town water supply and about 3.3 x 10^6 m^3 of groundwater is extracted each year for Port Hedland. The existing wellfield extends for about 14 km length of river, although the total area of groundwater exploration extends for 35 km. In addition, long stretches of the De Grey and Coongan Rivers with groundwater salinity less than 1000 mg/L TDS remain undeveloped and prospects for large supplies are good. However, no exploration has been undertaken beyond approximately 50 km upstream of the Great Northern Highway and further investigations are required to adequately assess the groundwater resources in these areas. The Mount Goldsworthy Wellfield is 30 km upstream of the Great Northern Highway, and bores in the wellfield abstracted between 0.5 x 10^6 and 1.5 x 10^6 m^3 of groundwater each year between 1977 and 1989 (Australian Groundwater Consultants Pty. Ltd., 1990a) with no long term affect on the aquifer. The wellfield was decommissioned in March, 1993 and there is potential for groundwater supplies from the existing wellfield. There is good potential for small supplies of fresh to saline groundwater for pastoral use with fresh supplies located mostly in the vicinity of the drainages.

Valleyfill aquifer. It is possible at a regional scale and with the data available to define the area under which the valleyfill will contain significant groundwater resources. Thick sequences of valleyfill deposits occur in the Fortescue River valley and the larger valleys of the Hamersley Range. There could be 1500 km of valleys within the Hamersley Range with a significant thickness of saturated valleyfill deposit. Large quantities of town and mining water supplies are currently abstracted from valleyfill sequences, both along the Fortescue River (eg. Millstream, Wittenoom & down stream of Newman) and within the Hamersley Range (eg. Tom Price & Paraburdoo). In most cases, however, the valleyfill aquifer is exploited in conjunction with other underlying aquifers.

Bore yields along the Fortescue River valley range between 100 and 1500 m^3/d, but yields of up to 2000 m^3/d should be possible with proper exploration. Yields of greater than 3000 m^3/d are common in bores constructed in the basement rocks in conjunction with the valleyfill deposits. There is, therefore, good potential for further development of town and mining supplies. Drilling depths from less than 10m to greater than 50 m may be required to intersect the watertable and to reach total bore depths.

The valleyfill deposits are mostly unexplored away from the major mining centres and the depth to basement rocks not known for most of the area. Further exploration is required to adequately assess the groundwater resources of the valleyfill aquifers in the Hamersley Range. Geophysical surveying could be undertaken to help identify drilling sites and drilling should continue into the basement rocks until there is little potential for increasing the bore yield with depth. The best exploration sites along the Fortescue River are within the zone of fresh to marginal groundwater where large drainages discharge over outwash fans along the valley sides. Within drainages drilling should be undertaken close to the valley centre where the chances of intersecting calcrete are greatest.

CHEMICALLY DEPOSITED ROCK AQUIFERS

The chemically deposited rock aquifers include the calcrete and Pisolitic limonite aquifers. These rocks, in particular the calcrete, are found throughout the Pilbara Region (Fig. 6), but do not necessarily represent aquifers everywhere.

Calcrete aquifer. The calcrete occurs both along drainages and as capping over other rock formations. Where it occurs along drainages it generally forms part of the valleyfill sequence. The calcrete may be up to 25m thick, but is generally less than 10m thick, with a saturated thickness of less than 5m. Where it occurs as a capping, especially within the Ashburton River catchment, it covers wide areas (>10 km wide), but is invariably unsaturated. Groundwater recharge occurs mostly by leakage from the drainages during surface water flows and to a lesser extent by direct infiltration of rainfall over the surface. Estimates of recharge are 100 000 m^3/year/km length of river. Bore yields are generally between 50 and 100 m^3/d because of the thin saturated thickness of the aquifer. However, calcrete has high secondary porosity and permeability and in places can yield large quantities of groundwater. For example, at Millstream, bore yields as high as 5500 m^3/d have been recorded. Groundwater salinity is mostly fresh to marginal, but may be brackish to saline during prolonged dry periods and where groundwater from basement rocks discharges into the aquifers.

The minor calcrete aquifers are difficult to delineate at a regional scale, reliable data is sparse and the groundwater resources have not been estimated. However, the aquifers have good potential for small pastoral supplies of groundwater , although in places elevated salinity values may make the groundwater unsuitable for domestic use. Further hydrogeological mapping is required, especially along the Oakover River and Ashburton River valleys, to better define the potential of the calcrete as an aquifer.

Pisolitic limonite aquifer. The pisolitic limonite does not outcrop extensively (Fig. 6). The aquifers occupy channels incised into basement rocks by prior drainages. The aquifers are bounded by basement rocks, but sometimes may be in hydraulic connection with the basement rocks where these are weathered and fractured. In some areas the pisolitic limonite outcrops along drainages and also extends into the subsurface below the drainages. It is often unsaturated where it outcrops outside the drainages, but forms large local aquifers where it occurs below the drainages. Pisolitic limonite aquifers also occur in places on the Onslow coastal plain and may be in hydraulic connection with the overlying Trealla Limestone or alluvial aquifer. Drilling and testing of the aquifer has been largely restricted to mining areas such as Yandi Mine, Deepdale and Millstream. Within the Fortescue

River valley, the aquifer reaches thicknesses of 21 m at Dales Gorge and 70 m at Yandi Mine, whereas on the coastal plain the aquifer is seldom thicker than 5 m. As a result, bore yields range between 500 and 5000 m^3/d, in comparison to less than 100 m^3/d on the coastal plain.

There is little potential within the coastal plain for large supplies of groundwater for town and horticultural use from the pisolitic limonite due to low recharge and brackish groundwater. Large supplies of brackish to saline groundwater are, however, available, and drilling depths of 50 m may be required to intersect the aquifer. The smaller volumes required for pastoral requirements are better met from the overlying aquifers as these require shallower bores. Inland, the pisolitic limestone aquifer has potential for town and horticultural groundwater supplies where really thick deposits extend over long distances along present drainage lines. Aquifer storage, however, is small due to the narrow aquifer widths, and large scale abstraction through prolonged dry periods may produce large declines in the watertable.

SEDIMENTARY ROCK AQUIFERS

The sedimentary rock aquifers comprise the Carnarvon and Canning Basin aquifers. These basins are situated in the northwestern and northeastern margins of the study area (Fig. 5). The aquifers are both confined and unconfined and contain primary porosity providing storage capacity. Recharge is by means of direct rainfall infiltration and leakage from drainages during surface water flows. Groundwater flow patterns occur on a regional scale away from the recharge areas.

The Canning Basin contains three major aquifers, namely the unconfined Broome Sandstone aquifer and the confined Wallal Sandstone and Paterson Formation aquifers (Fig. 8). The Cretaceous Parda Formation may form local unconfined aquifers, but only over very small areas, is too thin to contain large volumes of potable groundwater and is unimportant for development of large supplies. The Broome Sandstone and Wallal Sandstone aquifers underlie Cainozoic sediments of the Great Sandy Desert and are bound by Permian sediments and basement rocks to the south and arbitrarily to the east. They are bound by the alluvial sediments of the DeGrey River to the west and the Broome Sandstone aquifer is bound by the ocean to the north, while the Wallal Sandstone aquifer extends offshore. The Paterson Formation aquifer is located in the north-south trending trench of the Ankatel Shelf and is bound by the basement rocks to the east, west and south and by Jurassic and Cretaceous sediments to the north.

Broome Sandstone aquifer. The Broome Sandstone aquifer is a major unconfined aquifer comprising the Cretaceous Broome Sandstone which rests on the Jarlemai Siltstone over most of the study area, but it is in direct hydraulic connection with the Wallal Sandstone aquifer where the Jarlemai Siltstone is absent. It also extends further south than the Jarlemai Siltstone and Wallal Sandstone and rests directly on basement rocks where both these units are absent. Groundwater recharge occurs via direct infiltration of rainfall over the surface of the aquifer and indirectly by leakage through the thin Parda Formation and Cainozoic sediments. The quantity of recharge is variable depending on the rainfall intensity and prevailing climatic conditions at the time of rainfall and not all rainfall events are of sufficient significance to recharge the aquifer. Groundwater storage is estimated at about 3290 x 10^6 m^3. Groundwater flows north and northwest, from the recharge areas toward the coast and Leech (1979) calculated that there is 20 x 10^6 m^3/year of groundwater throughflow where the aquifer is 100 km wide. Groundwater salinity is variable but, to the west of Shay Gap, there is a general increase in groundwater salinity in the direction of groundwater flow from less than 1000 mg/L TDS in the south to greater than 10 000 mg/L TDS in the northwest. No salinity data are available for the aquifer in the southeast of the area. The Broome Sandstone aquifer has potential to provide large quantities of groundwater. Large diameter bores slotted over the full saturated aquifer thickness may be capable of 1000 m^3/d. The groundwater throughflow with salinity less than 1000 mg/L TDS occurs over about a 30 km aquifer width and this is equivalent to about 650 m^3/d/km of aquifer section perpendicular to flow. Under these conditions, a bore spacing of about 1.5 km would be required for bores discharging at 1000 m^3/d. However, Leech (1979) identified levels of nitrate in groundwater from the aquifer to be above those recommended for human consumption and suggested that conjunctive use from both the unconfined aquifers would be required to reduce nitrate to safe levels. There is potential for pastoral supplies of fresh to marginal water over most of the eastern part of the area but brackish and saline groundwater is common further north and west. Drilling depths required to intersect the watertable will vary from less than 5 m to greater than 30 m. In the south, where the Broome Sandstone is unsaturated, drilling will need to continue into the underlying Wallal Sandstone or basement rocks to obtain groundwater supplies.

Wallal Sandstone aquifer. The Wallal Sandstone is a major confined aquifer comprising the Jurassic Wallal Sandstone which rests on basement rocks over most of the western Canning Basin. The aquifer is recharged by infiltration through the overlying Broome Sandstone and groundwater flow within the study area is from the southeast to the northwest. Throughflow was calculated to total 21x 10^6 m^3/year (Leech, 1979). The volume of groundwater held in storage is about 55 000 x 10^6 m^3. Groundwater is fresh to saline, but over most of the area it has a salinity of less than 1000 mg/L TDS indicating relatively rapid recharge. The groundwater salinity increases in the direction of groundwater flow and there is a sharp increase in salinity in the far northwest of the study area where groundwater salinity is greater than 10 000 mg/L. .

The Wallal Sandstone aquifer also has the potential to supply large volumes of groundwater for town or horticultural use. Most large diameter bores should be capable of between 1000 and 2000 m^3/d. If all the estimated throughflow is available as safe yield, then the anticipated spacing of bores discharging at 1500 m^3/d will range from 7 km in the south to 0.5 km in the north along a line orientated north-northeast, perpendicular to the direction of groundwater flow. The aquifer also has potential for pastoral supplies of fresh to saline groundwater, but drilling depths of between 40 and 150 m may be required to intersect the aquifer.

Paterson Formation aquifer. The Paterson Formation is a major multilayer aquifer, but little is currently known about its hydrogeology. Groundwater in the aquifer is presumably recharged by infiltration of rainfall and surface water flows, as well as by inflow from adjacent basement rocks. Groundwater flow is most likely to be from south toward the north where discharge may occur through outflow into the Mesozoic sediments to the north of the buried trench. Data are sparse, but indicate groundwater in the aquifer can be under artesian conditions in places and discharge is, also, likely to occur by leakage into the overlying Cainozoic deposits or surface drainages where upward hydraulic gradients exist. Groundwater salinity may be fresh in the south, but will increase toward the north in the direction of flow, and available data indicates that groundwater is saline in the potential discharge area at the northern end of the trench.

Groundwater occurs as a consequence of primary porosity in the sand and sandstone beds within the Paterson Formation and is confined by clay and silt layers. Using an assumed specific yield of 0.01 and saturated thickness of the aquifer, as determined from drilling data, the total available groundwater stored in the aquifer is 2562 x 10^6 m^3. The Paterson Formation Aquifer may contain large quantities of groundwater for town and horticultural supply, but data are sparse and further investigations are required to adequately assess the groundwater resources of the aquifer. Bore yields of about 500 m^3/d have been recorded from bores screened against about 10 m of the aquifer. Additional field investigation is required to better assess this aquifer within the Oakover River valley.

The Carnarvon Basin contains two major confined aquifers, namely the Yarraloola Conglomerate aquifer of Cretaceous age and the Lyons Group aquifer of Permian age. The aquifers underlie Cainozoic deposits on the Onslow coastal plain and rest on Proterozoic basement rocks (Fig. 9). Groundwater in the aquifers is mostly under artesian pressure with temperatures ranging between 40 and 70 ^{0} C (Moors, 1980).

Yarraloola Conglomerate aquifer. The Yarraloola Conglomerate aquifer is comprised of the Yarraloola Conglomerate, Nanutarra Formation, Birdrong Sandstone, and the overlying Trealla Limestone . It overlies the Lyons Group aquifer and is confined by the Muderong Shale over most of the coastal plain . Groundwater recharge occurs mostly by leakage from the alluvial aquifers and in particular from rivers. Temporal data on groundwater level response to surface flows are not available to adequately estimate the volume of recharge to the aquifer. Groundwater held in storage in the aquifer, where it occurs within 200m of the surface, is about 60 x10^6 m^3. Recharge to the outcropping Yarraloola Conglomerate and Nanutarra Formation to the east of the coastal plain occurs mostly by leakage from surface drainages that traverse the aquifer and minimal recharge occurs by direct infiltration of rainfall.

Groundwater flow in the Yarraloola Conglomerate aquifer beneath the Onslow coastal plain is similar to that in the alluvial aquifers. Groundwater flows from intake areas where the Yarraloola Conglomerate outcrops close to where the major rivers enter the Onslow coastal plain, in a direction outward from the rivers and down dip toward the west. The groundwater moves slowly and Allen (1988) estimated groundwater flow velocities in the aquifer to be about 4 m/year. Groundwater discharge may occur by downward leakage into the Lyons Group aquifer, elsewhere, by leakage into the overlying sediments where upward hydraulic gradient exist and by groundwater flow offshore. Groundwater discharge may also occur by upward movement of groundwater along faults.

The salinity of the groundwater beneath the Onslow coastal plain is fresh to marginal where the Yarraloola Conglomerate subcrops the alluvial deposits of the major drainages (300 - 900 mg/L). The salinity, however, increases with depth and along the direction of groundwater flow. Salinities at depth, range from 6000 to 40 000 mg/L TDS. Groundwater in the aquifer to the east of the coastal plain is mostly saline, but fresh and brackish groundwater occurs in narrow strips under and adjacent to the drainages.

