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## Groundwater prospectivity in the Midlands area

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# Groundwater Prospectivity In the Midlands Area

*A Water for Food project*



# Groundwater Prospectivity

## In the Midlands Area

*A Water for Food project*

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For

Department of Water and Environmental Regulation



Government of **Western Australia**  
Department of **Water and Environmental Regulation**

June 2018

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# Contents

Summary.....	i
1 Background.....	1
2 Assessment methodology .....	3
2.1 Approach used in resolving 3-D hydrogeological complexity .....	3
2.2 Methodology.....	3
3 Aquifer framework.....	6
3.1 Superficial aquifer.....	7
3.2 Mirrabooka aquifer .....	7
3.3 Kardinya Shale .....	8
3.4 Leederville aquifer .....	8
3.5 South Perth Shale .....	8
3.6 Parmelia aquifer .....	9
3.7 Otorowiri Formation.....	9
3.8 Yarragadee aquifer.....	9
3.9 Cadda and Cattamarra Formations .....	10
3.10 Eneabba Formation, Lesueur Sandstone and Woodada Formation .....	10
3.11 Kockatea Shale .....	10
3.12 Permian formations .....	10
3.13 Outside of the basin .....	11
4 Aquifer yield potential.....	20
5 Salinity .....	28
6 Depth to groundwater.....	35
7 Groundwater prospectivity .....	42
8 Level of confidence .....	50
9 Conclusions .....	58

## Tables

Table 3-1 Stratigraphic succession and hydrostratigraphic units. ....	12
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## Figures

Figure 1-1 Water for Food Midlands project area.....	2
Figure 2-1 Methodology flow diagram. ....	5
Figure 3-1 Geology at the watertable depth slice. ....	14
Figure 3-2 Geology at the 100 m depth slice.....	15
Figure 3-3 Geology at the 250 m depth slice.....	16
Figure 3-4 Geology at the 500 m depth slice.....	17
Figure 3-5 Geology at the 750 m depth slice.....	18
Figure 3-6 Geology at the 1000 m depth slice.....	19
Figure 4-1 Yield potential at the watertable. ....	22
Figure 4-2 Yield potential at the 100 m depth slice. ....	23
Figure 4-3 Yield potential at the 250 m depth slice. ....	24

Figure 4-4 Yield potential at the 500 m depth slice. ....	25
Figure 4-5 Yield potential at the 750 m depth slice. ....	26
Figure 4-6 Yield potential at the 1000 m depth slice. ....	27
Figure 5-1 Groundwater salinity at the watertable. ....	29
Figure 5-2 Groundwater salinity at the 100 m depth slice. ....	30
Figure 5-3 Groundwater salinity at the 250 m depth slice. ....	31
Figure 5-4 Groundwater salinity at the 500 m depth slice. ....	32
Figure 5-5 Groundwater salinity at the 750 m depth slice. ....	33
Figure 5-6 Groundwater salinity at the 1000 m depth slice. ....	34
Figure 6-1 Depth to watertable. ....	36
Figure 6-2 Water level depth for the 100 m depth slice. ....	37
Figure 6-3 Water level depth for the 250 m depth slice. ....	38
Figure 6-4 Water level depth for the 500 m depth slice. ....	39
Figure 6-5 Water level depth for the 750 m depth slice. ....	40
Figure 6-6 Water level depth for the 1000 m depth slice. ....	41
Figure 7-1 Prospectivity chart. ....	43
Figure 7-2 Groundwater prospectivity at the watertable. ....	44
Figure 7-3 Groundwater prospectivity for the 100 m depth slice. ....	45
Figure 7-4 Groundwater prospectivity for the 250 m depth slice. ....	46
Figure 7-5 Groundwater prospectivity for the 500 m depth slice. ....	47
Figure 7-6 Groundwater prospectivity for the 750 m depth slice. ....	48
Figure 7-7 Groundwater prospectivity for the 1000 m depth slice. ....	49
Figure 8-1 Bore and well distribution for the watertable depth slice. ....	52
Figure 8-2 Bore and well distribution for the 100 m depth slice. ....	53
Figure 8-3 Bore and well distribution for the 250 m depth slice. ....	54
Figure 8-4 Bore and well distribution for the 500 m depth slice. ....	55
Figure 8-5 Bore and well distribution for the 750 m depth slice. ....	56
Figure 8-7 Bore and well distribution for the 1000 m depth slice. ....	57

# Summary

Hydrogeological mapping completed as part of this project represents groundwater resource prospectivity for irrigated agriculture in the Midlands project area. There has been no previous attempt to develop a groundwater prospectivity layer for the groundwater resources in Western Australia. As such, an original methodology has been progressively developed following ongoing discussion and review. This document provides an explanation of each digital layer and how the presented information may be used / interpreted.

Hydrogeological cross sections in the northern Perth Basin Bulletin were assessed using a preliminary criterion including aquifer type, salinity and depth to provide an indication of groundwater prospectivity. There were significant challenges and complexities in the resolving each criterion, especially representing the 3-D perspective; as such, it was decided to develop the data into depth slices that represent the near watertable conditions, then at depths of 100 m, 250 m, 500 m, 750 m and 1000 m below ground level.

The focus was to resolve the physical / hydrogeological attributes associated with the groundwater resource being hydrostratigraphy (major and minor aquifer types and aquitards), groundwater salinity, aquifer yield potential and depth to watertable. Anthropogenic attributes such as resource allocation and GDEs could be assessed subsequently as additional constraints to pumping groundwater.

The hydrostratigraphy was compiled as the first dataset and is based on the interpretations presented in the *Northern Perth Basin: Geology, Hydrogeology and Groundwater Resources* (referred to as the 'Bulletin'). Additional data from more recent groundwater resource assessments were also included. The objective of the interpretation was to accurately map the distribution and extent of the major aquifers, minor aquifers, and aquitards throughout the project area.

Geological units were classified according to the dominant lithology of the formation into four classifications of aquifer yield potential, being: high, moderate, low and very low. Most formations are sufficiently uniform, so that they conform to a single yield classification. Several formations have lithologies that vary across the basin, and have been divided into two or more yield zones. These formations include the Leederville Formation, where the Wanneroo Member is different to the Pinjar and Mariginiup Members; Carnac Formation of the Parmelia Group; and Yarragadee Formation Unit D.

The salinity contours developed in the Bulletin are used for each aquifer, but have been adapted where appropriate. For most aquifers, groundwater salinity is sufficiently uniform vertically through each unit that spatial mapping of groundwater salinity from the Bulletin can be applied to the full thickness. There is a general regional trend of increasing groundwater salinity with greater depth through the Yarragadee Formation and Carnac Formation, although salinity decreases with depth beneath parts of the Arrowsmith Region north of Badgingarra through Unit D of the Yarragadee Formation.

Watertable elevations for the superficial / unconfined aquifers and potentiometric heads for the confined aquifers were mapped within the Bulletin. The depth to groundwater across the project area was estimated using a DEM compared to the water level elevation. Areas of deeper groundwater are more expensive to drill and pumping costs are higher and increasingly uneconomic with greater depth.

Prospectivity for each depth slice was derived by combining the yield, salinity and water level depth classifications. Yield and salinity prospectivity has been derived, before being adjusted for the depth to water level. Figure S-1 shows the combined groundwater prospectivity for all depth slices representing the best prospectivity for any locality within the project area.

The resultant dataset will be useful for landowners and developers highlighting the opportunities and risks for accessing groundwater resources. It is envisaged that the final groundwater prospectivity and HQAL datasets will be combined to identify land parcels with suitable water and soil conditions across the entire project area. There is also scope for the dataset to be populated into the on-line regional GIS mapping tool (refer to <http://narvis.com.au/>) developed by Northern Agricultural Catchment Committee (NACC).

