MANAGING AND PROTECTING WESTERN AUSTRALIA'S MOST VITAL RESOURCE

WATER AND RIVERS
COMMISSION

Hydrogeology Report No. HR 62

GROUNDWATER RESOURCES OF THE PILBARA REGION, WESTERN AUSTRALIA

Summary Report

by

A. Wright

Groundwater Investigation Branch
Water and Rivers Commission
Perth, WA

March 1997

CONTENTS

TABLES

FIGURES

INTRODUCTION

The Pilbara Region is an important area for future economic development. The economic potential of the Pilbara is based primarily on its mineral resources, in particular iron ore, and offshore gas/petroleum. Other industries include agriculture, fishing and tourism. Water is recognised as an essential requirement for future development in this region. Groundwater represents an important source of water in the region and currently provides sustainable water supplies to towns, mining centres, industry and agriculture. In excess of $16 \times 10^6\ m^3/yr$ of groundwater is abstracted at existing Pilbara town/mine water supply schemes (Fig. 1). The most significant abstraction is from alluvial and valley fill aquifers on the coastal plains and within the Fortescue River valley and valleys of the Hamersley Range. Groundwater resources in basement rocks are exploited locally for mining and town supply, as well as infrastructure development. Shallow bores and wells adequately meet the requirements for pastoral supply throughout the region. Groundwater is also essential for the maintenance of ecosystems associated with springs and permanent pools within the drainage systems of the region.

Until the Skidmore report of 1996, no comprehensive, quantitative groundwater resource assessment of the Pilbara Region had been carried out and no regional hydrogeological mapping has, as yet, been undertaken . 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. As a result, the Water Authority of Western Australia (Water Authority) requested the Geological Survey of Western Australia (GSWA) to undertake a reconnaissance appraisal of the groundwater resources. The brief was:

> *to assess and evaluate the available data and make recommendations for future investigations, including exploratory drilling and regional hydrogeological mapping, particularly for 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*". A revision of this report resulted in a more succinct report by Wright (1997) entitled "*Groundwater resources of the Pilbara Region, Western Australia*".

This summary is based on the Skidmore and Wright reports and summarises the most important findings of the initial desk study appraisal.

PHYSIOGRAPHY AND GEOLOGY

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. The Hamersley and Chichester Ranges divide the region into three major river systems : the Ashburton , Fortescue , and DeGrey Rivers (Fig. 2). All rivers are ephemeral, indicating the erratic nature of rainfall, and flow only after heavy rain. Pools and springs commonly remain in the river beds for long periods after the rivers cease to flow. The rivers mostly flow through single well defined channels, but the channels may become braided on the coastal plains where the rivers cross extensive flood plains. Channels are commonly poorly defined near the coast , and many rivers dissipate in tidal creeks and on tidal flats.

The West Pilbara has an arid to semi- arid climate. Average annual rainfall ranges from 200 to 350 mm. Rainfall events are infrequent, irregular and often intense, separated by long dry spells. The most intense falls occur in summer and are often directly related to tropical cyclones. Summer temperatures can rise to 47^0 C resulting in extremely high evaporation rates.

The Pilbara Region has undergone a long geological evolution over a period of about 3500 million years. Precambrian 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 (Fig. 3). Later, sea level changes and subsidence led to the deposition of large Phanerozoic sedimentary basins that overlap the west and northeast margins of the region over small areas . 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 sedimentary basins.

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 surface runoff through Cainozoic deposits. All the geological formations of the Pilbara Region contain some groundwater, but not all represent aquifers. The quantity and quality of the groundwater held in the different aquifers varies greatly and some aquifers are therefore more significant than others. The aquifers in the Pilbara Region have been grouped, according to their characteristics, into four aquifer types as summarised in Table 1 and illustrated in Figure 4.

The prospects of locating large groundwater resources in the Pilbara Region are good (Table 2 and Fig. 5). Approximately 126 000 x 10^6 m^3 of groundwater are held in storage in the Pilbara Region and 660 x 10^6 m^3 are recharged annually. These groundwater resource estimates are only 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 (unconsolidated sediment and chemically deposited rock aquifers), while the fractured rocks contain small quantities of groundwater, but provide the dominant control on groundwater flow direction.

Table 1 : Aquifers of the Pilbara Region.