The Yarraloola Conglomerate aquifer has the best potential of the aquifers in the Carnarvon Basin. Bore yields in the coastal plain may be as high as 4500 m^3/d and fully slotted production bores, penetrating 10m or more of aquifer, should be capable of 1000 m^3/d. The aquifer may have potential for town and horticultural water supplies immediately surrounding the areas where the Robe, Cane and Ashburton Rivers enter the coastal plain, but large scale abstraction may induce the influx of adjacent saline groundwater. There is less potential along the Fortescue River, where the Yarraloola Conglomerate covers only a small area. The aquifer could augment town and horticultural supply from the alluvial aquifer. Elsewhere, there is no potential for fresh groundwater supplies. There is potential for large volumes of saline groundwater throughout most of the coastal plain and drilling depths to intersect the top of the aquifer will increase from less than 20 m in the east to over 200 m closer to the coast. Inland of the coastal plain there is only potential for brackish to saline pastoral supplies and at depths in excess of 30 m.

The Trealla Limestone of the Yarraloola Conglomerate aquifer occurs in the subsurface throughout much of the coastal plain. The formation thickness is 15 m and bore yields are generally less than 100 m^3/d. Bore yields of up to 900 m^3/d have been recorded in this formation, but these are very rare. About 300 000 m^3/year of fresh to marginal groundwater is drawn for Onslow town supply from several low yielding bores screening both limestone and alluvium along the Cane River. There is, however, little potential for large groundwater supplies from the limestone in isolation. There is potential for small supplies of brackish to saline groundwater for stock requirements throughout the coastal plain, but pastoral domestic requirement will only be met close to drainages.

Lyons Group aquifer The Lyons Group aquifer represents a large confined aquifer comprising formations of the Lyons Group. Hydraulic data for the Lyons Group aquifer are sparse. The Lyons Group sediments cover an area of about 550 km^2 and are generally less than 500 m thick. Where it occurs within 200 m of the surface it maybe about 65 m thick. Groundwater recharge occurs by downward leakage from the Yarraloola Conglomerate aquifer and groundwater flows toward the west to be discharged offshore. Discharge will also be affected by leakage into the Yarraloola Conglomerate aquifer and by groundwater movement through faults where upward hydraulic gradients exist. Groundwater in the aquifer is saline indicating very low rates of recharge. The salinity ranges from 6000 to 36 000 mg/L TDS, but is mostly greater than 20 000 mg/L TDS . The Lyons Group aquifer has poor potential for town or horticultural groundwater supply due to the salinity of the groundwater. It has good potential for large supplies of saline groundwater, and drilling depths of over 100 m would be required . Estimated artesian flow rates from bores of up to 5000 m^3/d have been recorded, but bore yield data are scarce. It is probable that average yields in excess of 1000 m^3/d may be expected from the aquifer.

FRACTURED ROCK AQUIFERS

The fractured rock aquifers contain a host of different rock formations which constitute the basement rocks and represent the older aquifer units. Groundwater occurs where secondary porosity has developed in fractured and weathered zones or along bedding plane partings or joints. The rocks are tight outside the zones of secondary porosity and in these zones, do not contain groundwater. Groundwater storage is, thus, mostly small, but may be large locally in solution voids where these occur beneath thick sequences of Cainozoic deposits. Groundwater recharge is episodic and affected by direct infiltration of rainfall over areas where the rocks are fractured, jointed and weathered. Recharge will also occur by leakage from surface flows directly into the basement rocks or indirectly through superficial sediments where they overlie the basement rocks. Groundwater flow is largely controlled by local geological structures and weathering, and regional flow systems are absent.

Fractured rock aquifers may be grouped into sedimentary, metamorphic and igneous rock aquifers and cover most of the study area (Fig. 6).

Fractured Sedimentary-Rock Aquifers

Dolomitic aquifers. The dolomitic aquifers are utilised for both town and mining water supplies throughout the Fortescue River valley and Hamersley Range. The dolomitic formations include mostly dolomite with minor chert and dolomitic shale. The Pinjian Chert Breccia occurs as a replacement deposit in the upper portion of the dolomite in the Oakover River valley and similar deposits of chert breccia occur on the dolomite in the Fortescue River valley. The deposit is a massive layer of chert breccia cemented by secondary silica and is also included as part of the dolomitic aquifer. Drilling has been undertaken to depths of 100 m in the dolomites and lithological data indicate most bores intersect a number of fractured or cavernous zones to the total drilled depth. The cumulative total thickness of fractured and cavernous zones range from 9 to 25 m over the drilled intervals. Groundwater levels are deeper along the valley sides and decrease in depth towards the centre of the valleys. Most groundwater levels fall into the range of 15 to 70 m bgl. Groundwater is fresh to marginal and salinities range from 150 to 1500 mg/L. Some brackish groundwater may exist in shaly and less permeable sections, particularly those within the Bangemall and Ashburton Basins.

Bore yields from the dolomitic aquifers are variable depending on the intersected fracture and cavern density and range up to 1600 m^3/d. Where bores draw from thick valleyfill deposits in addition to the dolomite, yields of up to 5500 m^3/d have been recorded. Higher yields are likely to occur in the valley centres where the dolomite is well fractured and cavernous with lower yields closer to the sides of the valleys where the dolomite is mostly massive, hard and unfractured.

There is potential for town and horticultural groundwater supplies from the dolomitic aquifer within the Fortescue River valley and many of the valleys within the Hamersley Range where dolomite is overlain by thick sequences of valleyfill. However, the greatest potential is when the dolomite is exploited in conjunction with the valleyfill aquifer. There is limited potential for pastoral groundwater supply, as sections of the dolomite close to the surface or in outcrop, near the valley sides, are mostly massive and crystalline and bores constructed in these areas often fail to intersect significant saturated permeable zones and have been abandoned due to insufficient yield. Drilling depths down to about 100 m may be required to intersect the dolomite near the centre of the valleys where it is more fractured and cavernous and in these areas the valleyfill may represent a better target for pastoral water supply.

Dolomite occurs over large areas in the Pilbara Region other than the Fortescue River valley and Hamersley Range (Fig. 10), although little is known of its potential as an aquifer. In the Oakover River valley the dolomite appears to have potential for very large supplies of groundwater from large capacity bores. This must, however, be substantiated by drilling. Yields will be variable and may be dependant on the location of cavernous sections in the dolomite. There is also potential for pastoral supplies of fresh to brackish water, and drilling depths greater than 20 m and hard rock drilling techniques may be required. There is also potential for town and horticultural water supplies within the Ashburton River catchment. Long stretches of the Ashburton River and its tributaries flow across extensive dolomitic formations. These areas are often associated with extensive calcrete deposits which may indicate solution of the underlying dolomite and development of cavernous sections. The area probably has significant groundwater storage and potential for sustaining large capacity bores , but groundwater investigations are required to confirm this. Some potential exists for pastoral supplies, but the dolomite is likely to be mostly impermeable and hard where it occurs at shallow depths or in outcrop. Drilling depths required to intersect the dolomite range from less than 10 m close to outcrop to around 90 m under valley floors. Limited reconnaissance drilling should be undertaken within the Oakover River and Ashburton River valleys to substantiate the apparent aquifer potential within these areas.

BIF aquifer. Banded Iron Formation (BIF) aquifers have been identified as local aquifers only and are largely restricted to the Hamersley Range area. The BIF is comprised mostly of chert and jaspilite, with minor dolomitic shale. The rocks are brittle, relatively resistant and are preserved mostly in the cores of anticlines and as ridges. The upper sections of the Marra Mamba Iron Formation, which also includes minor interbedded shale, can be weathered and have well developed solution features. As a result the Marra Mamba Iron Formation can be a very productive aquifer locally. Thus although the BIF aquifers are generally not considered good regional groundwater targets, they do have potential as local aquifers. Groundwater levels are variable depending on the topography and range from 5 to 40 m bgl. Groundwater quality is mostly fresh to marginal with salinities ranging from 200 to 1400 mg/L

TDS. Brackish groundwater may occur in the discharge areas or where the *permeability of the rocks is low.*

The Brockman Iron Formation has no known potential for town or horticultural groundwater supplies. Some potential for pastoral supplies exists within valleys along fold hinge lines, where the aquifer underlies or is adjacent to alluvium in the drainages or thick sequences of valleyfill. Successful bores may have yields between 100 and 500 m^3/d. Areas where drainages have carved channels through strike ridges may indicate zones of weakness in the aquifer and represent good exploration sites. Bores intersecting fracture zones could provide yields up to 2000 m^3/d.

The Marra Mamba Iron Formation, although of limited potential, is utilised as a local aquifer for mine, road and rail water supply. Bore yields are variable and range up to 1000 m^3/d. Yields greater than 1500 m^3/d have been recorded, but most yields will probably be less than 500 m^3/d. The prospect of obtaining large groundwater supplies are therefore poor. The aquifer can, however, augment town and horticultural groundwater supplies when used in conjunction with valleyfill aquifers. The aquifer has potential for pastoral groundwater supplies, but hard rock drilling techniques will be required. The depth to the Marra Mamba Iron Formation will increase from the outcrop areas towards the valley centres where the depth to intersect the formation may be in excess of 100 m and watertable may be deeper than 30 m bgl. Bores drilled into the valleyfill should be continued into the Marra Mamba Iron Formation until there is no appreciable increase in yields with depth or the lithology indicates conditions unfavourable for groundwater supply.

Sandstone aquifer. - The sandstone aquifer comprising the Cliff Spring Formation (mostly agglomerate with some conglomerate and sandstone) and the Hardey Sandstone (sandstone grit and conglomerate, with some shale, mudstone, siltstone, tuff and basalt) are generally poor sources of groundwater. The Cliff Spring Formation rocks may weather to 16 m bgl, but porosity is expected to be negligible below 35 m depth. Groundwater levels are mostly around 5 m bgl with groundwater salinity fresh to marginal (150 to 1100 mg/L TDS) with a gradual increase in salinity along flow paths. The weathered zone in the Hardey Sandstone aquifer extends down to 30 m depth and bedding plain partings extend as deep as 150 m. Groundwater levels depend largely on topography, with fresh to marginal (350 to 1200 mg/L TDS) groundwater salinity.

The sandstone aquifers are only of local importance. Yields in the Cliff Springs Formation range between 100 and 250 m^3/d and are potentially only of use for pastoral water supplies. The Hardey Sandstone generally only has yields of up to 200 m^3/d, although yields of up to 1900 m^3/d have been recorded at Paraburdoo. The Hardey Sandstone, therefore, has potential for town and horticultural groundwater supply along drainages where recharge from stream flow is available and sustainable bore yields will be supported by utilising storage in the alluvium. Potential in the remaining area is minor and even for pastoral groundwater supply, the bores should be sited in the lower lying areas close to drainages where the groundwater will probably be within 10 m of the surface.

Undifferentiated sediment aquifer. The undifferentiated sediment aquifers (Bangemall and Ashburton Basins) include a variety of rock types including shale, mudstone, siltstone, sandstone, conglomerate, limestone, BIF, schist as well as mafic and felsic volcanic rocks. These form a range of local aquifers for which there are very little hydrogeological data. Groundwater potential may be restricted to areas where resistant and brittle rocks are located close to drainages.

Adjacent to the Hamersley Range the aquifers are often covered by valleyfill up to 130 m thick, but the depth of cover is variable. The zone of weathering may be as much as 65 m and fracturing has been recorded 40 m into fresh rock. Groundwater levels are variable, depending on topography, and range from 10 to 60 m bgl. Further south in the Ashburton River valley groundwater levels are shallower, seldom exceeding 30 m bgl. Groundwater salinity in the Hamersley Range is mostly fresh to marginal indicating rapid recharge, although brackish and saline water does occur. Salinities range from 400 to 5500 mg/L TDS. Within the Ashburton River valley groundwater salinities range from 6500 to 9000 mg/L TDS, whereas, in the surrounding areas salinities may range from 200 to 13 500 mg/L TDS.

The undifferentiated sediment aquifer is relatively unexplored and outside of the mining areas of the Hamersley Range, data are restricted to sparsely distributed pastoral bores and wells. Bore yields in the Hamersley Range are generally between 200 and 1000 m^3/d. Bore yields in excess of 2000 m^3/d are recorded where the aquifer is screened in conjunction with thick valleyfill sequences. Production bores with large sustainable yields are located in fracture zones close to drainages or under significant thickness of valleyfill where storage in the valleyfill aquifers can be utilised. Bore yields to the south, in the Ashburton River valley are poor and generally less than 150 m^3/d. Yields of greater than 1000 m^3/d are possible, but are very rare.

The undifferentiated sediment aquifer is not utilised for town or horticultural groundwater supplies on it's own. However , the aquifer does have potential to augment large supplies from the valleyfill aquifers in the Hamersley Range. Bores drilled through the valleyfill , into the basement, should be continued until no appreciable increase in yield is detected or until lithological data indicate poor potential for groundwater. The aquifer is mostly unexplored in the Ashburton River catchment and the groundwater potential is not known due to the lack of detailed, reliable data. Good sites for exploration will occur where the more brittle and resistant units are located below or adjacent to drainages. The aquifer has good potential for pastoral groundwater supplies throughout, but domestic water supplies will mostly be located adjacent to the drainages.

Metamorphic rock aquifer

The metamorphic rock aquifer consist of local aquifers comprising a variety of Capricorn Orogen metamorphic rocks belonging to the Proterozoic Morrissey Metamorphic Suite. The suite includes marble, amphibolite, gneiss, quartzite and schist. A veneer of Cainozoic sediments overlies the rocks away from the outcrops and drainage is poorly developed over these areas. Many pastoral bores and wells are constructed in the aquifer, but few data are available. Lithological data from a gas pipeline bore indicate that the water bearing zones coincided with the intersection of pegmatite veins at depths of 30 and 50 m, but no other data are available to indicate the aquifer thickness. Groundwater levels are variable and dependant on the topography and range from 2 to 23 m bgl, but most are less than 15 m bgl. Groundwater is mostly marginal to saline (450 to 10 500 mg/L TDS) suggesting poor recharge and low transmissivity. Data are not conclusive, but it appears that the freshest groundwater occurs close to the drainages. Bore yields of 500 and 540 m^3/d have been recorded from bores constructed in the rocks. Most yields will likely be less than 100 m^3/d, with rare yields from 500 to greater than 1000 m^3/d possible in the vicinity of fracture zones associated with intrusive veins and dykes.

There is no potential for town or horticultural groundwater supply from the aquifer due to low recharge and yields, as well as high salinity. There is potential for pastoral supplies of brackish to saline groundwater, and drilling in hard rock to depths exceeding 20 m may be required. Small supplies of fresh groundwater may sometimes be obtained close to the drainages. Further investigation involving supervised drilling is required to fully assess the groundwater resources of the aquifer.