Groundwater Prospectivity in the Midlands area

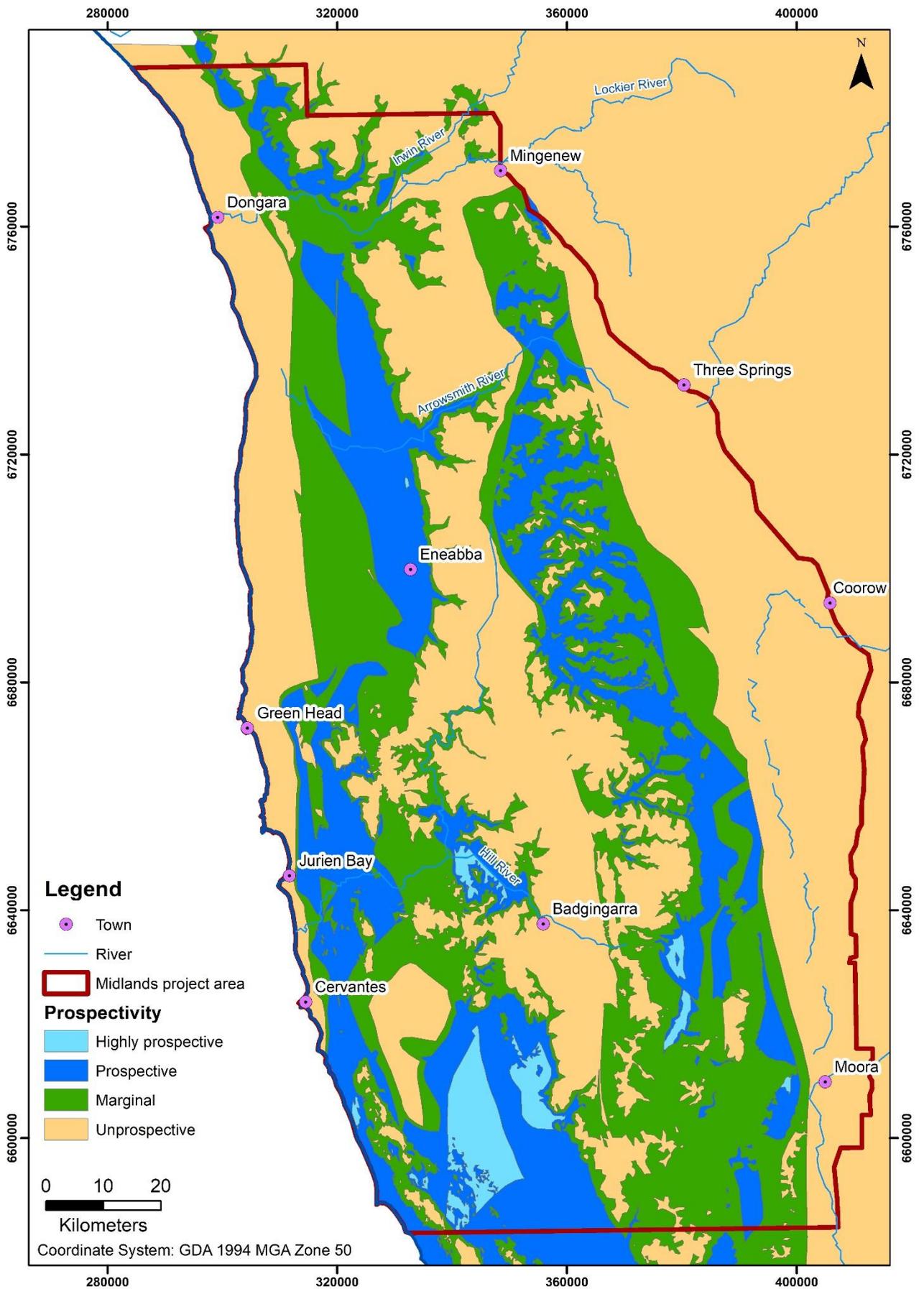


Figure S-1 Combined groundwater prospectivity for all depth slices.

# 1 Background

As part of the Water for Food Midlands project (Figure 1-1), Department of Primary Industries and Regional Development (DPIRD) is undertaking mapping of high-quality agricultural land (HQAL) to identify areas of agricultural value. This mapping utilises data relating to soils, land capability and rainfall, that is being integrated into a GIS-format that is easy to comprehend and can be incorporated into the planning process.

This report details the development and results of a GIS-based product that represents groundwater resource prospectivity for irrigated agriculture in the Midlands project area. The output maps will be useful for landowners and developers highlighting the opportunities and risks for accessing groundwater resources. It is envisaged that the final groundwater prospectivity and HQAL datasets will be combined to identify areas with suitable water and land conditions for irrigated agriculture.

There has been no previous attempt to develop a groundwater prospectivity layer for groundwater resources in Western Australia. As such, this methodology has been progressively developed with ongoing discussion and review between Hydrogeoscience, Hydroconcept and Department of Water and Environmental Regulation (DWER).

The primary reference for this work is the recently published northern Perth Basin Groundwater Bulletin entitled *Northern Perth Basin: Geology, Hydrogeology and Groundwater Resources* (Department of Water, 2017) (referred to here as the 'Bulletin') and associated digital data. Recent unpublished investigations from the DWER have provided further refinement in selected areas. For details on the physiography, geology and hydrogeology in the Midlands area, it is recommended to reference the Bulletin.



Figure 1-1 Water for Food Midlands project area.

## 2 Assessment methodology

### 2.1 Approach used in resolving 3-D hydrogeological complexity

It was recognised that representing 3-dimensional complexity of the North Perth Basin hydrogeology by 2-dimensional maps and spatial datasets was problematic. The use of discrete depth slices below ground level offered the best approach of evaluating hydrogeological attributes of aquifer type, salinity and water level depth, and the presentation of groundwater prospectivity. Depth slices were selected to represent the near watertable conditions, then depths of 100 m, 250 m, 500 m, 750 m and 1000 m below ground level. A Digital Elevation Model (DEM) representing ground level was used to generate surfaces representing each of the depth slices by subtracting each depth interval from the DEM. These depth slices were used in subsequent analysis.

The conditions at the watertable are important, as this is the first groundwater encountered at any horticultural development and groundwater resource management is largely focused on impacts at the watertable. This slice is unique in that it does not represent conditions at a particular depth below ground level.

The depths of 100 m, 250 m and 500 m were selected, as most groundwater abstraction and bores constructed by small to medium-sized horticultural developments are within the upper 500 m of the groundwater resource. Whilst, larger horticultural developments often access groundwater from deeper bores between 500 m and 1000 m. Conditions below 1000 m were not considered, as there is limited development of groundwater resources for horticulture beyond this depth.

### 2.2 Methodology

GIS analysis was used for mapping and comparing attributes across a 100 m raster grid that covers the project area utilising interpretations from the Bulletin. The prospectivity layer for each depth slice is a merged dataset, which combines hydrogeological attributes important for groundwater prospectivity in irrigated agriculture. These are aquifer yield potential, groundwater salinity, and depth to water. It should be noted that the watertable slice is the only one that incorporates the superficial formations beneath the coastal plain, as they are relatively thin and rarely exceed 100 m thickness. A methodology flow diagram for the derivation of groundwater prospectivity is given by Figure 2-1. The final derived datasets were converted to a vector format for presentation purposes.

The initial stage of groundwater prospectivity mapping required the development of an aquifer framework utilising the distribution of geological formations at each depth slice. Geological formations were classified into four aquifer yield potential types according to the dominant lithology of the formation, ranging from high to very low. Groundwater salinity and water level depth were also classified into four categories for each depth slice from very good to unsuitable (or highly prospective to not prospective). Further discussion on treatment of each of the hydrogeological attributes is covered in Chapters 3 to 6.

Groundwater prospectivity for each depth slice has been derived by combining the aquifer yield potential, salinity and water level depth classifications. The least desirable classification of each hydrogeological attribute determines the groundwater prospectivity.

For example, if salinity and yield potential are in the most suitable class but depth to water is in the least favourable class then the prospectivity for that cell will be the least desirable category (unsuitable). This methodology is applied to each depth slice to produce a groundwater prospectivity map for each depth slice. Combining the results from the six depth slices using the best prospectivity score from each depth provides an overall map that displays the best prospectivity available at a particular location. Chapter 7 provides further detail and the resultant prospectivity maps for each depth slice and the combined prospectivity.