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

[*Northern catchments* constitutes the area between the Chichester Range and the Port Hedland coastal plain]

* Aquifer potential is based on expected individual bore yields

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

Significant groundwater resources occur in the alluvial aquifers of the coastal plain 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 on the coastal plain, along the Coongan, Shaw, Strelley and Ashburton Rivers, but these are not proven.

Inland, the valleyfill aquifers, comprising alluvium, talus and scree slope deposits, and outwash fans, may contain major groundwater resources, especially if found in conjunction with pisolitic limonite and calcrete. Thick valleyfill sequences may be found in the Fortescue River valley and the valleys of the Hamersley Range. The saturated thickness of the sequence may be greater than 100 m and may form a major aquifer that can be 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 fractured rocks, and the largest supplies are obtained where the basement rocks comprise fractured and cavernous dolomite. Groundwater levels drop within the wellfields during drought periods, but rapidly recover due to recharge during cyclones.

Table 2 : Summary of groundwater resources of the 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	Alluvial	15	16580	12480	106	<1 000	Maj
sediment	Valleyfill	30	19740	43568	291	<1500	Maj
aquifer					397		
Chemically	Calcrete	15	4646	11658	46	5000	Maj
deposited	Pisolitic limonite	10	1419	1127		1500	Maj
rock aquifer					>46		
Sedimentary	Carnarvon Basin						
rock	Yarraloola Conglo	25	6345	18550	-	<1 000	Int
aquifer	Lyons Group	60	550	3300	-	<1 000	Int
	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	Fractured sedimentary						
rock	BIF	20	23070	4015	30	<500	Int
aquifer	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	<500	Min
	Mafic volcanic	10	31170	780	21	<500	Min
	Granitic	35	32490	2840	15	<500	Min
	Greenstone	30	11880	710	5	<500	Min
					157		

Aquifer potential (based on individual bore yields) Major > 500 m^3/day
Intermediate 100-500 m^3/day
Minor < 100m^3/day

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 salinity* and is important for pastoral and some small town requirements. Deposits of mesaform pisolitic limonite can contain significant quantities of fresh to marginal salinity groundwater where the deposits extend for large distances along drainages in the upland areas. However, the aquifers are narrow, have small storage, and large scale abstraction from them will not be sustainable throughout prolonged dry periods without causing large declines in the watertable. The deposits are unsaturated where they occur as mesas.

Calcrete occurs generally along flat reaches of ancestral or existing water courses. The calcrete is often cavernous and can contain large quantities of groundwater,

* Note Salinity as TDS (total dissolved solids)

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

especially where it occurs in conjunction with alluvium and other valleyfill deposits 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 dolomitic basement rocks. However, few data are available to assess the resources of the calcrete in these areas as the saturated thickness is unknown.

Dolomitic formations are prospective for groundwater where they underlie thick sequences of valleyfill in the Fortescue River valley and Hamersley Range. Hydrogeological data from the dolomite formations in the Oakover River and Ashburton River valleys are sparse, but groundwater resources appear quite prospective (Fig. 5). Exploratory field mapping and drilling are, 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. Fresh 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 Lyons Group aquifer 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. Large fresh groundwater resources occur in the Broome Sandstone and Wallal Sandstone aquifers, with prospects for groundwater abstraction greatest in the area northwest of Shay Gap Wellfield. The main constraints imposed on developing these aquifers are the remoteness of the area and quality of the groundwater for potable use. Any wellfields developed, should utilise both the Broome Sandstone and Wallal Sandstone aquifers in order to blend the water and overcome the water quality constraints. Paterson Formation sediments occur in a trough down to 500 m depth, carved into the Pilbara Craton. Few data are available to assess the resources, but the Paterson Formation aquifer may contain large quantities of fresh to saline groundwater under artesian pressure.

Storage and permeability are low in the fractured 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 lithological and hydraulic data. Groundwater flow is largely controlled by geological structures and regional flow systems are mostly absent. The location of high yielding bores in fractured rock aquifers is site specific and dependant on intersecting zones of well developed secondary porosity. The best target for exploration within the igneous rock aquifers is close to intrusive dykes and quartz veins. Large yields may be sustainable in the vicinity of drainages where recharge can occur by infiltration of accumulated 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 fractured rocks will be low, but use of hydrogeological assessments with geophysical surveying will help to increase the success rate. The saturated Cainozoic deposits are in hydraulic connection with the fractured rocks and these should be used conjunctively. Bores should be drilled through the Cainozoic deposits into the fractured rocks where possible, until there is no appreciable increase in yields with depth or the lithology indicates conditions unfavourable for groundwater supply.