Igneous rock aquifer

The igneous rock aquifer includes mafic and felsic volcanic rocks of the Hamersley Basin and granitic and greenstone rocks of the Pilbara Craton. The volcanic rocks extend along the southern and western margins of the Pilbara Craton, as well as in the Hamersley Range (Newman and Tom Price - Paraburdoo areas). The Archaean granites and greenstones are located north of the Chichester Range, and underlie the Port Hedland coastal plain deposits in the north (Fig. 6). There are also granitic rocks of Proterozoic age of the Gascoyne Complex in the Nunutarra area (Fig. 5).

The sequence containing the local mafic volcanic rocks is dominated by basalt, but other rocks include tuff and agglomerate with minor siltstone, sandstone, shale, chert jaspilite and felsic volcanics. The rocks occur mostly as outcrop with colluvial and eluvial material poorly developed over most of the area, but clay gilgai structure is well developed over the surface in places. Joints and fractures are extensive, but mostly extend only to shallow depths. Significant fracturing seldom occurs below 30 m bgl although fracture zones have been intersected down to 50 m bgl. Groundwater levels in the aquifer are generally less than 15 m bgl, but fall during prolonged dry spells and spring discharges are often not sustainable throughout the dry period. Large sustainable supplies can be obtained only locally where the aquifer is close to the drainages. Groundwater salinity is mostly fresh to marginal, indicating rapid recharge, but some brackish groundwater does occur in areas of low permeability or discharge zones.

The mafic volcanic rocks are not considered to have good potential as major groundwater supplies. Many bores constructed in the mafic volcanic rocks fail to intersect sufficient saturated zones of weathering or fracturing and are reported to be dry when drilled or were abandoned due to insufficient yields. Yields are generally less than 100 m^3/d, although correctly sited and constructed bores along the larger alluvial valleys can yield up to 500m^3/d. Yields of 1000 m^3/d have been encounted but are rare and generally unsustainable. The mafic volcanic rocks have poor potential for town and horticultural groundwater supplies over most of the area due to low yields and low recharge. However, the prospects are good close to the larger valleys and Paraburdoo obtains large groundwater supplies for town and mining purposes from the Bellary Creek valley. There may be potential to augment town water supplies and potential bore sites should be investigated along the West Pilbara Water Supply Scheme pipeline route where it traverses the aquifer. The aquifer has good potential for small supplies for pastoral requirements and drilling depths required will mostly be less than 30 m, but rugged terrain may hamper access for drilling equipment.

The felsic volcanic rocks comprise undifferentiated Archaean felsic volcanic rocks and the Proterozoic Woongarra Volcanics. The rocks are mostly brittle and are often brecciated in outcrop (de la Hunty, 1965). Drilling in the Marble Bar area indicated maximum depths of fracturing of about 90 to 100 m bgl. The rocks mostly form a poor aquifer, but sustainable yields on a local scale may be located close to drainages. Few pastoral bores are constructed in the felsic volcanic rocks. Some success has, however, occurred for town supply. At Marble Bar, for example, the aquifer supplies approximately 0.15 x 10^6 m^3/yr along the Coongan River. The location of high yielding bores is, however, site specific and dependant on the geology and several exploration bores may be required to locate one successful production bore. Away from drainages, where recharge occurs only from direct infiltration of rainfall, the potential is restricted to low yielding pastoral bores. Hard rock drilling techniques will be required to depths of about 30 m.

In granite and greenstone rocks the groundwater occurs mainly in the upper weathered zone and where the host rock is intruded by quartz veins and pegmatite. The thickness of the weathered zone seldom exceeds 50 m and groundwater levels vary between 3 and 20 m bgl. Groundwater movement may be slow or rapid depending on the structural and topographical conditions. Recharge occurs in topographically elevated areas and the upper reaches of drainages. Groundwater salinity ranges from less than 500 mg/L TDS along drainages to greater than 10 000 mg/L TDS in the north.

Yields from granitic and greenstone rock aquifers are extremely variable, site specific and range from dry to 2000 m^3/d. The largest yields are likely to occur from the intrusive quartz veins and may not be sustainable away from the drainages. The granite aquifers are productive locally from intense fracturing, mostly around intrusive quartz veins or where the weathered profile is thick. Elsewhere, the aquifer is poor and yields seldom exceed 100 m^3/d. The greenstone aquifers are also productive locally and prospects are best in the more brittle and resistant units (BIF, quartzite and felsic volcanics) where they underlie or are adjacent to drainages. Clay minerals filling joints and fractures reduce secondary porosity in the mafic and ultramafic rocks and these are less prospective.

The granite and greenstone rock aquifers can only be considered to have minor groundwater resource potential. Within the Pilbara Craton the potential for town and horticultural water supplies from large capacity bores is poor. The location of high yielding bores in the granite is site specific and dependant on the nature of fracturing and weathering of the rocks. Both the granitic and greenstone rocks have potential for groundwater supplies from low yielding pastoral bores, but hard rock drilling techniques may be required to depths greater than 25 m. The best target for exploration within the granites are close to intrusive dykes and quartz veins near drainages where the groundwater is freshest and larger yields may be sustained. The most prospective rock types within the greenstones are BIF, chert and basalt, particularly where they are crossed by, or adjacent to drainages. Schists and amphibolites have poor prospects. There are, however, local exceptions. The cleaved sandstone sequence of the Mosquito Creek Formation, for example, is currently utilised for town water supply at Nullagine during drought periods and has indicated the potential to provide large capacity production bores capable of sustaining yields of greater than 300 m^3/d.

On the coastal plain, there is potential to augment town and horticultural water supplies drawn from the alluvial aquifer. Drilling should be continued into the granitic and greenstone rocks, under the alluvium until no appreciable increase in yield is recorded or lithological data indicate poor groundwater potential. The aquifer in the coastal area has little potential for pastoral groundwater supplies as the overlying alluvial aquifer is more readily exploitable.

Those areas containing granitic and greenstone rocks to the south of the Fortescue River are not suitable for exploitation due to limited storage, recharge and bore yields. In many areas the rugged terrain may also hamper access.

GROUNDWATER RESOURCE DEVELOPMENT

Groundwater comprises most of the major water supplies in the Pilbara Region. Groundwater meets the town , mining, industrial, and agricultural water supply needs and has the potential to meet future demands as projected to the year 2025. It is , however, essential that the groundwater resources are correctly exploited and managed to ensure the ecological sustainable development of the Pilbara Region.

DEVELOPMENT POTENTIAL

The prospects of locating large groundwater resources in the Pilbara Region are good (Fig. 11). Approximately 126 000 x 10^6 m^3 of groundwater is held in storage in the Pilbara Region and about 660 x 10^6 m^3 is recharged annually. These groundwater resource estimates are initial estimates, as most available data are concentrated around the populated centres and mines, with large areas of the region remaining unexplored. Groundwater storage and recharge is greatest in the Cainozoic deposits, and the basement rocks contain small quantities of groundwater, but provide the dominant control on groundwater flow direction (Table 5). Figure 12 indicates the areas of greatest groundwater potential in the Pilbara Region and takes both quality and quantity aspects of the resource into consideration.

Significant groundwater resources occur in the alluvial aquifers of the coastal plains and in particular along the major river drainages. Large resources are proven along the De Grey, Yule, Turner, Fortescue and Robe Rivers. Significant resources may also be available within the coastal plain along the Coongan, Shaw, Strelley and Ashburton Rivers, but these are not proven. Additional, smaller, groundwater resources may be available along the Pewah, Sherlock, Little Sherlock, George, Jones and Harding Rivers close to where they emerge onto the coastal plain. Further work is now required to more accurately assess the resource potential within the Port Hedland coastal plain.

Inland, the valleyfill aquifers, comprising alluvium, talus and scree slope deposits, and outwash fans, may contain major groundwater resources, especially when exploited in conjunction with pisolitic limonite and calcrete aquifers. Thick valleyfill sequences may be found in the Fortescue River valley and within the valleys of the Hamersley Range. The saturated thickness of the sequence may be greater than 100 m and forms a major aquifer that is utilised for town and mining water supplies around the larger centres of Tom Price, Newman and Paraburdoo. Groundwater is generally drawn from the valleyfill in conjunction with underlying basement rocks and the largest supplies are obtained where the basement comprises fractured and cavernous dolomite.

Alluvium, outside the coastal plains and valleyfill sequences of the Fortescue River valley and Hamersley Range, is usually thin and does not contain large groundwater resources. Groundwater in the alluvium is mostly fresh to marginal and it is important for pastoral groundwater requirements and some small town requirements. Deposits of pisolitic limonite can contain significant quantities of fresh to marginal groundwater where it extends for large distances along the present drainages in the upland areas. However, the aquifers are narrow, have only small storage volumes and large scale abstraction from them will not be sustainable throughout prolonged dry periods without causing large declines in the watertable. The deposits are often unsaturated where they are not adjacent to drainages.

Calcrete occurs generally along flat reaches of ancestral or existing water courses. It is often cavernous and can contain large quantities of groundwater. Calcrete occurs in conjunction with alluvium and other valleyfill close to the major drainages. Calcrete deposits outside of the Fortescue River valley and the Hamersley Range generally have limited saturated thickness and constitute poor aquifers. The calcrete, developed over large areas in the Ashburton River and Oakover River valleys, may indicate significant dissolution of underlying dolomite basement rocks. However, very few data are available to adequately assess the resources of the calcrete in these areas as it's saturated thickness is unknown.

Dolomite formations are very prospective for groundwater where they underlie thick sequences of valleyfill in the Fortescue River valley and Hamersley Range. Hydrogeological data from the dolomitic formation in the Oakover River and Ashburton River valleys is sparse, but appear quite prospective (Fig. 10). Exploratory field mapping and drilling is, however, required to obtain a better understanding of these areas.

Carnarvon Basin sediments underlying the alluvial aquifer on the Onslow coastal plain generally constitute poor aquifers. The Yarraloola Conglomerate aquifer contains large supplies of mostly saline groundwater under artesian pressure and at a temperature of about 40° C. Fresher groundwater exists in small areas close to where the Yarraloola Conglomerate subcrops the alluvial aquifer in the vicinity of the drainages. Large resources of saline groundwater at temperatures between 40 and 70° C exist in the deeper aquifers at depths mostly greater than 200 m bgl. Small local resources of groundwater are contained in the Trealla Limestone. It is utilised for Onslow town supply in conjunction with the alluvial aquifer along the Cane River.

Large groundwater resources are available in Canning Basin sediments in the northeast of the study area. Large fresh resources are proven in the Jurassic and Cretaceous sediments, with groundwater abstraction prospects best in the area northwest of the Shay Gap Wellfield. The main constraints imposed on developing these aquifers are the remoteness of the area and quality of the groundwater for a given use. Any wellfield should develop both aquifers. The Permian sediments occur in a trough up to 500 m deep, carved into the Pilbara Craton. Few data are available to adequately assess the resources, but the Paterson Formation sediments may contain large quantities of fresh to saline groundwater under artesian pressures.

Storage and permeability are quite low in the basement rocks and zones of fracturing and weathering are mostly discontinuous. The saturated thickness of the fractured rock aquifers is variable and poorly defined due to the lack of detailed lithological and hydraulic data. Groundwater flow is largely controlled by geological structures and regionally connected flow systems are absent. The location of high yielding bores in fractured rocks is site specific and dependant on intersecting thick zones of well developed secondary porosity. The best target for exploration within the igneous rock aquifers are close to intrusive dykes and quartz veins. Large yields will only be sustainable in the vicinity of drainages where recharge can occur by infiltration of runnoff and where additional storage from the alluvium or valleyfill may be available.

The success rate for the location of high yielding production bores in basement rocks will be low, but use of geophysical surveying and hydrogeological assessments will increase the success rate. The success rate for the location of high yielding production bores will be higher in the alluvium and valleyfill and geophysical surveying should be undertaken to aid drilling site selection. The percentage of success for random drilling in the basement rocks and the superficial deposits is low. The Cainozoic deposits are mostly in hydraulic connection with the basement rocks and both should be used conjunctively if possible.

Groundwater in the Pilbara Region is mostly potable. However, groundwater quality can be poor in interfluvial areas on the coastal plains, in the Carnarvon Basin sediments below the Onslow Coastal Plain, as well as in areas where mineralisation has occurred, close to sites of mineral processing, and in the Cretaceous Canning Basin sediments where elevated levels of nitrate are recorded. Figure 13 provides some indication of the groundwater salinity based on the limited number of bore records that have salinity data in AQWABASE.

GROUNDWATER SUPPLY DEMANDS

Recent water service and demand projections undertaken by the Water and Rivers Commission (WRC, 1996) suggest that the demand for water will increase some 50 % to 167.6 x 10^6 m^3 by the year 2025. This increase is largely due to the expected industrial growth in Karratha and Port Hedland, where as much as 70 x 10^6 m^3 of water could be required by the year 2025.

The expected increased industrial and town water demand at Port Hedland and Karratha could possibly be met by groundwater resources, but will require regional groundwater supply schemes based on conjunctive use. The unconsolidated sedimentary aquifers have the potential to meet this demand if individual wellfields are combined into a regional network and when the aquifers are exploited in conjunction with the fractured rock aquifers, in particular the dolomitic aquifer. Table 7 provides a summary of the possible groundwater potential for the Port Hedland coastal area. Detailed investigations have identified additional wellfields and wellfield extensions along the Cane, Lower Robe, Lower Fortescue and DeGrey Rivers. Further investigations are, however, still required along the upper Robe, Maitland, Yule, Turner, Shaw, DeGrey and Coongan Rivers to confirm the desk study estimates. This is important as the 'additional potential' given for each wellfield (column 5 in Table 7) is a desk study estimate and needs field verification.

Table 7 : Groundwater supply prospects for the Dampier - Port Hedland area.

Water supply scheme\area	Wellfield	Current usage	Predicted available potential		
			Field study*	Additional**	Total
West Pilbara	Millstream	4.9	10.7		10.7
	Lower Robe River	-	10.0		10.0
	Lower Fortescue River	-	16.0		16.0
	Maitland	-		3.0	3.0
		4.9			39.7
East Pilbara	DeGrey River	3.3	6.0	8.0	14.0
	Yule River	2.6	6.0	4.0	10.0
	Turner River	-		3.0	3.0
	Goldsworthy	-	1.5		1.5
		5.9			28.5
Canning Basin	Broome & Wallal	-	>15.0		15.0 - 50.0

All units in millions of cubic metres per year (x $10^6 m^3$ / yr)

* Value based on a field investigation

** Value based on desk study

Town and mine water supply needs can be met in most areas by exploiting local aquifers. The water supply predictions for inland centres indicate that future demands can be met by extensions of the existing wellfields. The use of geophysical surveys and in some areas hydrogeological assessments, will ensure greater success in locating higher yielding bores.