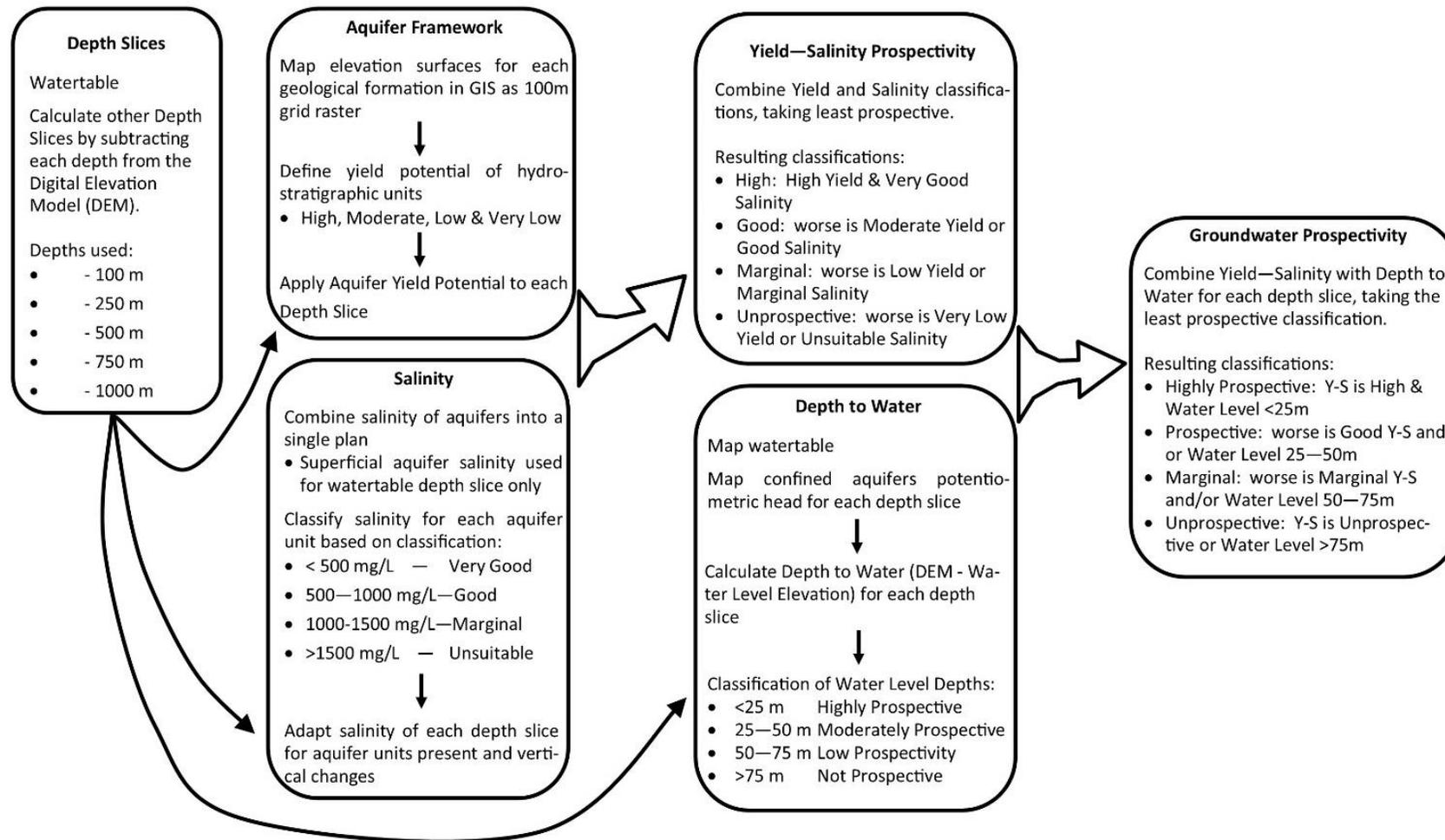


Figure 2-1 Methodology flow diagram.

### 3 Aquifer framework

Resolution of the geological formations making up the hydrostratigraphy was an obvious initial stage for groundwater prospectivity mapping, as this was the strongest element of our understanding. Mapping of the distribution and basal elevations of the geological formations is based on interpretations presented in the Bulletin with additional data from more recent groundwater resource assessments at Allanooka (Schafer, 2016) and North Gingin (Tuffs, 2016). Throughout the project area the extent of geological formations for each depth slice has been calculated using GIS by comparing the depth slice elevation raster file with the basal elevations of the geological formations. Surficial units were not incorporated, including palaeochannel deposits and the Yallalie Basin upon the Dandaragan Plateau, owing to their limited, shallow extent and poorly understood properties.

Each geological formation represents a hydrostratigraphic unit forming either a major aquifer, minor aquifer or aquitard. There were opportunities for further differentiation of the hydrostratigraphy in terms of major and minor aquifers. This is the case the superficial aquifer being separated into the Tamala Limestone and Bassendean Sand; as well as differentiating parts of the Yarragadee Formation.

There were some obvious groupings based on aquifer development potential being:

- Separation of the aquitards (with no groundwater prospectivity) – these include the Kockatea, Otorowiri, South Perth and Kardinya Shales;
- Permian aquifers were mapped as having low potential yields - despite some local aquifers; these aquifers are however unprospective as they are typically saline and unsuitable for irrigation developments;
- Cadda Formation and Cattamarra Coal Measures are grouped into a single hydrostratigraphic unit;
- Eneabba Formation and Lesueur Sandstone form a hydrostratigraphic unit;
- Units A, B and C of the Yarragadee aquifer are grouped together;
- Unit D of the Yarragadee aquifer is mapped separately owing to its poorer aquifer potential relative to the deeper Yarragadee Formation units;
- Leederville Formation and Parmelia Group are mapped separately owing to the poor aquifer potential of the Carnac Formation in the Parmelia Group;
- The surficial aquifers on the Dandaragan Plateau have not to be included, as they are thin localised systems;
- Superficial formations are mapped as a single unit but are subdivided based on distribution of the Tamala Limestone and Bassendean Sand for yield potential.

Following are more detailed descriptions of each hydrostratigraphic unit including the interpretation methodology and assumptions. The stratigraphic succession and its relationship with the hydrostratigraphy is summarised in Table 3-1, and the geology mapped for each of the depth slices is presented by Figures 3-1 to 3-6.

### 3.1 Superficial aquifer

The superficial aquifer is a laterally extensive but relatively thin unconfined aquifer extending throughout the Swan Coastal Plain found over the western portion of the northern Perth Basin between Geraldton in the north, Gingin in the south and bound by the Gingin Scarp to the east. The major water-yielding formations are the Tamala Limestone, Bassendean Sand, and Yoganup and Ascot Formations. The Guildford Formation is a thin shallow unit that is mostly unsaturated and typically sandy in this part of the basin, and has therefore been grouped with the Bassendean Sand. The Ascot and Yoganup Formations present beneath parts of the inland portion of the coastal plain are also grouped with the Bassendean Sand. Interbedded clay layers within the formations beneath the eastern portion of the Swan Coastal Plain form local aquitards, creating a multi-layered groundwater flow system.

These formations have a cumulative thickness typically of 20 to 30 m, with a maximum saturated thickness of about 60 m west of Regans Ford. The superficial formations are commonly unsaturated along their inland margin, and are also unsaturated south-east of Cervantes in the Nambung National Park area, where the watertable is within the underlying Lesueur Sandstone.

The superficial aquifer has been mapped as one hydrostratigraphic unit but separated into three distinct units in terms of its aquifer yield potential being Tamala Limestone with high yield; Bassendean Sand with moderate yield, and where the saturated thickness is just a few metres it is attributed a low yield potential. The separation was based on the surface geological mapping by Geological Survey of Western Australia (GSWA) and adopted in the Bulletin.

The dataset for the superficial aquifer is only represented in the hydrostratigraphic mapping at the watertable, as it is too thin for considering in the other depth slices.

### 3.2 Mirrabooka aquifer

The Mirrabooka aquifer is a relatively thin, sandy, semi-confined aquifer within the Mirrabooka Member of the Osborne Formation, including the Molecap and Poison Hill greensands, where these are in hydraulic connection. It is present in the eastern half of the northern Perth Basin between Coorow and Gingin, and extends southward into the Perth region, but its distribution is discontinuous. The thickness of the Mirrabooka aquifer is generally less than 50 m, but was found to be up to 90 m near the Muchea Fault. Generally, the thickness of the aquifer decreases towards the Gingin Scarp. Perched groundwater may exist within the aquifer and saturated sand beds are often discontinuous.

The Mirrabooka aquifer has been mapped as one hydrostratigraphic unit that includes the Molecap and Poison Hill Greensands, Gingin Chalk, and Mirrabooka Member of the Osborne Formation. There is some uncertainty about its distribution and depth owing to the limited number of bores that fully penetrate these hydrostratigraphic units. It is assigned as a low yield potential, although this could be moderate where sufficiently thick intervals of the Mirrabooka Sand are present.