Groundwater in the Pilbara Region is mostly potable. However, groundwater can be saline in interfluvial areas on the coastal plains and in the Carnarvon Basin sediments below the Onslow Coastal Plain. Groundwater quality may also be affected in areas where mineralisation or oil and gas accumulation has occurred, close to sites of mineral processing, and in the Broome Sandstone where elevated levels of nitrate have been recorded.

RESOURCE DEVELOPMENT

The greatest future need for groundwater supplies appears to be within the coastal plain at the towns of Port Hedland and Karratha. Current predictions suggest that this area could require 70 x 10^6 m^3 of water per annum by the year 2025 (WRC, 1996). This demand could be met by utilising the groundwater resources contained in the unconsolidated sediment aquifers, in particular those areas where river drainages cross the coastal plain, and the groundwater resources of the valleyfill aquifer of the lower Fortescue River valley. Table 3 is a summary of the groundwater potential for the Port Hedland coastal region. Detailed investigations have identified additional wellfields and wellfield extensions along the Cane, Lower Robe, Lower Fortescue and DeGrey Rivers. Further investigations are required along sections of the Ashburton, upper Robe, Maitland, Yule, Turner, Shaw, DeGrey and Coongan Rivers to confirm these initial estimates. Palaeochannels and abandoned channels represent important groundwater exploration targets and need to be identified and investigated. In the long term, attention will have to turn to the Canning Basin aquifers, especially if significant industrial growth takes place or the proposed irrigation of cotton becomes a reality. Large groundwater resources are available to the northwest and east of Shay Gap Wellfield.

Water supply demand predictions, elsewhere in the Pilbara Region, are relatively insignificant and could be met by extending existing bore fields. Four new mines may be developed in the area between Tom Price and Newman and will obtain water supplies from local aquifers. Similarly, pastoral water supply needs can be met from local aquifers. These will require hard rock drilling techniques and bore depths in excess of 30m.

Development of the groundwater resources may have a direct impact on the environment by lowering the watertable around individual bores and wellfields. The extent of the impact depends on the level of abstraction on the local hydrogeology. Groundwater levels drop during drought periods and rise as aquifers recover as a result of recharge during cyclones. The changing waterlevels and resultant impacts could be better understood and managed if all available data were contained in a GIS database.

Table 3 : 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	50.0	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

CONCLUSIONS AND RECOMMENDATIONS

Groundwater occurs throughout the Pilbara Region and resources are adequate to meet future town, mine and pastoral water supplies. Some reconnaissance field work would be needed in inland localities to enable a complete regional groundwater resource assessment. Further work is also required to define the sustainable yield of the Port Hedland coastal plain. Indications are that the unconsolidated sediment aquifers have adequate resources to meet the water demand expected from the industrial growth predicted for Port Hedland and Karratha. Additional field verification is necessary along some of the rivers. Should these investigations prove that the resources are inadequate then the groundwater resources of the Canning Basin will need to be utilised.

Attention also needs to be given to environmental and management issues. The extensive mining operations and increasing 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 the environmental issues that exist for each type of activity in order to formulate an environmental protection strategy for the groundwater resources in the region.

Groundwater will be a key resource in the development of the Pilbara Region and must be managed sustainably. The Water Corporation will probably continue to be the single largest supplier of urban and industrial water, particularly with regard to the coastal area. The Region, however, has a multitude of potential water users and cooperation is required between supplier, regulator and consumer to achieve efficient, sustainable and equitable utilisation and management of the groundwater resources. The Skidmore (1996) and Wright (1997) reports are important steps toward developing sound groundwater management policies and practices and represent 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.

The project brief also required that recommendations be made for future investigations, including exploratory drilling and regional hydrogeological mapping, particularly for those areas with potential for large groundwater supplies, but for which little data are available.

In order to complete a comprehensive groundwater assessment of the Region it will be necessary to undertake further hydrogeological investigations 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.