Pastoral water supply demands can be met throughout the region. All the rock formations within the Pilbara contain local aquifers with adequate potential to meet stock and domestic water supplies. This may, however, require the drilling of bores rather than the construction of wells, as was common practice in the past.

MANAGEMENT ISSUES

The extremely low and irregular rainfall of the region ensures that groundwater is an important source of water and crucial to the development of the region. It is, therefore, essential that the groundwater resources are effectively exploited and managed. Some key factors that should be considered are:

Over exploitation. The unconsolidated sediment aquifers are capable of yielding large quantities of groundwater which are replenished annually from rainfall and seepage from surface drainages. These aquifers, by virtue of their unconfined nature, are relatively easy to exploit and as a result generally heavily utilised (Fig. 2). This groundwater usage must be controlled to avoid over exploitation and possible groundwater deterioration. Declining groundwater levels not only result in declining bore yields, but could have environmental impacts, such as stress to vegetation and reduced groundwater flow to springs and river pools. Abstraction of groundwater from an aquifer may give rise to intrusion of more saline groundwater from the surrounding aquifer. This is especially true for the wetlands and marshes on the coastal plains, and for the Millstream area. The need to prevent salinization of fresh groundwater supplies is therefore a major constraint. It may be necessary for a portion of the natural throughflow to be left to discharge naturally in order to prevent ingress of more saline water.

Groundwater quality. Groundwater quality throughout the Pilbara Region, is mostly potable. Salinity and hardness (due to dissolution of carbonate rocks) are two, natural, limiting factors in deciding on the suitability of a resource for a particular purpose. In the Pilbara, groundwater degradation can occur locally due to factors such as sulphide mineralisation and ore processing. High fluoride levels have been recorded in areas of tin mineralisation in the granitic country (Blockley, 1980, and Whincup, 1966a) and high levels of arsenic and sulphate occur in groundwater from areas of mineralisation in the greenstone sequences (Allen, 1965). Nitrate levels above the recommended acceptable limits have been recorded in groundwater from the Cretaceous sediments of the Canning Basin (Leech, 1979) and cyanide has been recorded in groundwater close to gold ore treatment areas (Allen, 1965). Uranium levels above those recommended for drinking water (NHMRC, 1994) can be located in the Yarraloola Conglomerate aquifer around where the Ashburton River enters the Onslow coastal plain and elevated levels of heavy metals can result from bore, pump and pipe fittings (Layton Groundwater Consultants, 1979). It is possible that groundwater from the Cretaceous sequence below the Onslow coastal plain be accompanied by residual, biodegraded hydrocarbons and gas.

Land surface subsidence. The collapse or subsidence of the land surface could possibly occur due to dewatering of confining layers of silt and clay in areas where excessive declines in the potentiometric surface occur or from net downward movement of the land surface into cavities developed in carbonate rocks. Potential for dewatering of confining layers occur in the Fortescue River valley, the valleys of the Hamersley Range, and the Carnarvon and Canning Basins. The potential for land subsidence or collapse over cavities developed in carbonate rocks occurs throughout the Fortescue River valley, the valleys of the Hamersley Range and the Oakover River valley where superficial Cainozoic deposits overlie dolomite.

The process of sinkhole development is natural and occurs in karstic terrains throughout the world. However, the onset of sinkhole development can be induced in the vicinity of wellfields by increasing the hydraulic gradient, groundwater flow velocities and recharge through groundwater abstraction and thereby increasing the rate of denudation of the carbonate rocks. Sinkholes and collapse structures up to Proterozoic age have been recorded in the Carawine Dolomite within the Oakover River valley (Hickman, 1978) and sinkholes developed in the valley fill within the Southern Fortescue area and the Fortescue River valley have been observed from the early 1980's.

Conjunctive use. The utilisation together of different sources for water supply can provide considerable operating and economic advantages, as well as greater security of supply. Conjunctive use can either involve different aquifers or both surface and groundwater. When declining watertable levels occur or environmental impacts are experienced, pumping from the unconfined aquifer can be modified, and increased from the confining aquifer, to continue meeting the required scheme yield. Groundwater can be used to supplement supplies of surface water. In times of drought, the groundwater can be used while the surface water resources are conserved, and during periods of adequate surface water supply, the groundwater aquifer can be rested. The Harding Dam / Millstream Aquifer Scheme is such a system.

Artificial recharge. The artificial recharge of groundwater resources is a valuable means of supplementing the natural recharge, especially in areas like the Pilbara Region where rainfall is both limited and unreliable. Artificial recharge is especially applicable in situations where excess surface water is periodically available or where high evaporation losses make underground storage preferable. A scheme of this nature is currently operating at Newman where water from the Ophthalmia Dam recharges, via infiltration basins and the reservoir itself, the underlying unconfined aquifer from which the groundwater is pumped, as required for the Newman town water supply. Artificial recharge of confined aquifers is more difficult and expensive and not viable in the Pilbara Region. Prior treatment of the recharge water is generally required and various mechanical, physio-chemical and biological problems tend to reduce the amount of recharge which can be achieved.

CONCLUSIONS

Groundwater occurs throughout the Pilbara Region in the Precambrian basement rocks, Phanerozoic sedimentary basins and Cainozoic deposits. It originates from direct rainfall recharge over outcropping basement rocks and from infiltration of rainfall and surface runoff through Cainozoic deposits. Groundwater currently provides reliable, sustainable water supplies to towns, mines, industries and agriculture. In excess of $16 \times 10^6 m^3/yr$ of groundwater is abstracted at Pilbara town and mine water supply schemes. The most significant abstraction takes place from the alluvial and valleyfill aquifers located on the coastal plain and within the Fortescue River valley and Hamersley Range. Groundwater resources in basement rocks are exploited locally for mining and town supply as well as for infrastructure development. Shallow bores and wells adequately meet the requirements for pastoral supply throughout the region.

This assessment represents the first comprehensive, quantitative assessment of the groundwater resources on a regional scale in the Pilbara Region. No systematic hydrogeological mapping has as yet been done. Most hydrogeological data are concentrated in relatively small areas around existing towns and mining centres. Numerous pastoral and mining exploration bores exist throughout the region, but these generally provide little, if any, reliable hydrogeological data.

The most significant and exploitable groundwater resources of the Pilbara Region are contained in the unconsolidated sediment and chemically deposited aquifers ; alluvial aquifers on the coastal plains and valleyfill and calcrete aquifers within the major inland drainages. The greatest potential occurs where these aquifers may be exploited in conjunction with underlying fractured rock aquifers and in particular the dolomites. Fractured rock aquifers represent important local sources of groundwater to meet small town and mining operation and infrastructure development needs. The Canning Basin aquifers represent the largest untapped groundwater resource in the region. The Wallal Sandstone aquifer is a substantial resource and has a larger storage than any other known aquifer in the Pilbara Region. The remoteness of these aquifers currently represent a major development constraint. This will, however, change as demand for water increases.

The greatest future need for groundwater supplies appear to be in Port Hedland and Karratha, within the coastal plains (WRC, 1996). The predicted water demand could possibly be met by the groundwater resources contained in the alluvial aquifers, inparticular those areas where river drainages cross the coastal plain, and the valleyfill aquifer of the lower Fortescue River valley. Detailed hydrogeological investigations have identified new wellfields and extensions to existing wellfields along the Cane, Robe, Fortescue, and DeGrey Rivers. Further investigations are required along sections of the Ashburton, Robe, Maitland, Yule, Turner, Shaw, DeGrey and

Coongan Rivers to confirm the desk study estimates. Palaeochannels and abandoned channels represent important groundwater exploration targets and need to be identified and investigated. Individual wellfields should form part of the existing East and West Pibara Water Supply Schemes to maximise the benefits of conjunctive use and ensure efficient groundwater resource management. Where available, surface water resources should be used to supplement the groundwater resources.

Water supply demand predictions for elsewhere in the Pilbara Region are relatively insignificant and could be met by extending existing bore fields. The use of geophysical surveying and hydrogeological assessments would increase the possibility of obtaining high yielding bores and avoid any potential over exploitation of the local aquifer. Similarly any pastoral stock and domestic water supply needs could be met from local aquifers. These will require hard rock drilling techniques and bore depths in excess of 30 m.

The extensive mining operations and proposed industrial activity in the Pilbara have the potential to locally affect the groundwater balance and the associated environment. Many of the aquifers are vulnerable to over exploitation and contamination. It is therefore, necessary to determine what possible environmental issues exist for each type of activity inorder to formulate an environmental protection strategy for groundwater resources in the region.

Groundwater will continue to be the major resource in the development of the Pilbara Region and must be managed as a sustainable resource. Close cooperation is required between supplier, regulator and consumer to achieve efficient, sustainable and equitable exploitation and management of the groundwater resource. This report, together with the Skidmore (1996) report, is the first step towards developing sound groundwater management policies and practices and represents the end product of a desk study assessment of the groundwater resources which included :

a) an inventory of groundwater resources , and
b) assessment of groundwater abstraction potential.

RECOMMENDATIONS

Further hydrogeological investigations are required to :

(a) verify the desk study groundwater resource estimates for the coastal area of Port Hedland and Karratha, and
(b) obtain a better understanding of aquifer potential in areas with little or no reliable field data.

Figure 12 indicates those areas where further hydrogeological investigations need to be undertaken. Priority should be given to meeting water supply problems. Attention should initially be concentrated on confirming the groundwater potential in the coastal area in order to establish whether the groundwater resources can meet the predicted water demand for Karratha and Port Hedland. It is recommended that the WRC :

1. Undertake a regional study in the Port Hedland coastal plain to :

    (a) determine the groundwater potential along the entire Turner, Yule, Shaw, DeGrey and Coongan Rivers within the coastal plain,
    (b) obtain a better understanding of the groundwater potential within the fractured rock aquifers, in particular the sheared and fractured rocks of the Roebourne - Dampier area,
    (c) examine the environmental impact of both the increased industrial activity and groundwater abstraction,
    (d) explore the concepts of conjunctive use and artificial recharge, and
    (e) undertake several small reconnaissance studies to determine the nature and potential of the valleyfill sequence and underlying basement rocks at the following localities within the Fortescue and upper Robe River valleys:
        1. upstream of Deepdale.
        2. major alluvial fans entering the Fortescue River valley from the Hamersley Ranges.

2. Undertakes the following tasks to obtain a better understanding of the regional groundwater potential :

- An investigation should be undertaken to determine the potential of the Oakover River valley aquifers (alluvium, calcrete and dolomite). This should be of an exploratory nature and involve field mapping and drilling. The investigation should also include the Paterson Formation aquifer.

- Exploration, including drilling of superficial sediments and basement rocks, should be undertaken in the Ashburton River valley where large areas of calcrete outcrop along drainages traversing dolomitic formations. Potential exploration areas lie along Wannery Creek, Ethel River and the upper reaches of the Ashburton River.

- Assess the potential environmental impact that the various mining and industrial activities may have on the different aquifers.
- Develop a GIS database for the region.
- Further investigate the groundwater potential within the Canning Basin east of the Shay Gap Wellfield.

It is recommended that the next phase (Stage 2) of the project involve 5 investigations as outlined in the proposed workplan (Appendix B).

These recommendations would enable the WRC to produce a comprehensive groundwater resource assessment report for the entire Pilbara Region. This would include published maps and reports and a GIS database tailored to the needs of the Water and Rivers Commission, Pilbara Development Commission, Water Corporation, Department of Resources Development, mining industry, agricultural industry and other stake holders.