The Mirrabooka aquifer is considered an important minor aquifer that has not been fully resolved. It is recommended that further investigations are undertaken to better understand its distribution.

### 3.3 Kardinya Shale

The Kardinya Shale Member forms an aquitard that is present in the southern portion of the project area. It consists of moderately to tightly consolidated, interbedded siltstone and shale with minor thin interbeds of fine- to medium-grained sandstone. It is present in the west beneath the coastal plain, and in the east adjacent to the Gingin Scarp where it occupies a north–south elongate trough stretching from Gingin to north of Moora. The average intersected thickness is about 80 m, but may be up to 235 m north-west of Moora. It has very low yield potential.

### 3.4 Leederville aquifer

The Leederville aquifer is a major multilayered aquifer of sandstone, siltstone and shale below the coastal plain and southern Dandaragan Plateau. The aquifer consists of the Leederville Formation and the Henley Sandstone Member of the Osborne Formation (where present). Within the Pinjar and Mariginiup Members of the Leederville Formation about half of the aquifer consists of sandstone, although parts of the sandstone are clayey.

The Leederville aquifer extends from south of Cataby in a southerly direction towards the Perth region. The Leederville and Leederville–Parmelia aquifers are hydraulically connected across the Gingin Scarp. However, in this transition zone, the Leederville Formation is thin and comprises the less permeable Mariginiup Member, which limits groundwater flow between these two aquifers.

Groundwater within the Leederville aquifer is confined by the overlying Kardinya Shale Member, which forms an aquitard beneath the western and central parts of the coastal plain south of Lancelin. Where the Kardinya Shale Member is absent, the Leederville aquifer is hydraulically connected with the overlying superficial aquifer.

The Leederville aquifer has been mapped as one hydrostratigraphic unit but is separated into the three distinct units in terms of aquifer yield potential. The Pinjar and Mariginiup Members have been assigned low aquifer yield potential, while the Wanneroo Member has a high yield potential.

Data used in the interpretation was primarily from the GSWA drill hole lines, Red Gully investigation bores and recent groundwater investigations at North Gingin. There was limited data in the southeast, south of Moora, which prevented full resolution of the Leederville aquifer. There are also some data points with questionable depth information, which required additional interpretation and assumptions.

### 3.5 South Perth Shale

The South Perth Shale is a significant aquitard that consists mainly of thinly bedded, grey, brown-black or black siltstone and shale, with minor thin sandy and calcareous beds. It is present beneath the coastal plain south of Nilgen Swamp but does not appear to occur east of the Gingin Scarp. The average intersected thickness is about 64 m, with a maximum thickness of up to 180 m. It has a low yield potential.

### 3.6 Parmelia aquifer

For this assessment, the Parmelia aquifer includes the Charlotte Sandstone and Jervoise Sandstone in the northern and central parts of the Dandaragan Plateau, and Carnac Formation in southern parts of the Dandaragan Plateau. The Charlotte Sandstone and Jervoise Sandstone are sandy formations that have high aquifer yield potential, while the Carnac Formation has low aquifer yield potential.

The Parmelia aquifer thickens eastward from the margin of Otorowiri Formation outcrop, reaching a maximum thickness of about 1300 m west and south of Moora, but elsewhere it is generally between 300 and 500 m thick. There is a need to better resolve the Carnac Formation to the south of the Agaton Borefield, as there is a noticeable increase in salinity and increase in clayey portion.

### 3.7 Otorowiri Formation

The Otorowiri Formation is a significant aquitard that separates the Leederville-Parmelia and Yarragadee aquifers. It comprises shale and siltstone with minor thin beds of fine-grained sandstone. The formation thickens southward to 102 m in Eneabba Line EL2A. To the south of the Eneabba Line, the formation is less distinct and difficult to distinguish from overlying shale of the Carnac Formation. It has a very low yield potential.

### 3.8 Yarragadee aquifer

The Yarragadee aquifer is the largest regional aquifer in the northern Perth Basin, containing a great thickness of low-salinity groundwater. It includes the Yarragadee Formation and the hydraulically-connected Gage Sandstone, which overlies the Yarragadee Formation in the south.

The Yarragadee aquifer consists of a multilayered sequence of sandstone beds with very fine to very coarse grained and granule-sized quartz sand that are often feldspathic with variable amounts of matrix clay, and interbedded siltstone, shale and claystone. There are four sub-units within the Yarragadee Formation that have distinctive lithologies: units A and C are predominantly unconsolidated sandstone, while units B and D are predominantly siltstone, shale and claystone with sandstone beds.

The Yarragadee Formation has been separated into two hydrostratigraphic units. Units A, B and C are combined owing to their high aquifer yield potential, and Unit D has a low to moderate aquifer yield potential due to its higher clay portion. Although Unit B can be dominated by clay and silt lithology, it does contain thick sand intervals that are highly productive for water.

There has been some revision of the Yarragadee Formation to incorporate more recent drilling data at Allanooka (Schafer, 2016) and North Gingin (Tuffs, 2016), in particular the lithological and groundwater salinity data. This has resulted in some revision to the base of the Yarragadee Formation (Unit A) and Unit D from that in the Bulletin.

There is some variability in the lithological nature of Unit D in central eastern parts, otherwise the Yarragadee Formation is well resolved and uniform over large areas.

### 3.9 Cadda and Cattamarra Formations

The Cattamarra Coal Measures consist of interbedded sandstone, carbonaceous siltstone and claystone. The Cadda Formation contains predominantly sandstone and siltstone in upper parts and clay/shale in lower parts. The substantial layers of clay and siltstone confine water-bearing horizons.

The Cadda and Cattamarra Formations form one hydrostratigraphic unit owing to their lithological similarities, and are assigned moderate yield potential. These formations have an extent within the upper 1000 m limited to the central western portion, where it separates the Yarragadee and Lesueur Formations.

### 3.10 Eneabba Formation, Lesueur Sandstone and Woodada Formation

The Eneabba Formation comprises sandstone with interbedded siltstone and claystone. The Lesueur Sandstone is comprised predominantly of fine to very coarse-grained quartz sand; whereas the Woodada Formation comprises fine-grained sandstone interbedded with siltstone.

On the Beagle Ridge and western portion of the Cadda Terrace, the aquifer contains fresh groundwater within the Lesueur Sandstone extending 100 km north of Wedge Island and up to 18 km wide, bound by the Cattamarra Coal Measures or Eneabba Formation in the east and the Kockatea Shale to the west. The aquifer also extends through most of the basin at depth confined beneath the Cattamarra Coal Measures.

The Eneabba Formation, Lesueur Sandstone and Woodada Formation form one hydrostratigraphic unit. It has a moderate yield potential, while in the Lesueur Sandstone it also has a moderate yield potential for depths less or equal to 250 m, but considered to have low yield potential for depths of greater than 250 m. The lower yield potential for greater depths is the result of increasing degree of sandstone cementation reducing aquifer permeability.

### 3.11 Kockatea Shale

The Kockatea Shale is a significant aquitard comprising light grey and greenish grey to black, micaceous shale, with minor siltstone and sandstone. It is widespread throughout the northern Perth Basin, extending as subcrop beneath the superficial formations along the coast from Wedge Island in the south to Leeman in the north. It has very low yield potential.

### 3.12 Permian formations

The Permian formations include, in order of deposition, the Nangetty Formation, Holmwood Shale, High Cliff Sandstone, Irwin Coal Measures, Carynginia Formation and the Wagina Sandstone. Generally, the Nangetty Formation, High Cliff Sandstone, Irwin Coal Measures and Wagina Sandstone form aquifers, while the Carynginia Formation and Holmwood Shale form aquitards.

For this assessment, all Permian formations have been combined into one hydrostratigraphic unit with low yield potential. Some minor aquifers are present, but typically groundwater salinity is poor, unsuitable for horticultural purposes and of a low prospectivity. In addition, the aquifer distribution is poorly resolved.

### 3.13 Outside of the basin

The Yandanooka / Moora Groups and crystalline basement are two hydrostratigraphic units that are mapped outside of the basin but are within the project area. These contain localised and largely saline groundwater resources, which have only been included for completeness.

Table 3-1 Stratigraphic succession and hydrostratigraphic units.