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 thus recommended that :

1. A regional study be undertaken 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. Undertake a number of additional investigations in order to obtain a more comprehensive understanding of regional groundwater resources :

- 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 drainage's traversing dolomitic formations. Potential exploration areas lie along Wannery Creek, Ethel River and the upper reaches of the Ashburton River.

- An assessment of the potential environmental impact that the various mining and industrial activities may have on the different aquifers should be carried out.

- A GIS database should be developed for the Region to bring all information together as it is produced to provide a clear and evolving picture of the Regions groundwater resources.

- Further investigate the groundwater potential within the Canning Basin east of the Shay Gap Wellfield.

Implementation of these recommendations would enable the State 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. Appendix A contains a brief outline of the full work programme required to accomplish this.

REFERENCES

Skidmore, D.J.P., 1996, Groundwater resources of the major catchments in the Pilbara Region, Western Australia: Water and Rivers Commission Hydrogeological Report 35 (unpublished).

Water and Rivers Commission, 1996, Pilbara Region water resources review and development plan 1996: Water and Rivers Commission Report WRAP 4 .

Wright, A., 1997, Groundwater resources of the Pilbara Region, Western Australia: Water and Rivers Commission Hydrogeological Report HR 61 (unpublished).

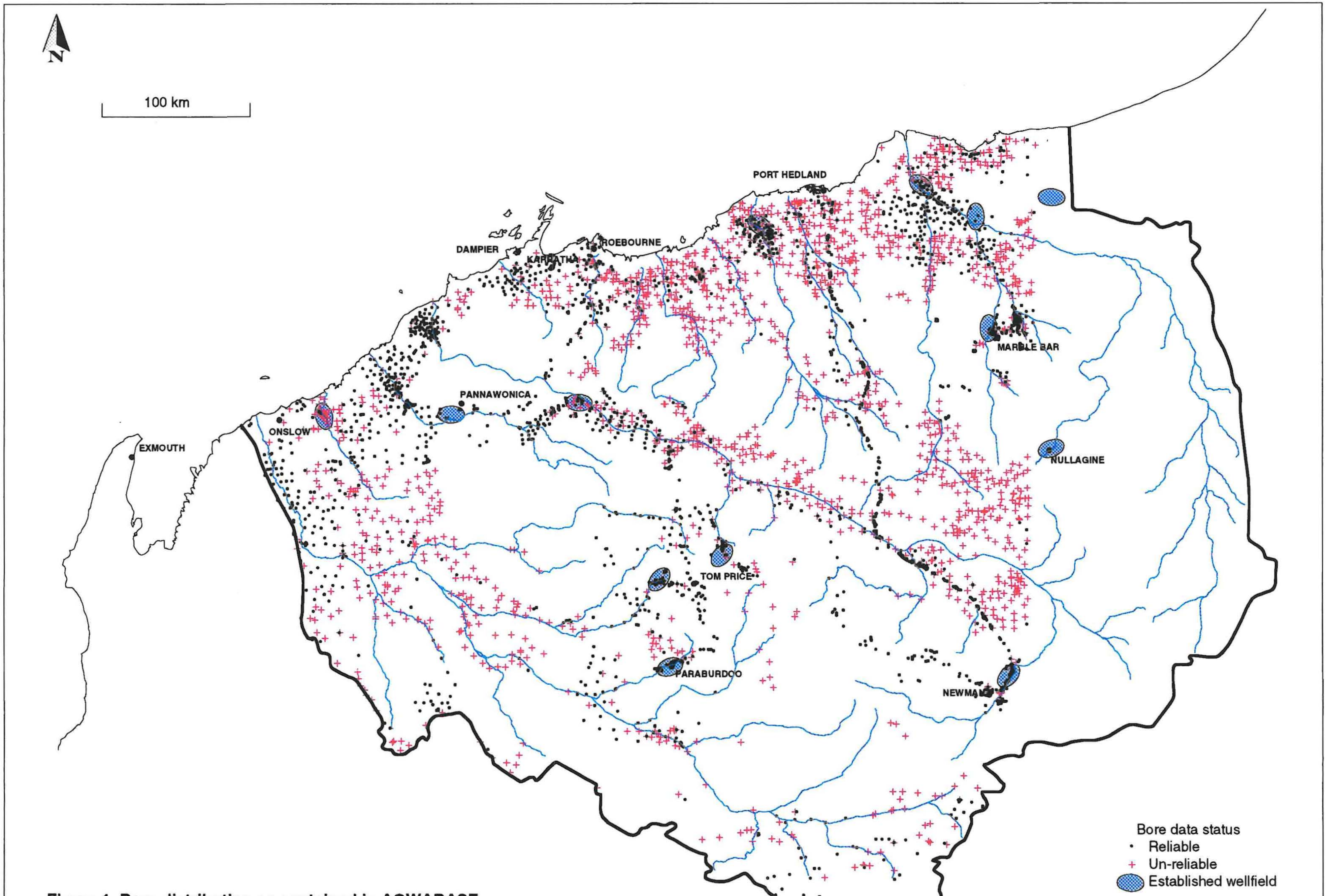

Figure 1. Bore distribution as contained in AQWABASE and major groundwater supply schemes