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FIGURES

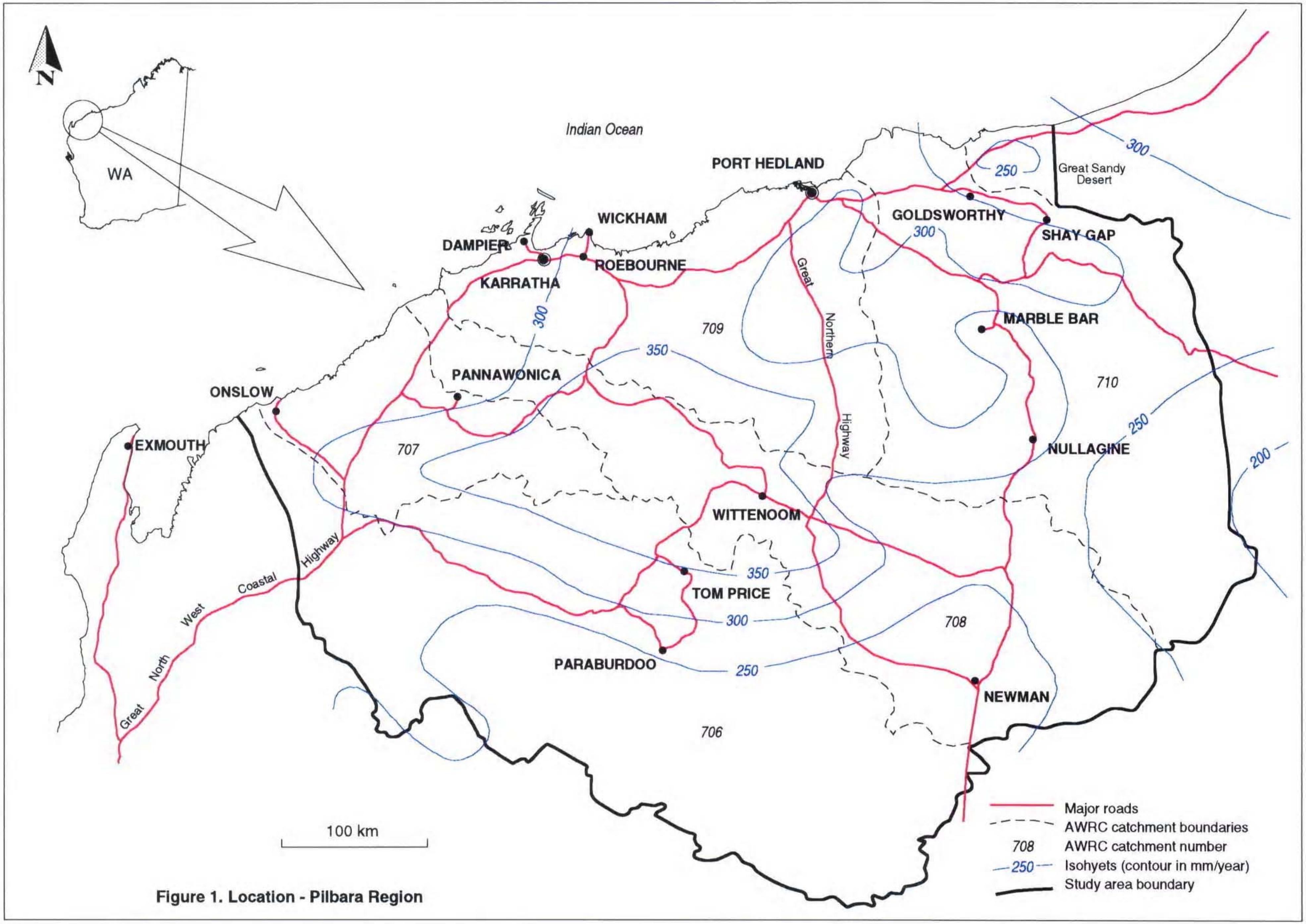

Figure 1. Location - Pilbara Region

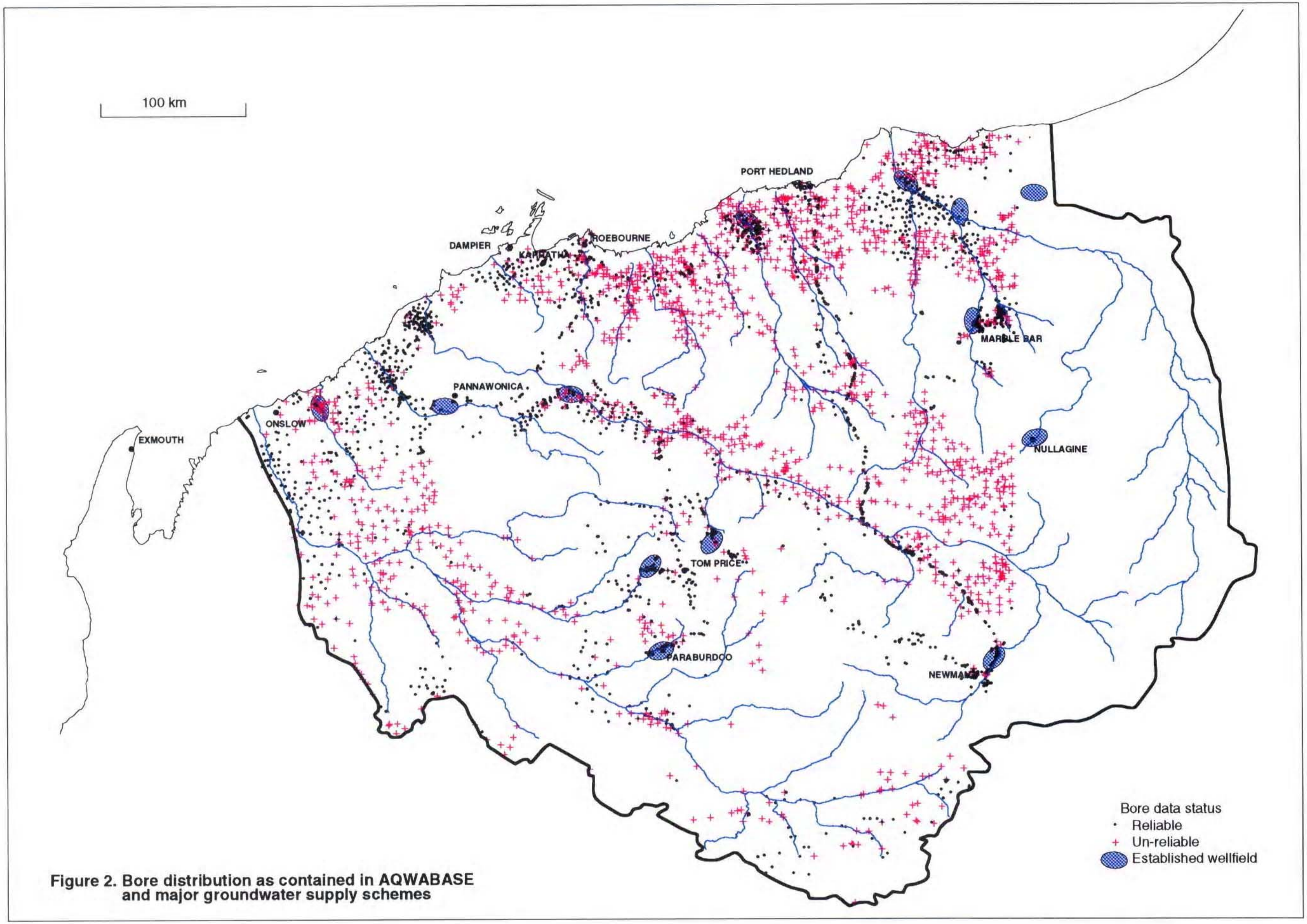

Figure 2. Bore distribution as contained in AQWABASE and major groundwater supply schemes

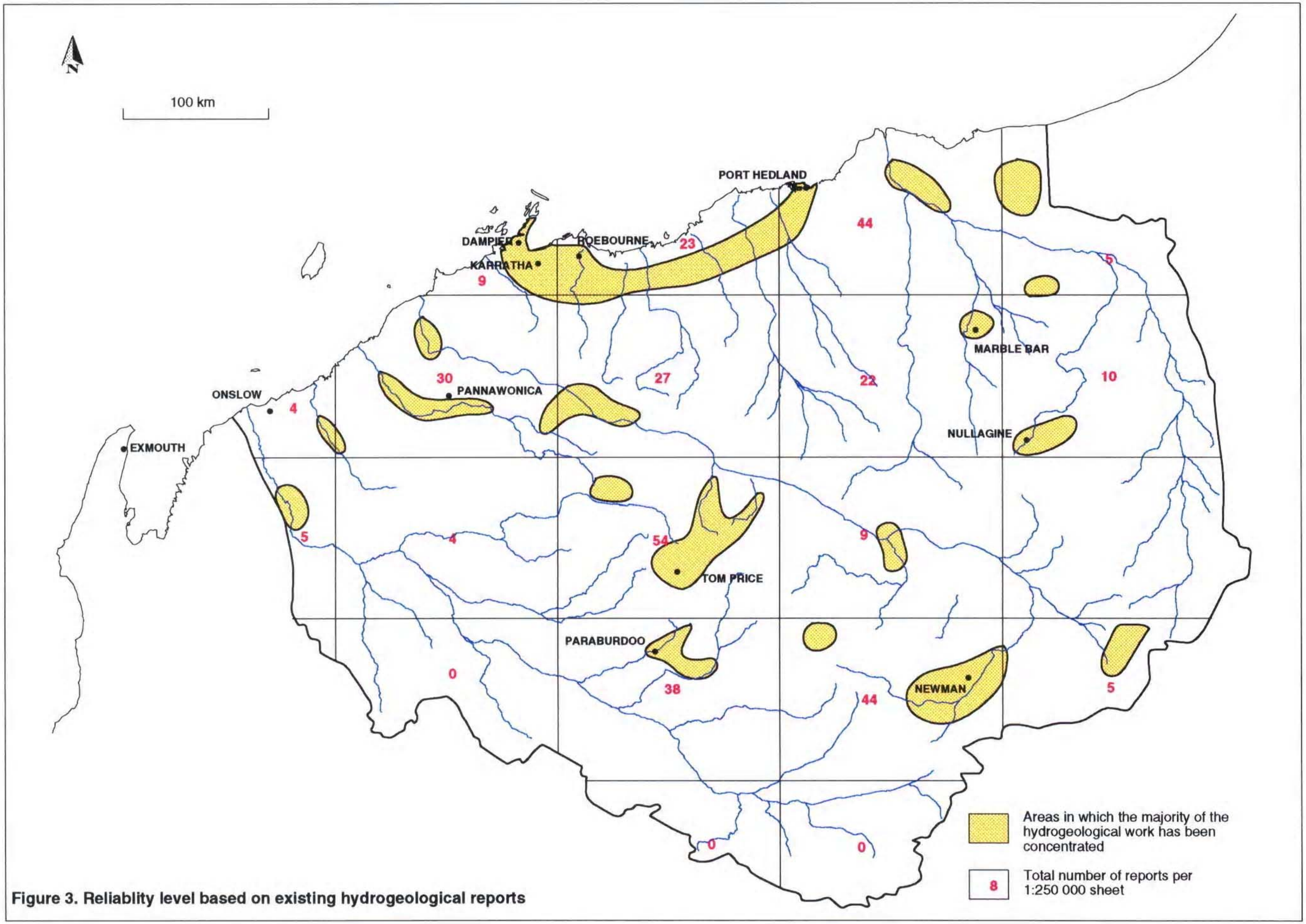

Figure 3. Reliablity level based on existing hydrogeological reports

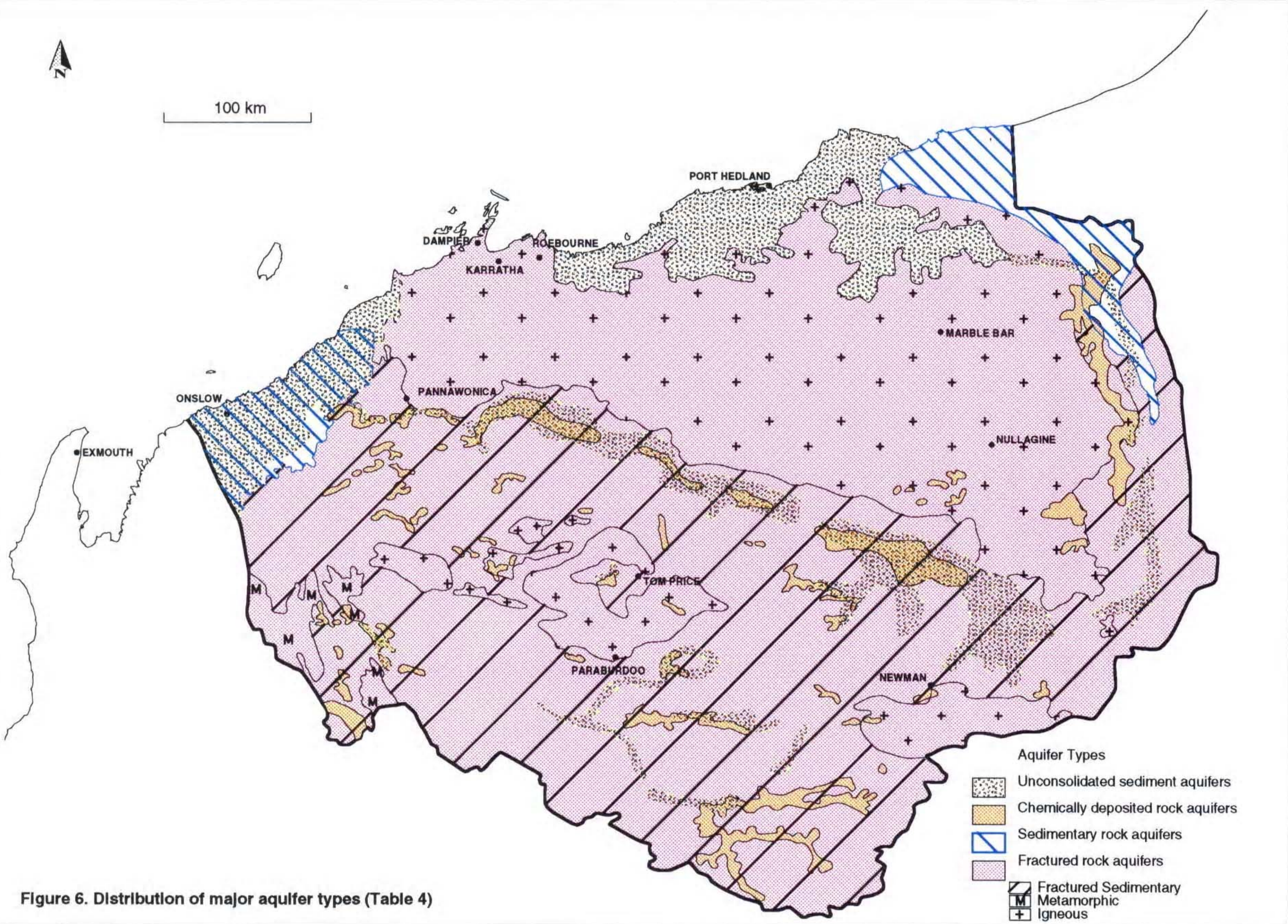

Figure 6. Distribution of major aquifer types (Table 4)

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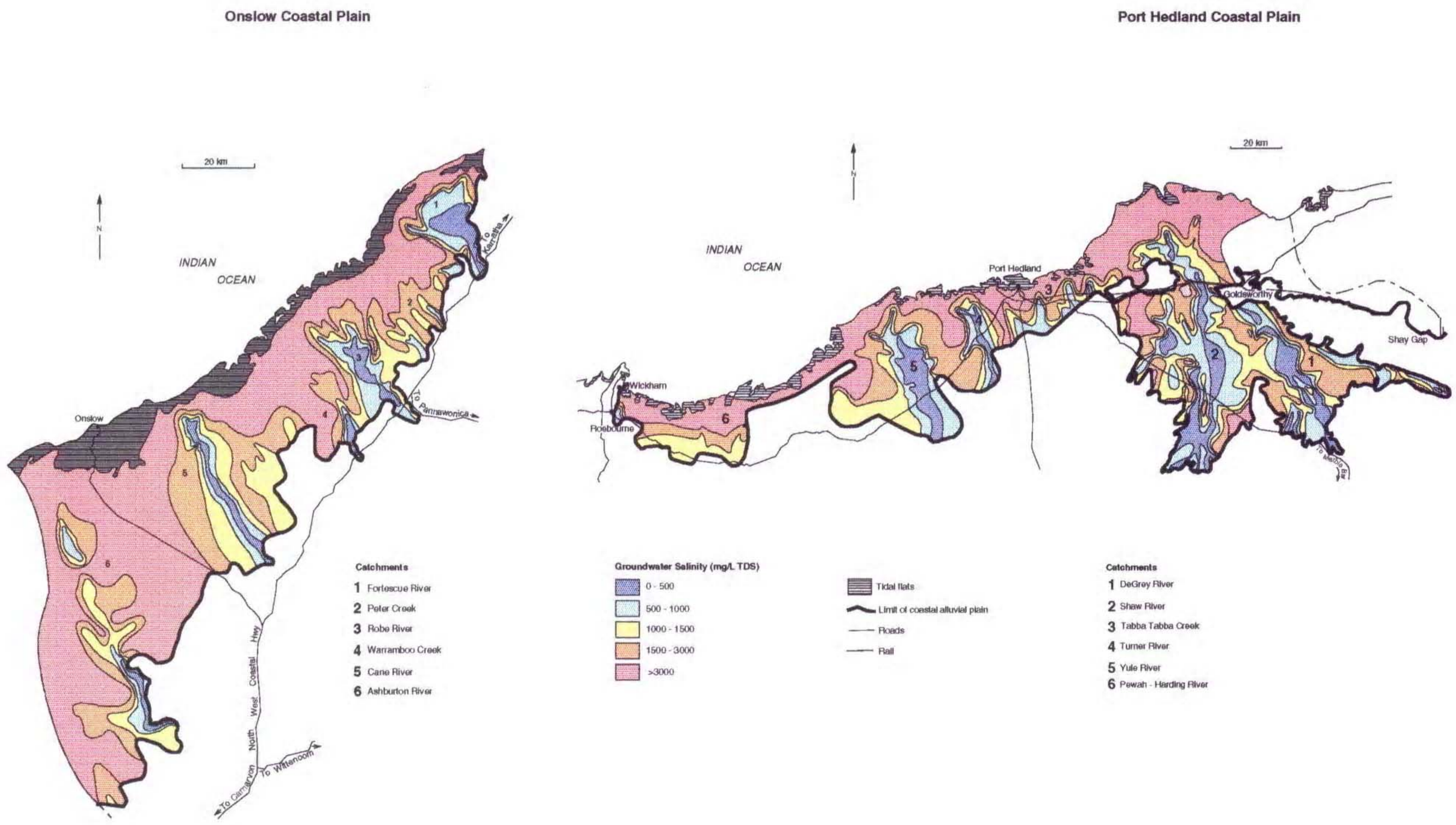