Period	Stratigraphy		Lithology	Hydrostratigraphic Unit	
Quaternary	Superficial formations	Safety Bay Sand	Sand	Superficial aquifer	
		Muchea Limestone; Bassendean Sand; Tamala Limestone; Guildford Clay	Sand, limestone, clay and "coffee rock"		
Neogene		Ascot Formation / Yoganup Formation	Sand, clay and limestone		
Cretaceous	Coolyena Group	Lancelin Formation / Poison Hill Greensand	Sandstone and clay, glauconitic; Mudstone, calcareous and glauconitic	Mirrabooka aquifer	
		Gingin Chalk	Chalk, sandy and glauconitic		
		Molecap Greensand	Sandstone, glauconitic		
		Osborne Formation	<i>Mirrabooka Member</i>	Sandstone, glauconitic, with siltstone and shale	Kardinya aquitard
	<i>Kardinya Shale Member</i>		Siltstone and shale, minor sandstone		
	<i>Henley Sandstone Member</i>		Sandstone, minor siltstone and claystone	Leederville aquifer	
	Leederville Formation	<i>Pinjar Member</i>	Sandstone, siltstone and shale	Leederville aquifer	
		<i>Wanneroo Member</i>	Sandstone, with lesser siltstone and shale		
		<i>Mariginiup Member</i>	Sandstone, siltstone and shale		
	South Perth Formation		Siltstone and shale, minor sandstone	South Perth aquitard	
	Gage Sandstone		Sandstone, siltstone and shale	Part of Yarragadee aquifer	
	Paleogene	Parmelia Group	Charlotte Sandstone	Sandstone, minor siltstone and shale	Parmelia aquifer
			Carnac Formation	Siltstone and shale, minor sandstone	
			Jervoise Sandstone	Sandstone with some siltstone and shale	
Otorowiri Formation			Shale and siltstone, minor sandstone	Otorowiri aquitard	
Jurassic	Yarragadee Formation	Unit D	Shale, siltstone and clayey sandstone	Yarragadee aquifer	
		Unit A, B, C	Sandstone, clayey sandstone, siltstone and shale		

Period	Stratigraphy	Lithology	Hydrostratigraphic Unit
	Cadda Formation	Sandstone, siltstone, claystone/shale and limestone	<b>Cattamarra aquifer</b>
	Cattamarra Coal Measures	Sandstone, siltstone, shale and coal	
	Eneabba Formation	Sandstone, siltstone and claystone	<b>Eneabba – Lesueur aquifer</b>
Triassic	Lesueur Sandstone	Sandstone	
	Woodada Formation	Sandstone and siltstone	
	Kockatea Shale <i>Bookara Sandstone Member</i>	Shale, minor siltstone and sandstone	<b>Kockatea aquitard</b>
Permian	Wagina Sandstone / Dongara Sandstone / Beekeeper Formation	Sandstone, clayey sandstone, mudstone/shale and limestone	<b>Permian formations</b>
	Carynginia Formation / Mingenew Formation; Irwin River Coal Measures; High Cliff Sandstone; Holmwood Shale; Nangetty Formation	Siltstone, claystone and sandstone, coal	

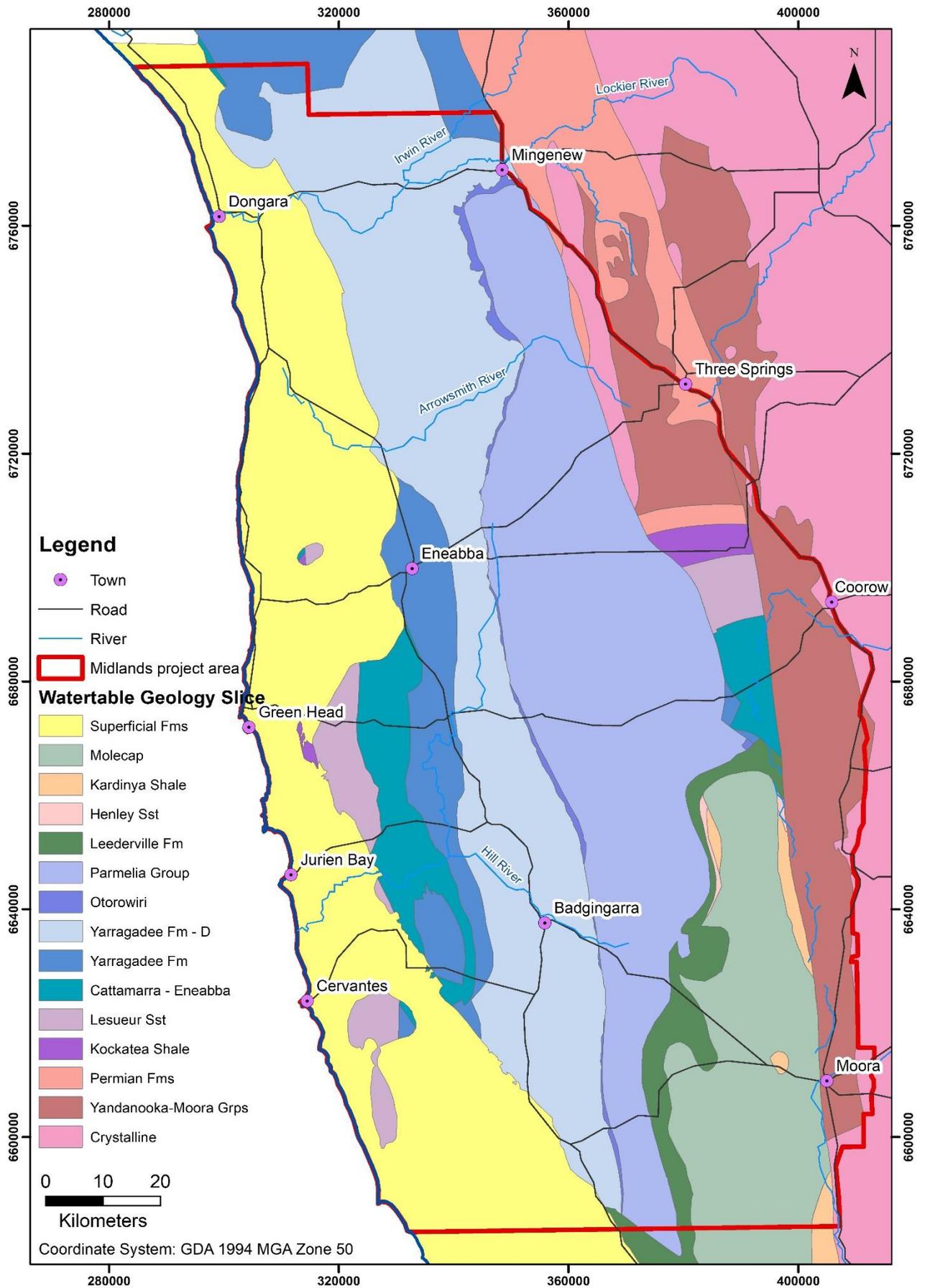


Figure 3-1 Geology at the watertable depth slice.