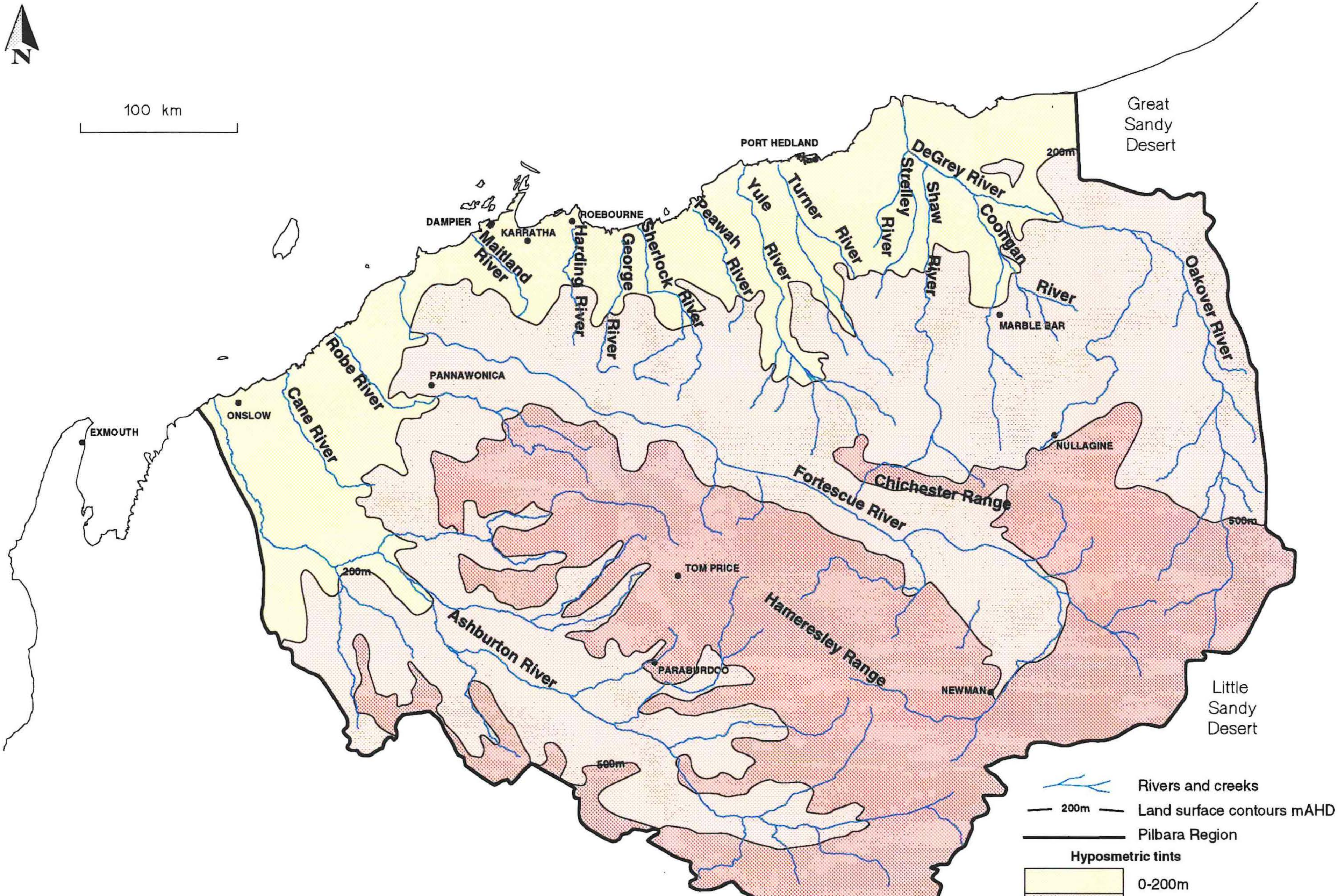

Figure 2. General topography