Figure 7. Groundwater salinities of the coastal alluvial aquifer

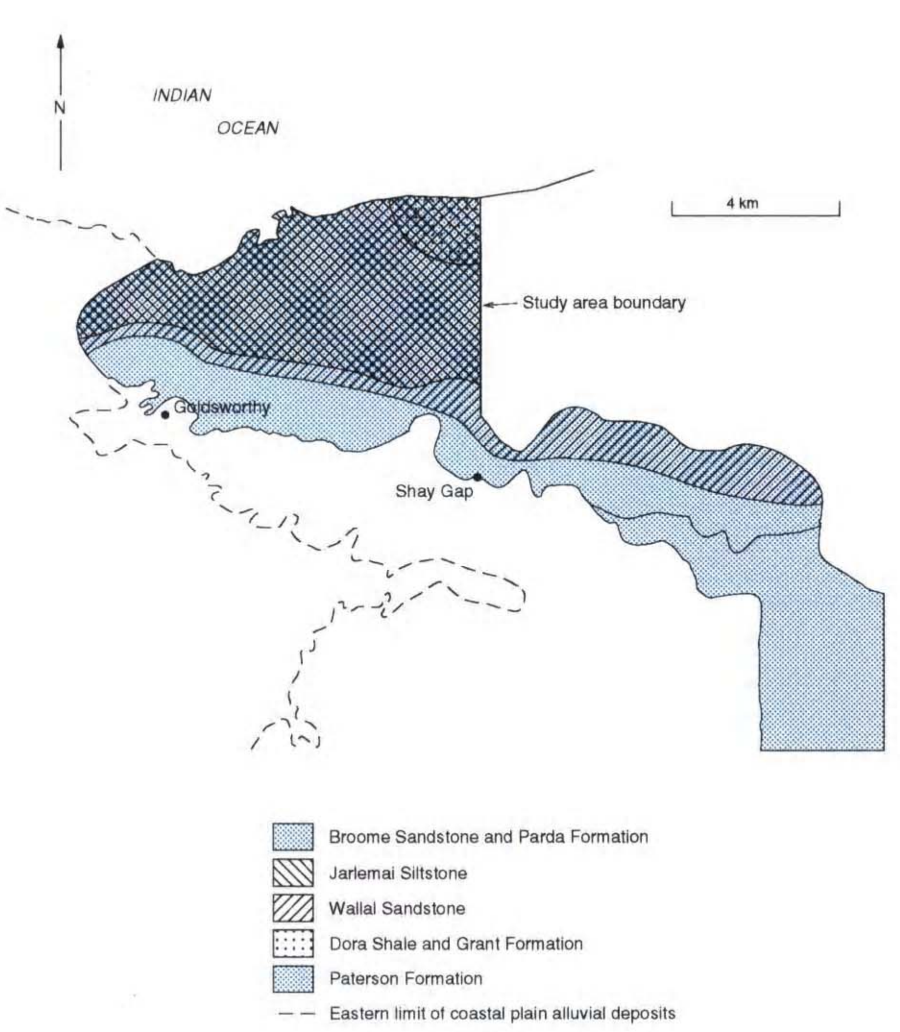

Figure 8. Approximate distribution of Canning Basin sediments

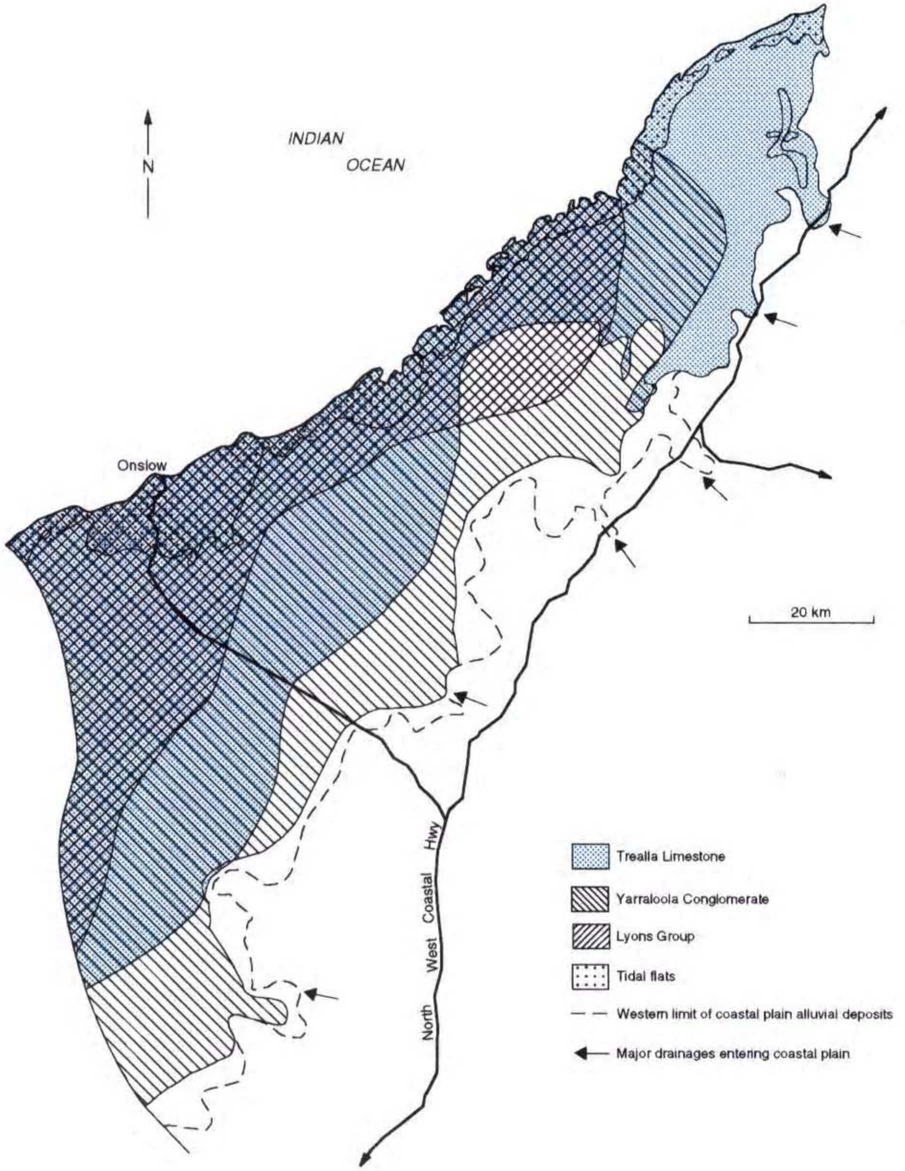

Figure 9. Approximate distribution of Canning Basin sediments.

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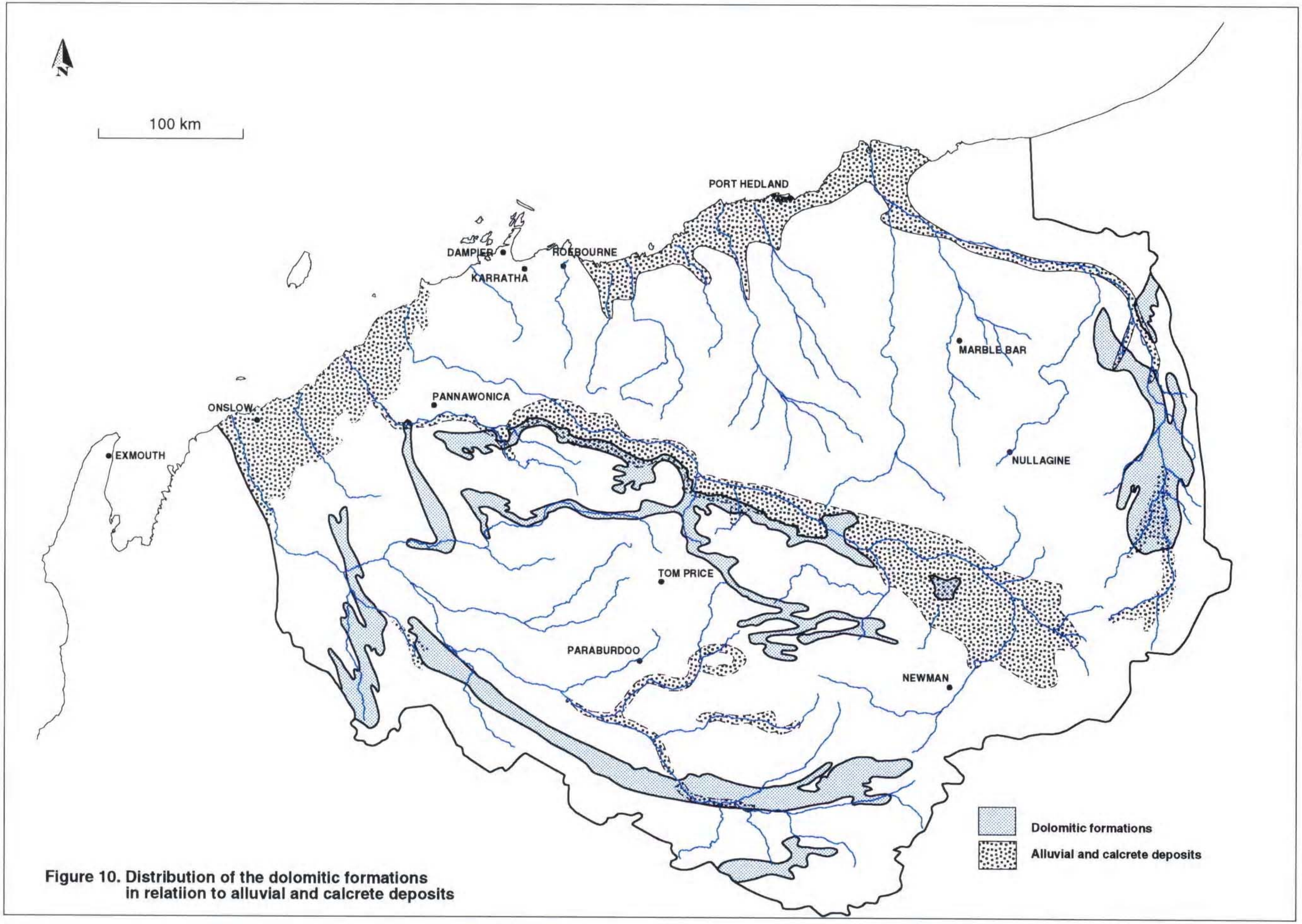

Figure 10. Distribution of the dolomitic formations in relatiion to alluvial and calcrete deposits

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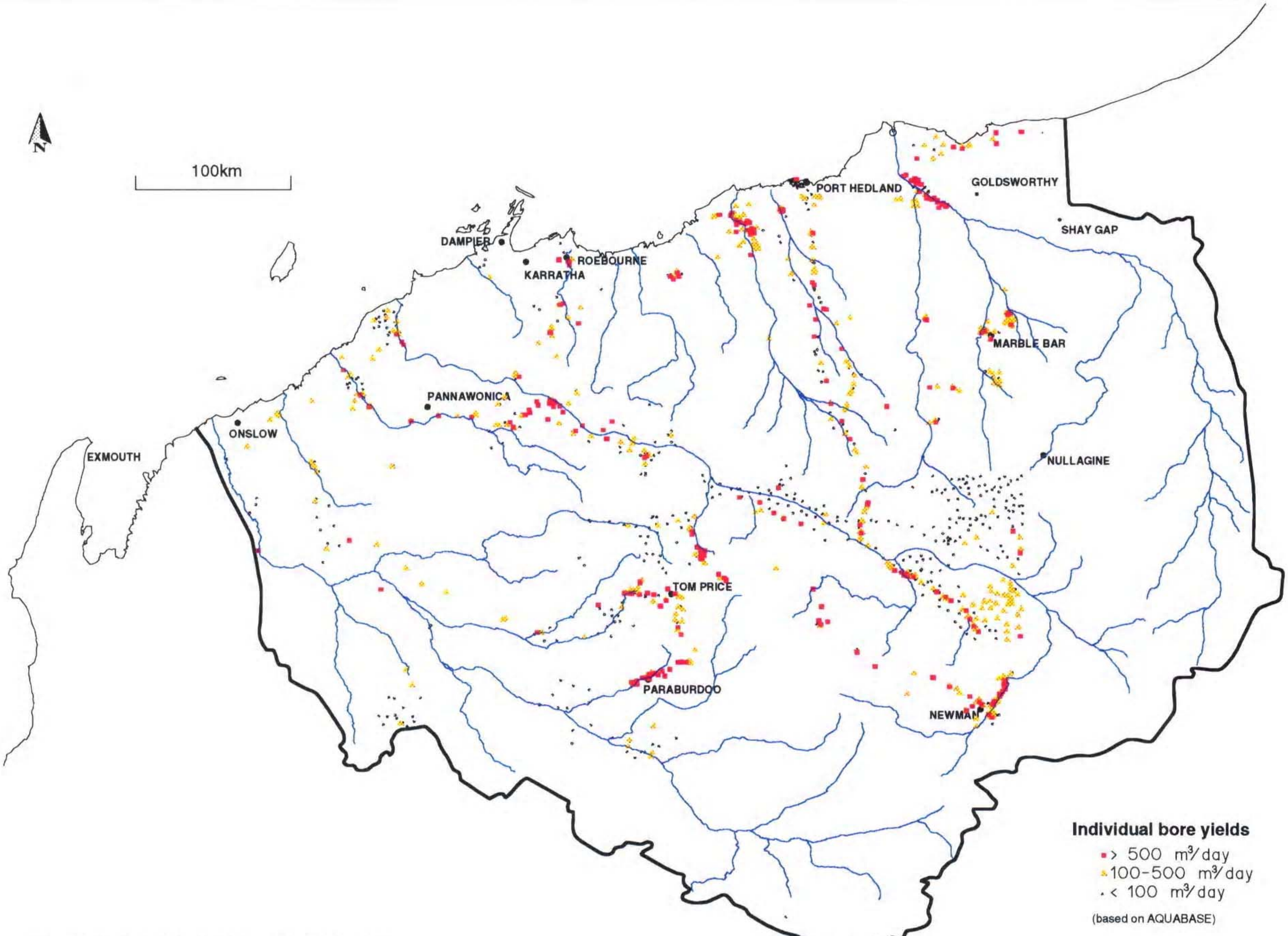