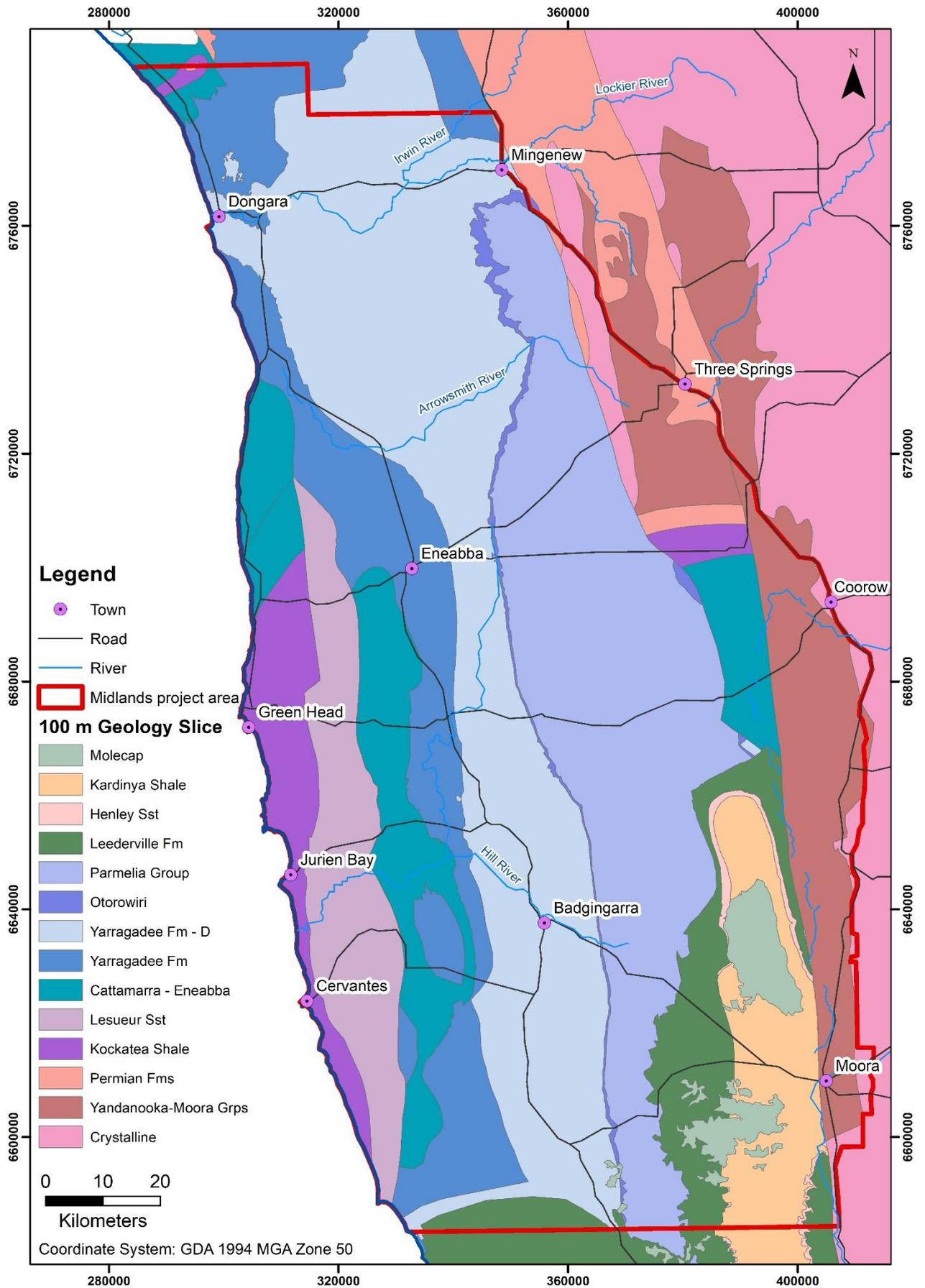


Figure 3-2 Geology at the 100 m depth slice.

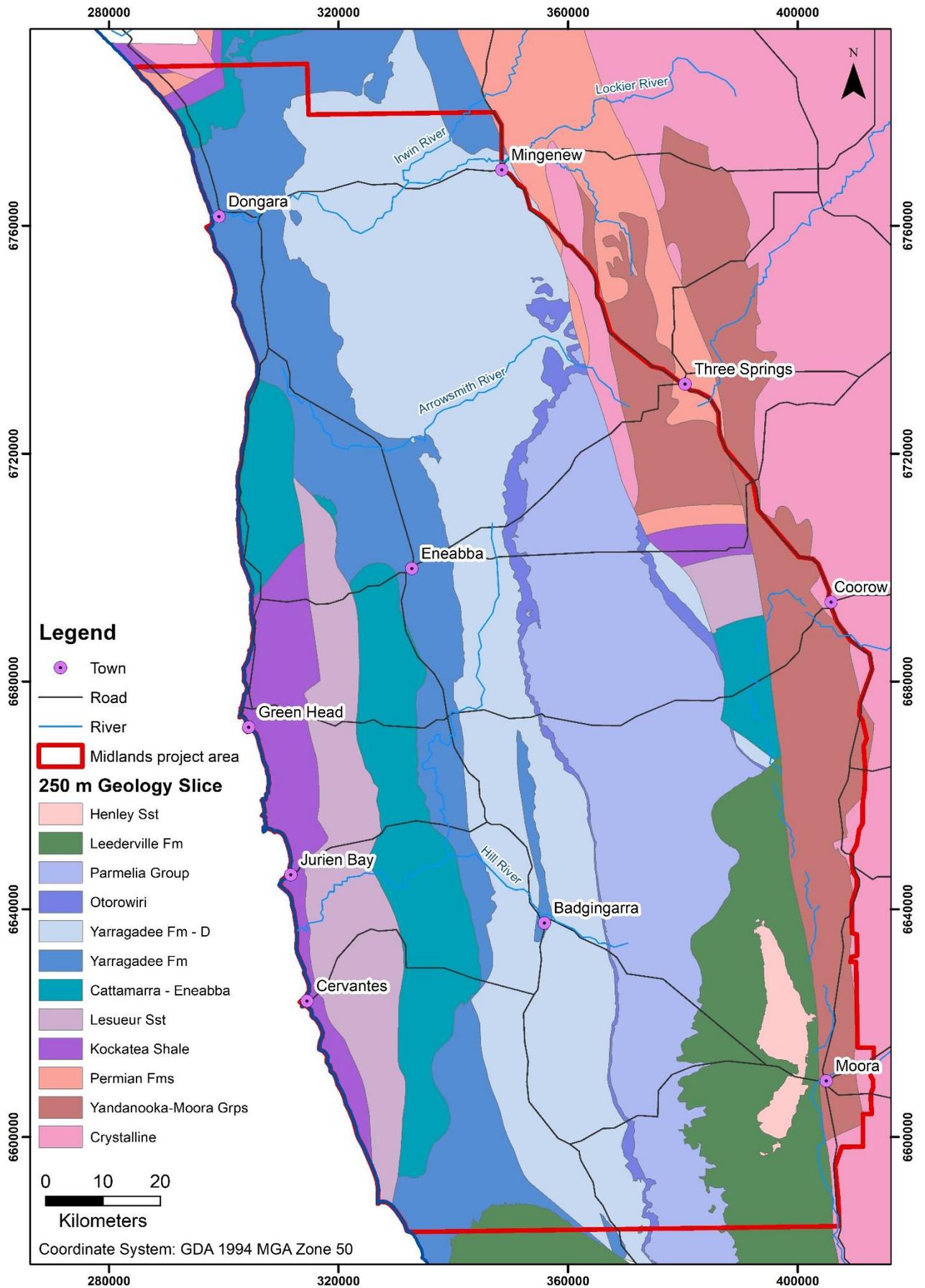


Figure 3-3 Geology at the 250 m depth slice.