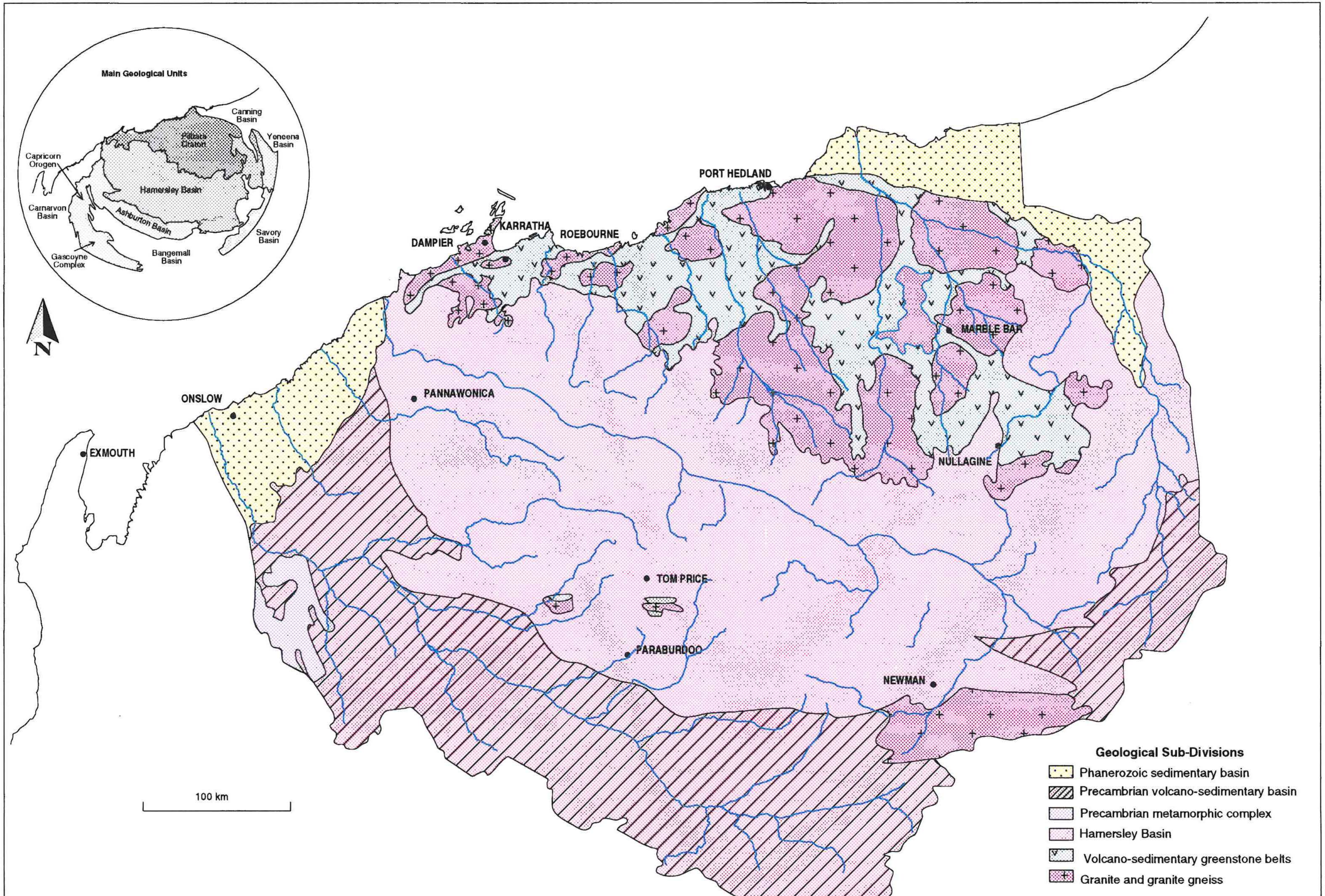

Figure 3. General geology