Figure 11. Bore yields in the Pilbara Region

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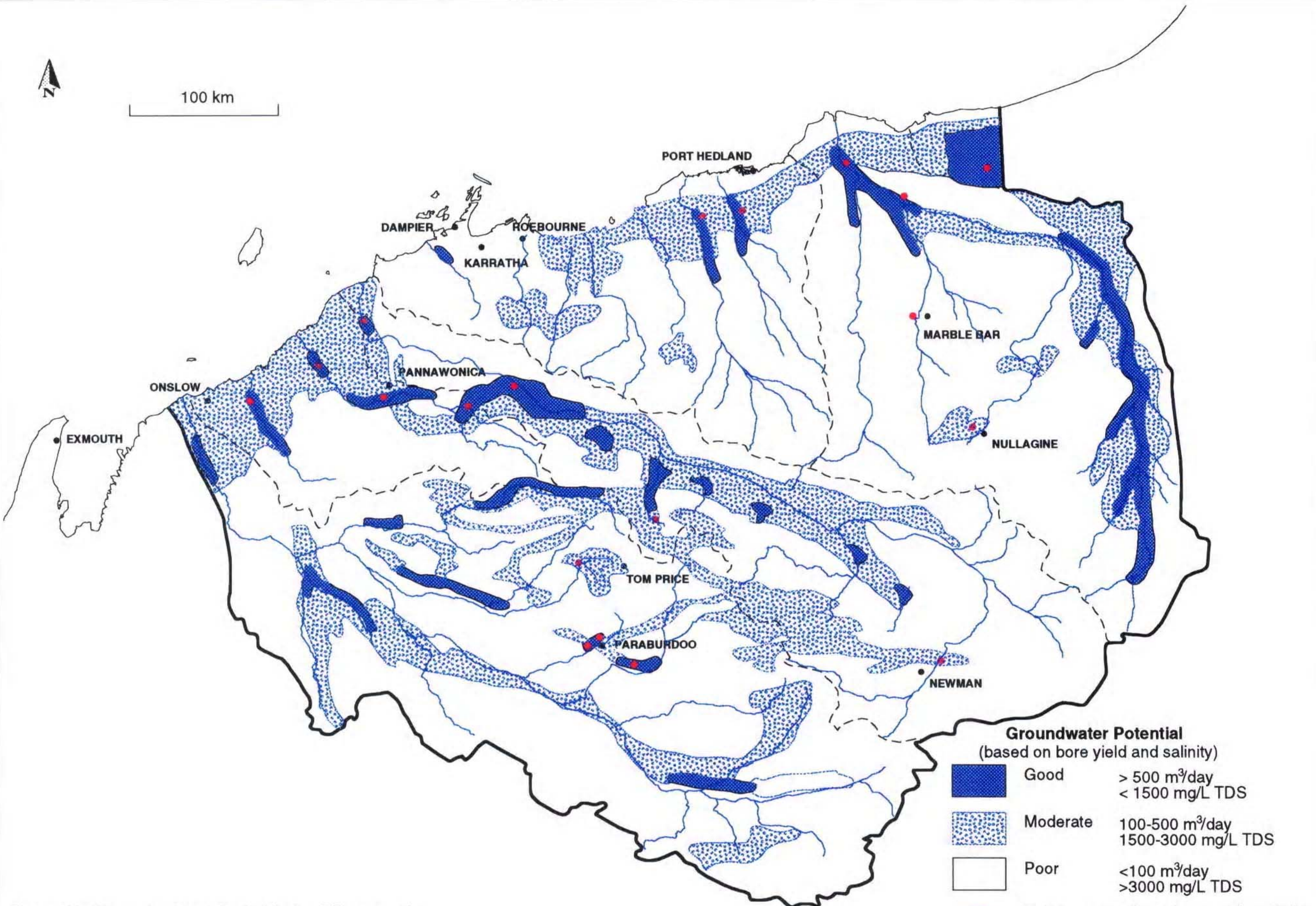

Figure 12. Groundwater potential in the Pilbara region

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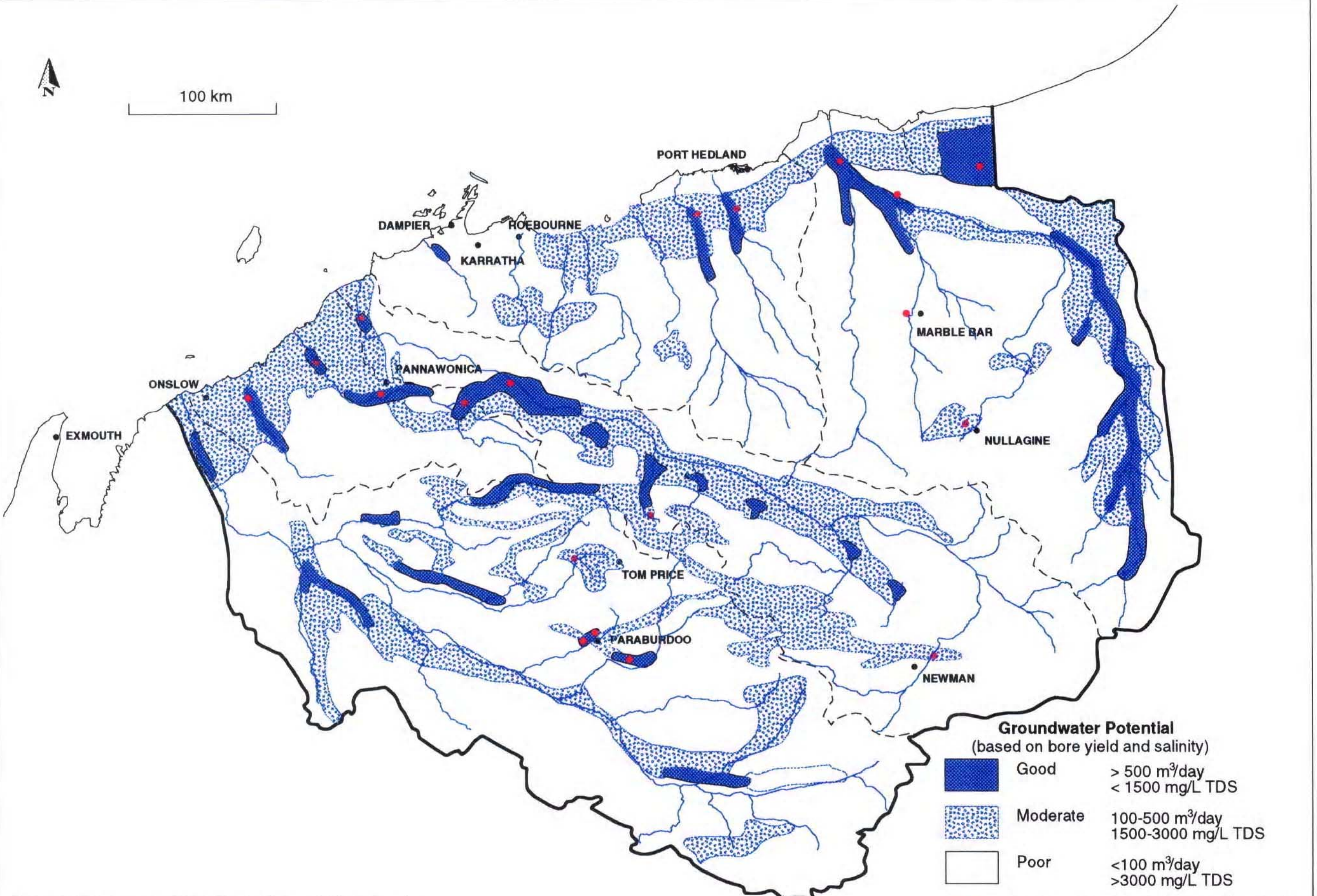

Figure 12. Groundwater potential in the Pilbara region

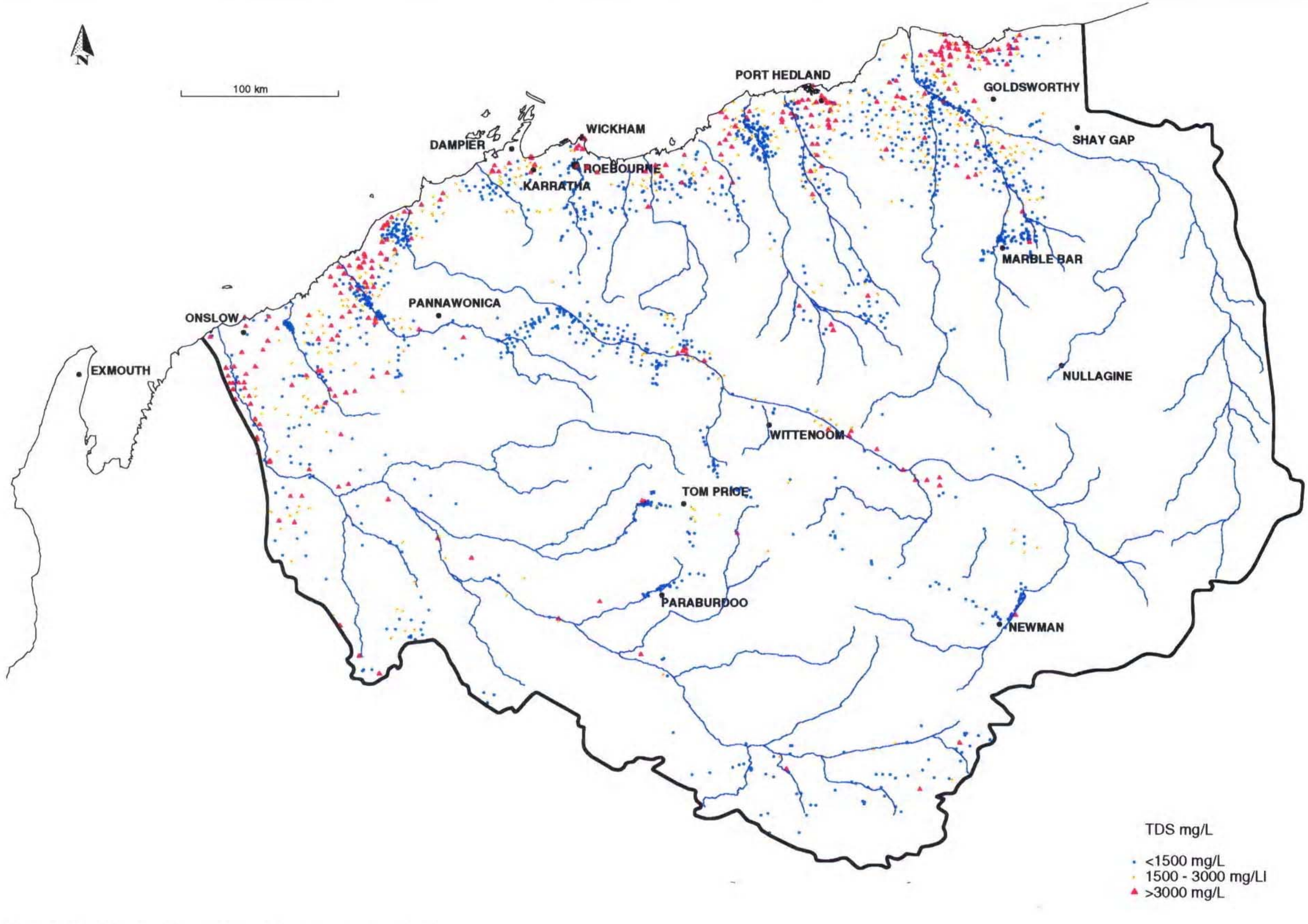

Figure 13. Groundwater salinity in the Pilbara Region

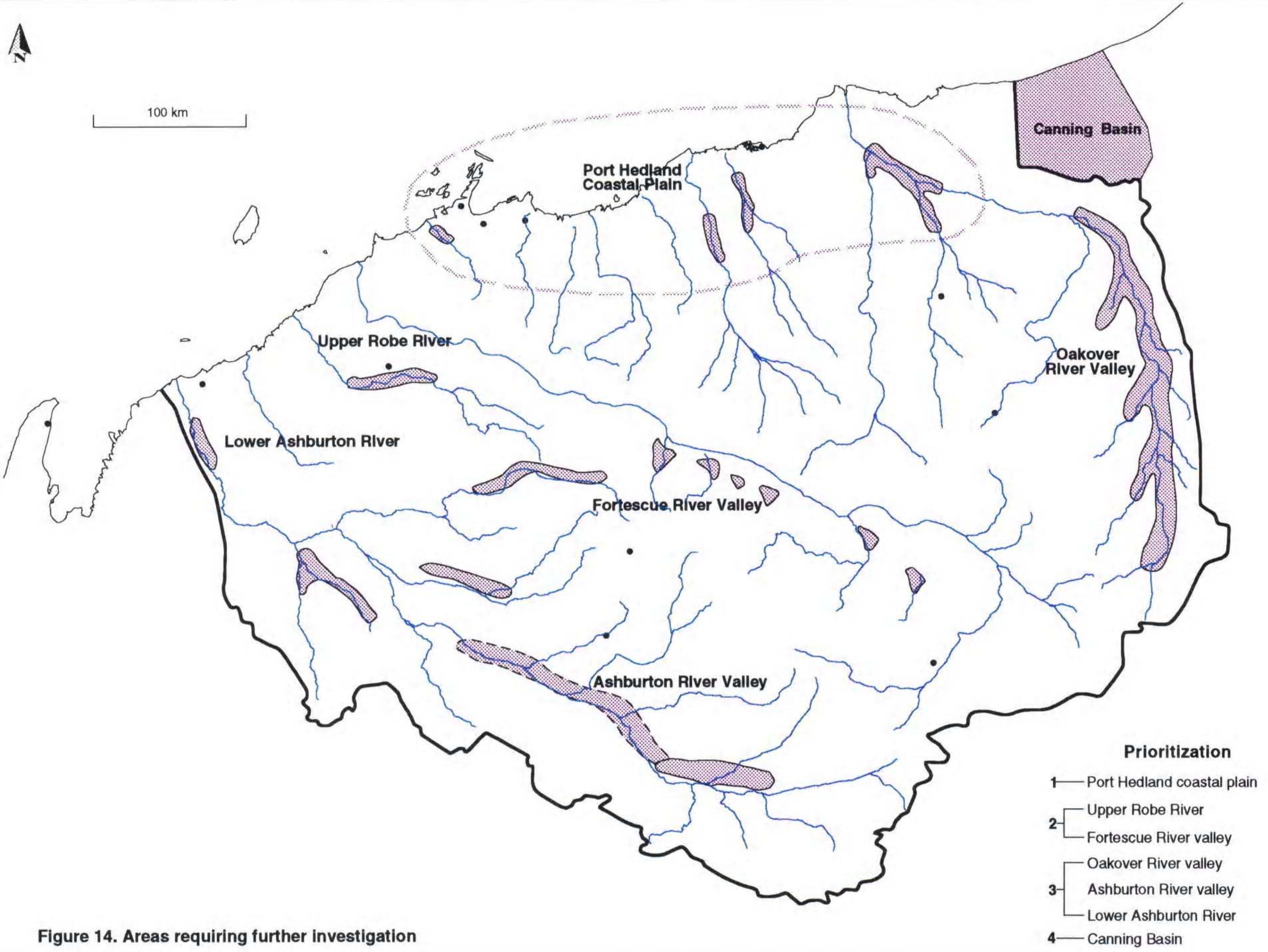

Figure 14. Areas requiring further investigation

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APPENDICES

A	Summary of groundwater resources as per AWRC drainage basin.
B	Proposed work plan (Stages 2& 3)