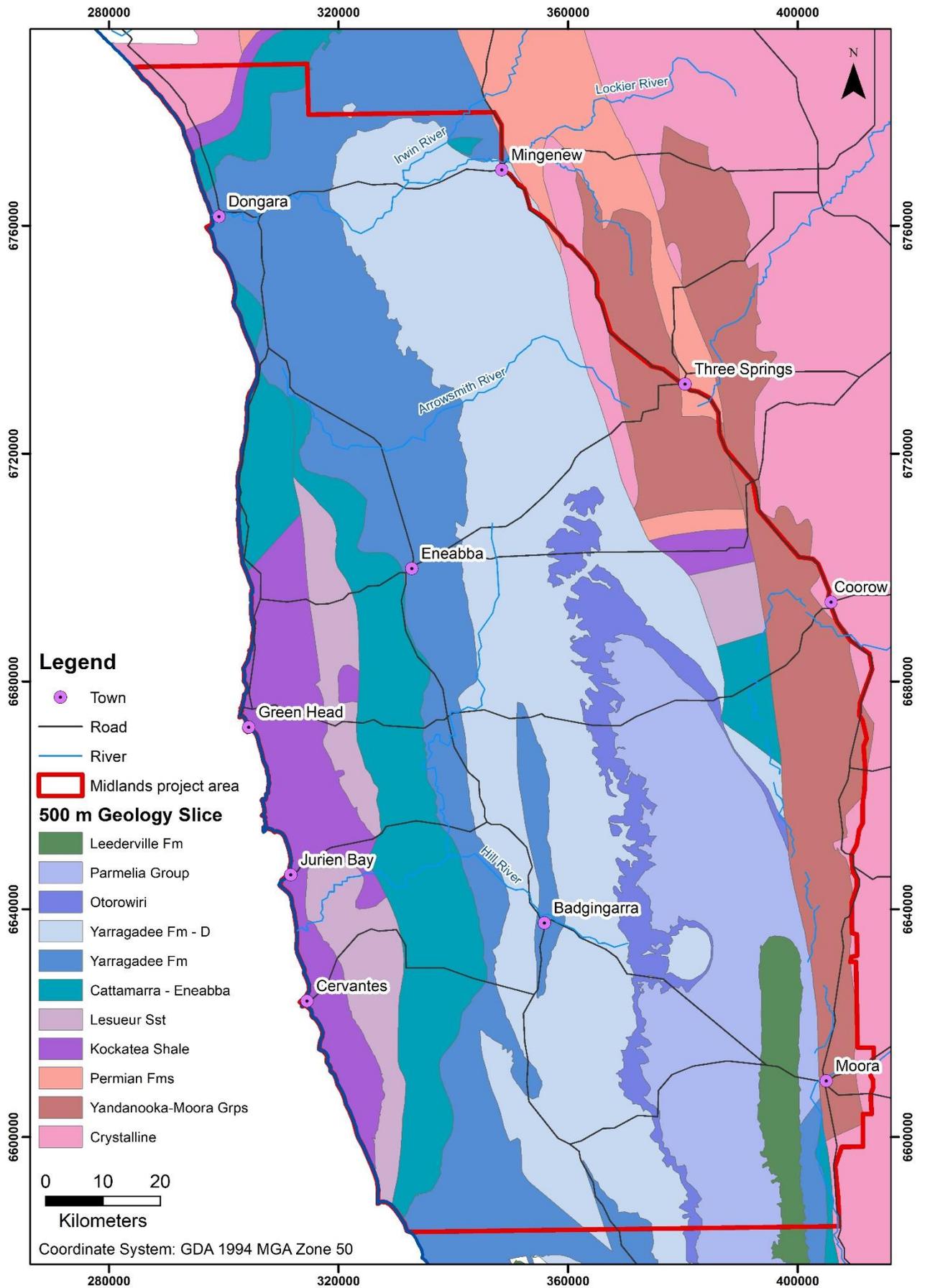


Figure 3-4 Geology at the 500 m depth slice.

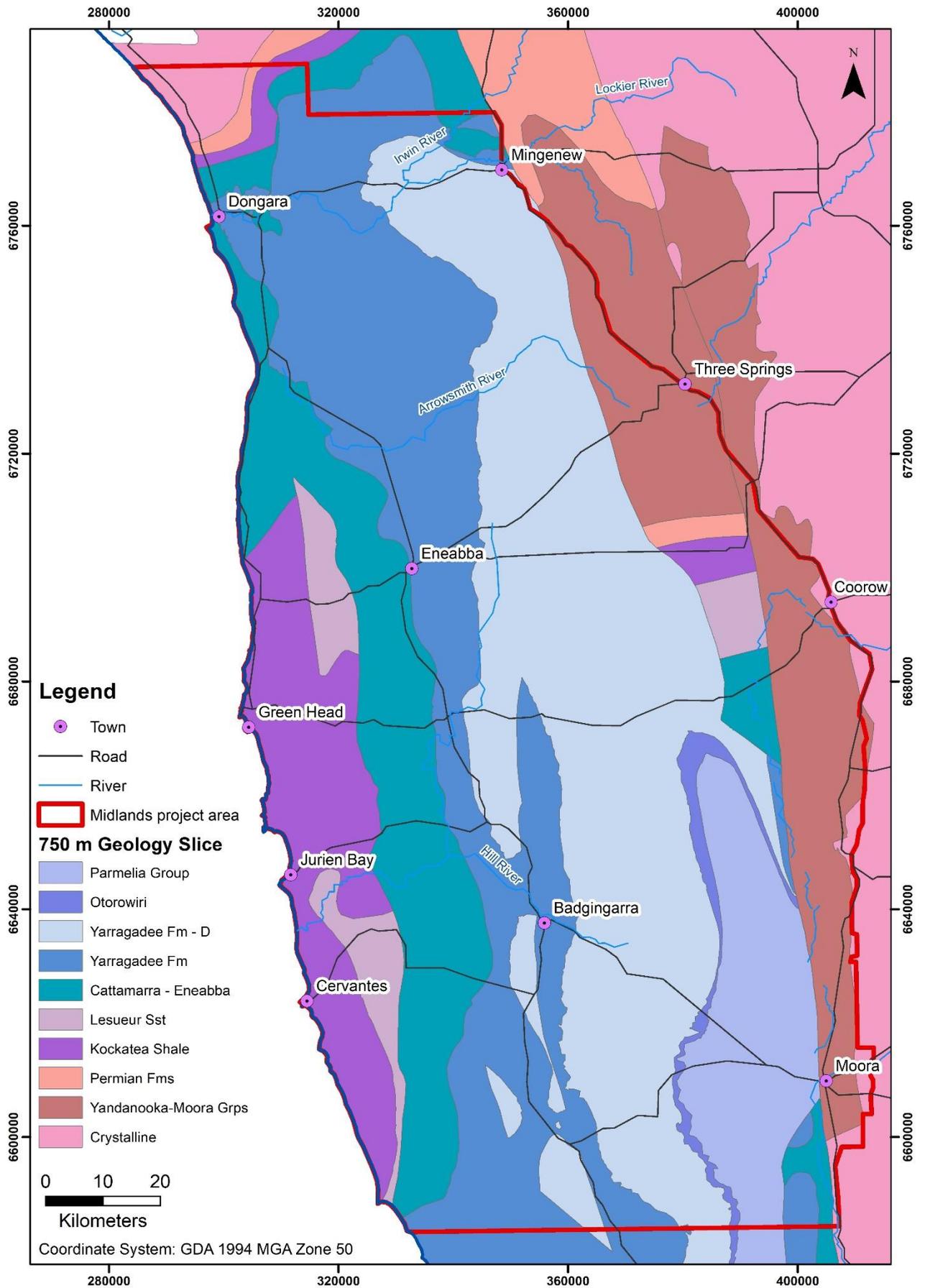


Figure 3-5 Geology at the 750 m depth slice.

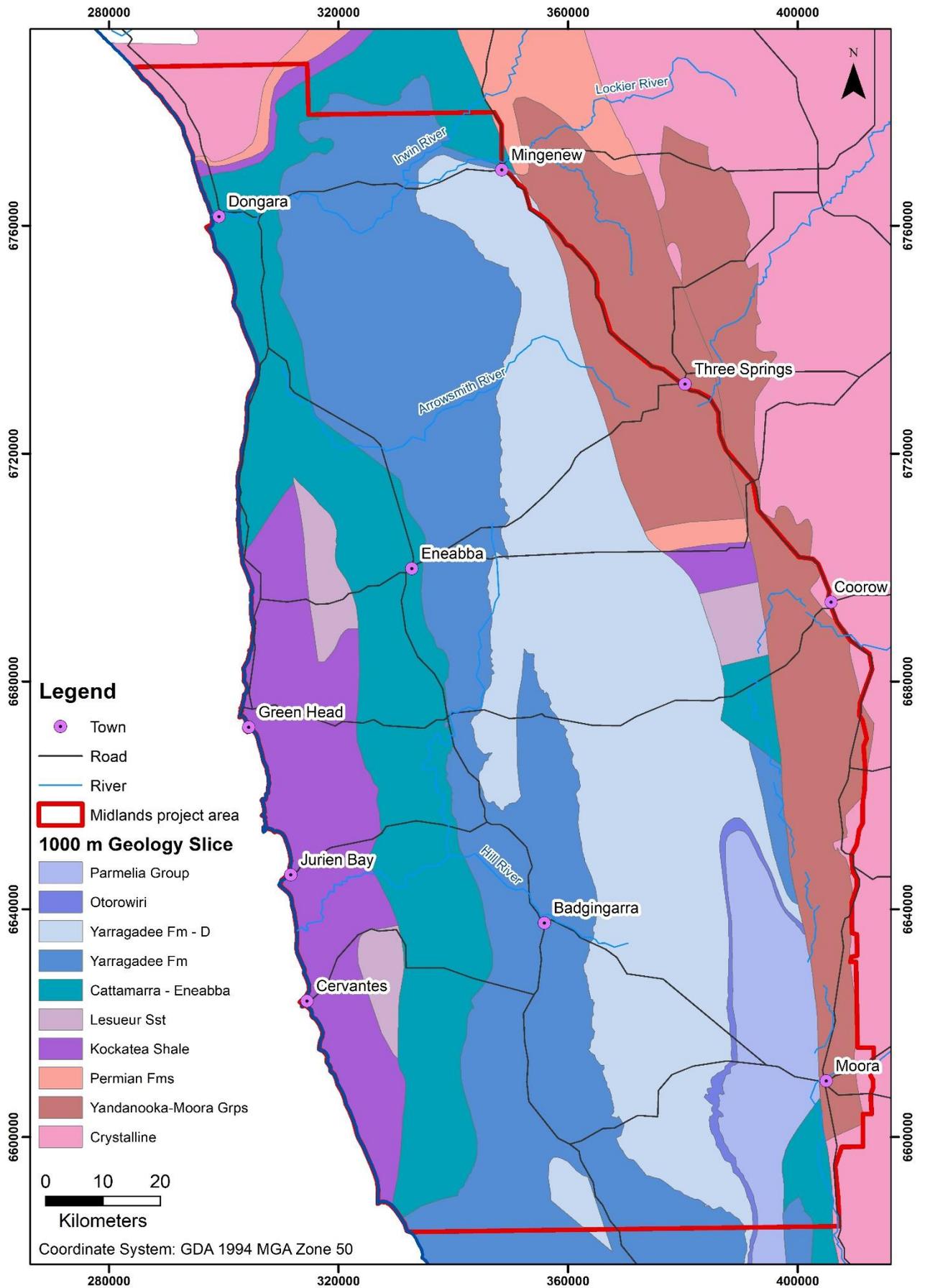


Figure 3-6 Geology at the 1000 m depth slice.