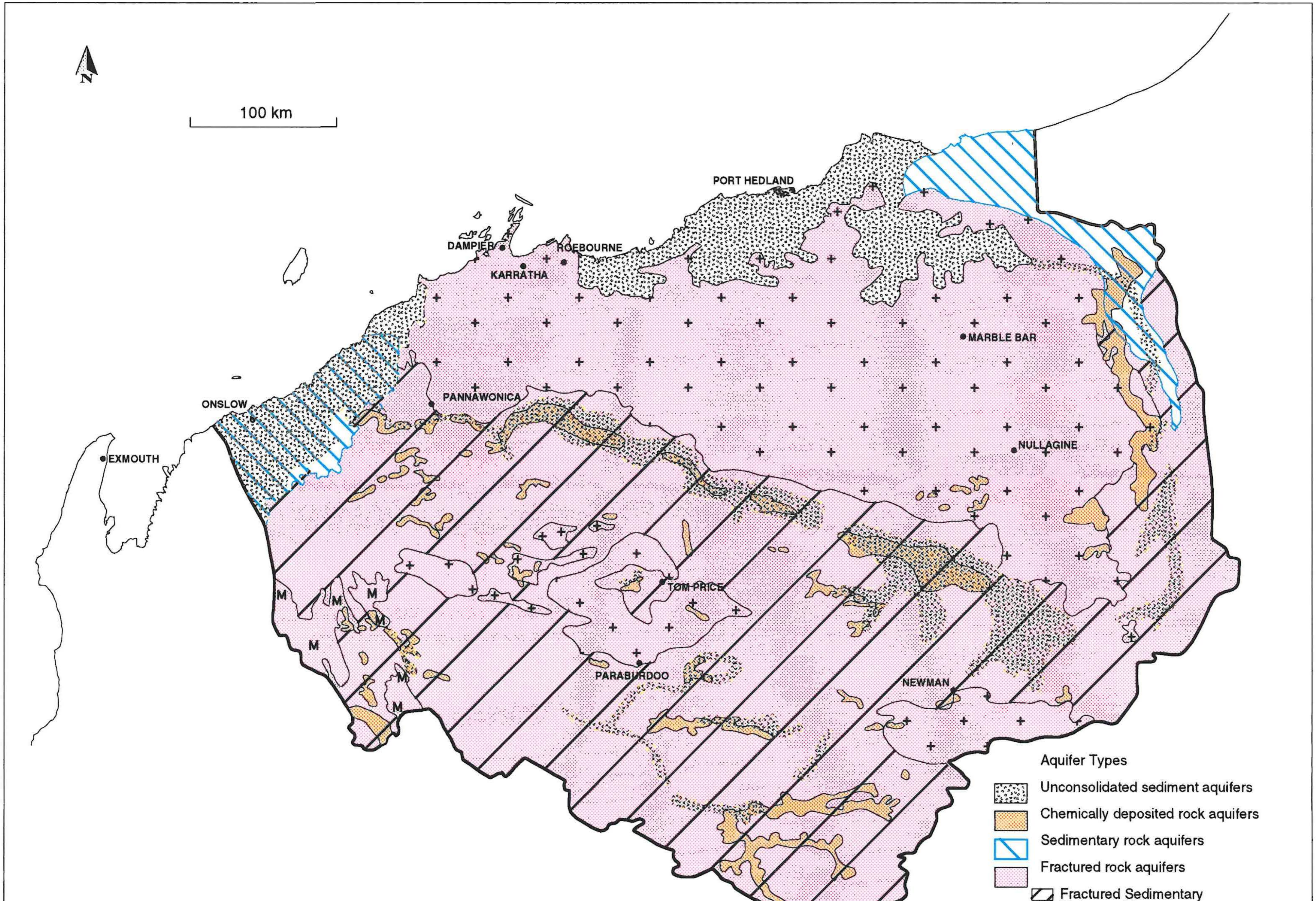

Figure 4. Distribution of major aquifer types (Table 4)