APPENDIX A

Summary of Pilbara Region groundwater resources (Skidmore, 1996)

Geographical Area	Basement rocks			Superficial deposits			Area Totals	
	Area km^2	Storage x 10^6 m^3	Recharge x 10^6 m^3/yr	Area km^2	Storage x 10^6 m^3	Recharge x 10^6 m^3/yr	Storage x 10^6 m^3	Recharge x 10^6 m^3/yr
Port Hedland Coast - Upland area	25428	6527	45	-	-	-	6527	45
Onslow Coast - Upland area	11970	1833	16	1217	2663	5	4496	21
DeGrey River - Upland area	47795	12262	86	971	3641	17	15904	103
Fortescue River - Upland area	44990	10845	66	14307	29549	191	40394	257
Ashburton River - Upland area	75556	7860	53	4212	10324	82	18184	135
Port Hedland Coastal Plain	9101	2240	-	8003	8826	49	11066	49
Onslow Coastal Plain	348	104	-	-	-	-	104	-
Alluvium	-	-	-	8580	3655	56	3655	56
Carnarvon Basin		-	-	8580	19637	-	19637	-
Canning Basin	-	-	-	7587	60852	63	60852	63
PILBARA TOTAL	215188	41672	266	53457	139147	463	**180820**	729

APPENDIX B

PILBARA GROUNDWATER RESOURCE
ASSESSMENT PROJECT

PROPOSED WORK PLAN [Stages 2 & 3]

Project : Regional workshop \ seminar

Tasks		Year 97\98	 98\99
A	Hold a workshop \ seminar at Port Hedland to present Stage 1 findings to interested and affected parties.	x	

Project : Port Hedland - Karratha coastal area

Tasks		Year 97\98	 98\99
A	Develop detail maps of each river area	x	
	Plot all bore data & analyse	x	
	Obtain all WC bore & wellfield data	x	
B	Do a structural analysis (palaeochannels)	x	
	Compilation of structural data - fractured rock areas	x	
	Identify environmentally sensitive issue & areas	x	
	Select 2 or 3 palaeochannel study areas	x	
	Select 2 or 3 waterlevel monitoring areas (recharge ?)	x	
	Select 1 shear \ fault zone in fractured rock area	x	
C	Undertake palaeochannel field studies	x	
	geophysices, drilling, test pumping	x	x
	Do waterlevel monitoring (recharge study)	x	x
	Drill & test pump selected fractured rock area		x
	Investigate environ. sensitive areas and if necessary drill, test pump, model		x
D	Data evaluation & report compilation		x

Project : Fortescue - Robe River area

		Year	
Tasks		**97\98**	**98\99**
A	Collect all data on Pannawonica wellfield & area	x	
	Analyse info. & develop map & conceptual model	x	
B	Identify areas where further drilling is required	x	
	Identify alluvial fans requiring further study	x	
	Select drilling sites	x	
C	Drill and test pump		x
	Evaluate data & record findings		x

Project : Oakover River valley

		Year	
Tasks		**97\98**	**98\99**
A	Develop large scale map of river valley	x	
	Plot all existing bore data & analyse	x	
B	Do basic field verification	x	x
	Select reconnaissance drilling sites	x	x
	Drill & test pump bores		x
C	Evaluate data & record information		x

Project : Ashburton River valley

		Year	
Tasks		**97\98**	**98\99**
A	Develop large scale map of river valley	x	
	Plot all existing bore data & analyse	x	
B	Do basic field verification	x	x
	Select reconnaissance drilling sites	x	x
	Drill & test pump bores		x
C	Evaluate data & record information		x

Project : Regional environmental impact assessment

Tasks		**Year** 98\99	 99\00
A	Identify environmentally sensitive issues	x	
B	Examine issues and areas	x	
C	Develop management strategies	x	x

Project : GIS database development

Tasks		**Year** 98\99	 99/00
A	Data collection	x	
B	Database development	x	x

Project : Product development

Tasks		**Year** 98\99	 99\00
A	Synthesis of all data \ information		x
	Evaluation & strategy development		x
B	Workshopping		x
C	Report & map preparation		x
D	Presentation of products		x

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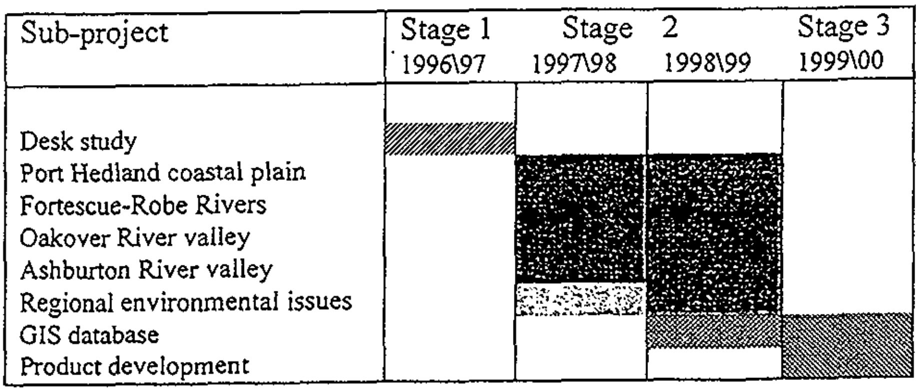

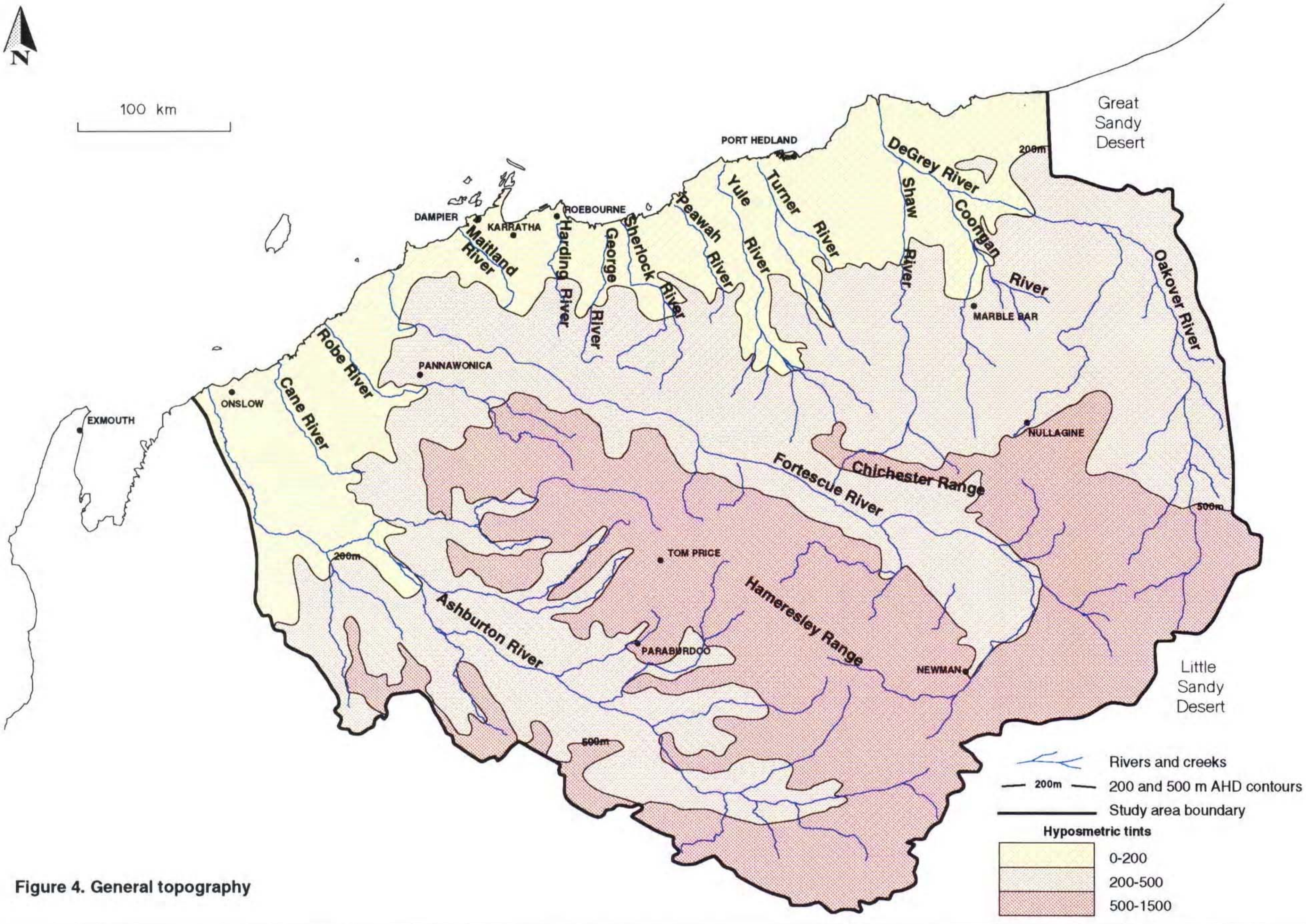

Figure 4. General topography

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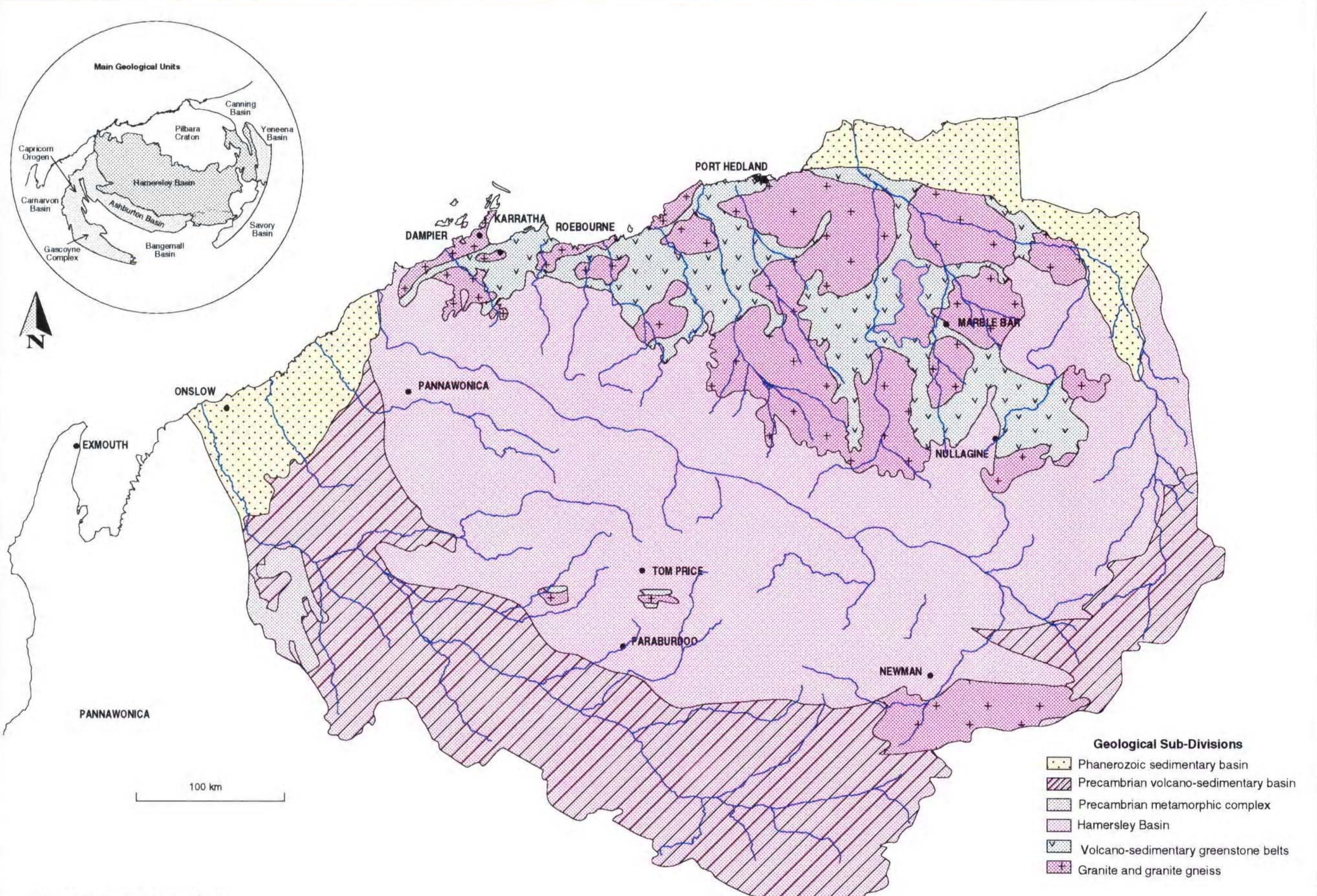

Figure 5. General geology