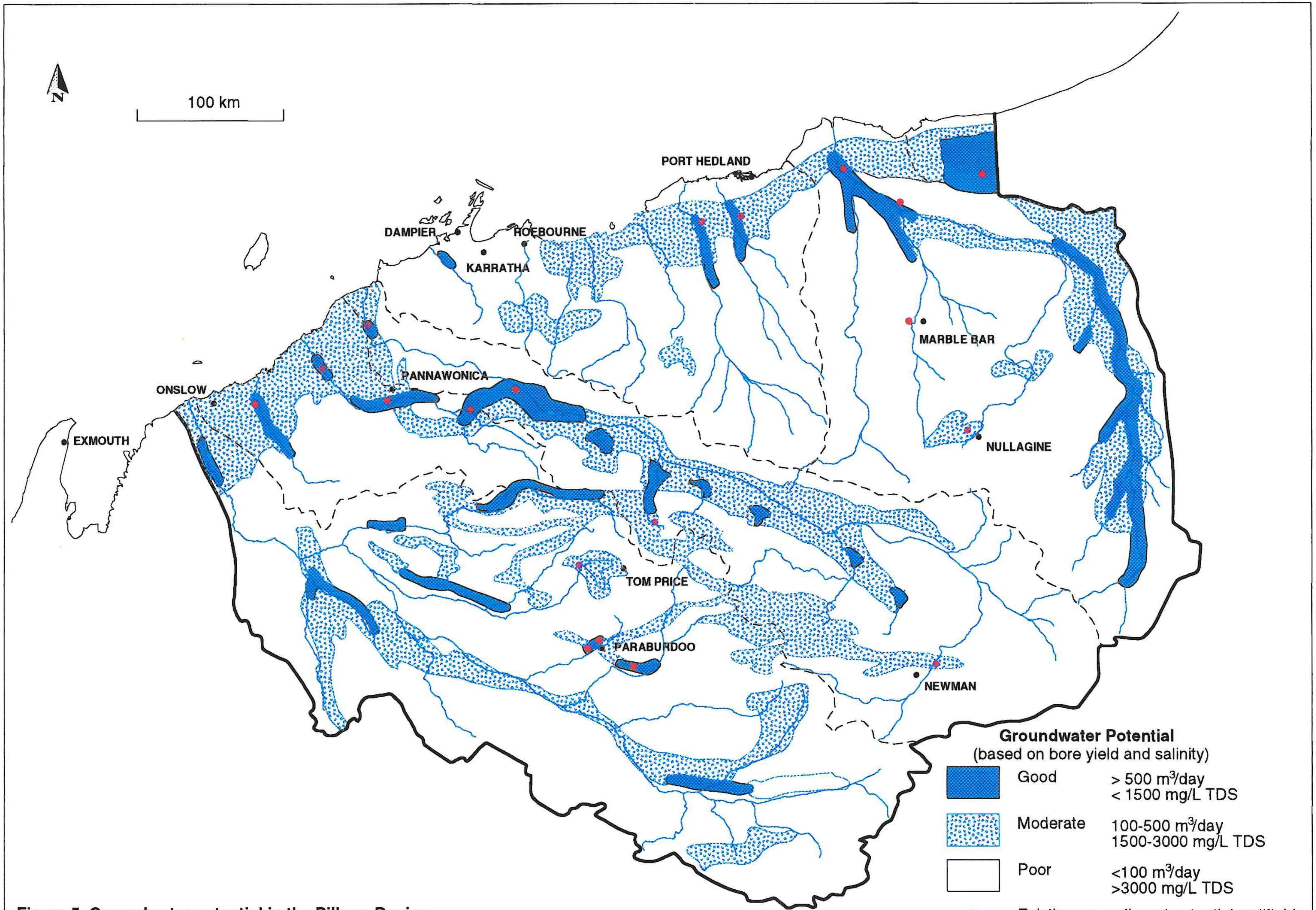

Figure 5. Groundwater potential in the Pilbara Region

APPENDIX A

PILBARA GROUNDWATER RESOURCE
ASSESSMENT PROJECT

PROPOSED WORK PLAN [Stages 2 & 3]

Note : The timelines are notional and will depend on establishment of priorities and sources of funding. The staging below would be the fastest to gain a full Regional understanding of groundwater resources.

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

Tasks		**Year** 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

Tasks		**Year** 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

Tasks		**Year** 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

GANTT CHART