## 4 Aquifer yield potential

Bores with sufficiently large yields are critical for irrigated agricultural developments that depend upon groundwater resources. This is largely an economic consideration related to capital and operational expenditure. For instance, low yielding aquifers may require a borefield comprising many bores to obtain the quantity of water that can be supplied by just a few or one bore in a high yielding aquifer. Suitable bore yields will vary according to irrigation requirements, but indicative criteria are less than 5 L/sec being very poor to uneconomic; 5 to 10 L/sec being marginal; 10 to 20 L/sec being good; 20 to 50 L/sec being very good; and greater than 50 L/sec being excellent. As such, an aquifer with higher bore yields is more prospective than an aquifer with lower bore yields.

Geological units were classified according to the dominant lithology of the formation into four classifications of aquifer yield potential, being: high, moderate, low and very low. Most formations are sufficiently uniform so that they conform to a single yield classification. Several formations have lithologies that vary across the basin or with depth, which have been divided into two or more yield zones. These formations include the Leederville Formation, where the Wanneroo Member is different to the Pinjar and Mariginiup Members; Carnac Formation of the Parmelia Group; and Yarragadee Formation Unit D. For these formations, borehole lithology, downhole geophysical logs (gamma-ray and resistivity) and airborne electromagnetic surveys (where available) have been used to assist classification. The yield potential mapped for each of the depth slices is presented by Figures 4-1 to 4-6.

High yielding aquifer units are commonly associated with sand-dominated formations and karstic limestone, including;

- Yarragadee Formation – Units A to C;
- Parmelia Group (excluding Otorowiri Formation and shale dominated parts of the Carnac Formation);
- Leederville Formation Wanneroo Member;
- Gage Sandstone;
- Henley Sandstone;
- Tamala Limestone comprising karstic limestone (calcarenite) and sands adjacent to the coastline.

Moderate yielding aquifer units tend to include formations with mixed portions of shale, silt and sand, and sandstone, such as:

- Lesueur Sandstone – shallower than 250 m depth;
- Cadda Formation – Cattamarra Coal Measures and Eneabba Formation – there is uncertainty of potential yields at greater depths;
- Yarragadee Formation Unit D – more sandy portions;
- Bassendean Sand where the saturated thickness is more than a few metres.

Low yielding aquifer units are typically associated with sediments containing abundant shale and silt with some sand that is often fine-grained. These include:

- Pinjar and Mariginiup Members of the Leederville Formation;
- Yarragadee Formation Unit D – more clayey portions;
- Parmelia Group Carnac Formation – clay dominated portion;
- Molecap Greensand (including Gingin Chalk and Poison Hill Greensand) –this incorporates the Mirrabooka Sandstone which may form a moderate yielding unit, although its distribution is poorly resolved;
- Lesueur Sandstone deeper than 250 m – the sandstone tends to become increasingly cemented and less permeable with depth (i.e. it is ‘tighter’);
- Permian Formations are variously shale or sandstone units – differentiation of each formation is not well mapped within the overall distribution of Permian Formations, and the yield distribution has effectively been averaged;
- Margins of Bassendean Sand where the saturated thickness is thin.

Very low yielding aquitard units are associated with dominantly shale and silt sediments, including:

- Kockatea Shale;
- Otorowiri Formation;
- South Perth Shale; and
- Kardinya Shale.

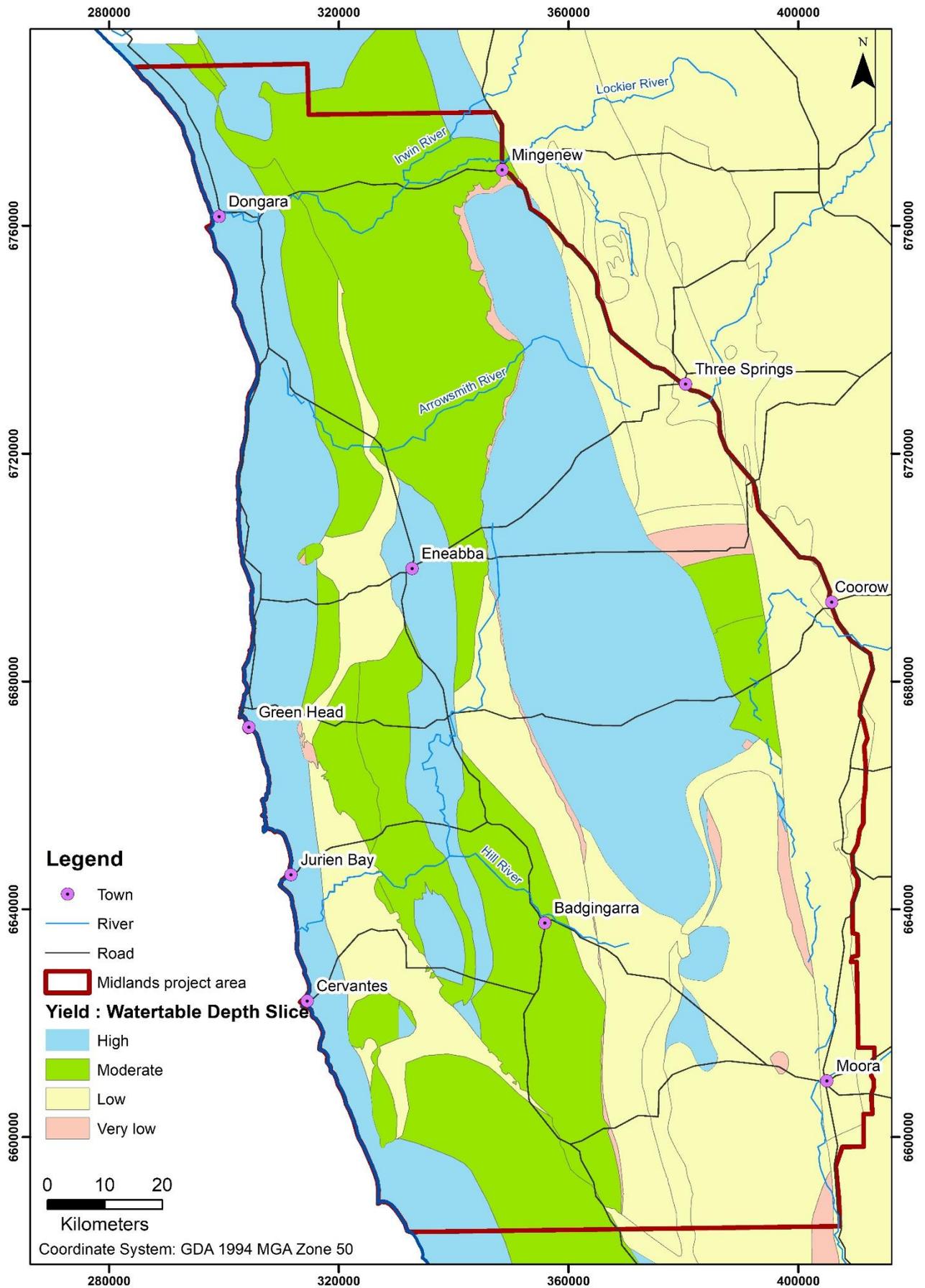


Figure 4-1 Yield potential at the watertable.

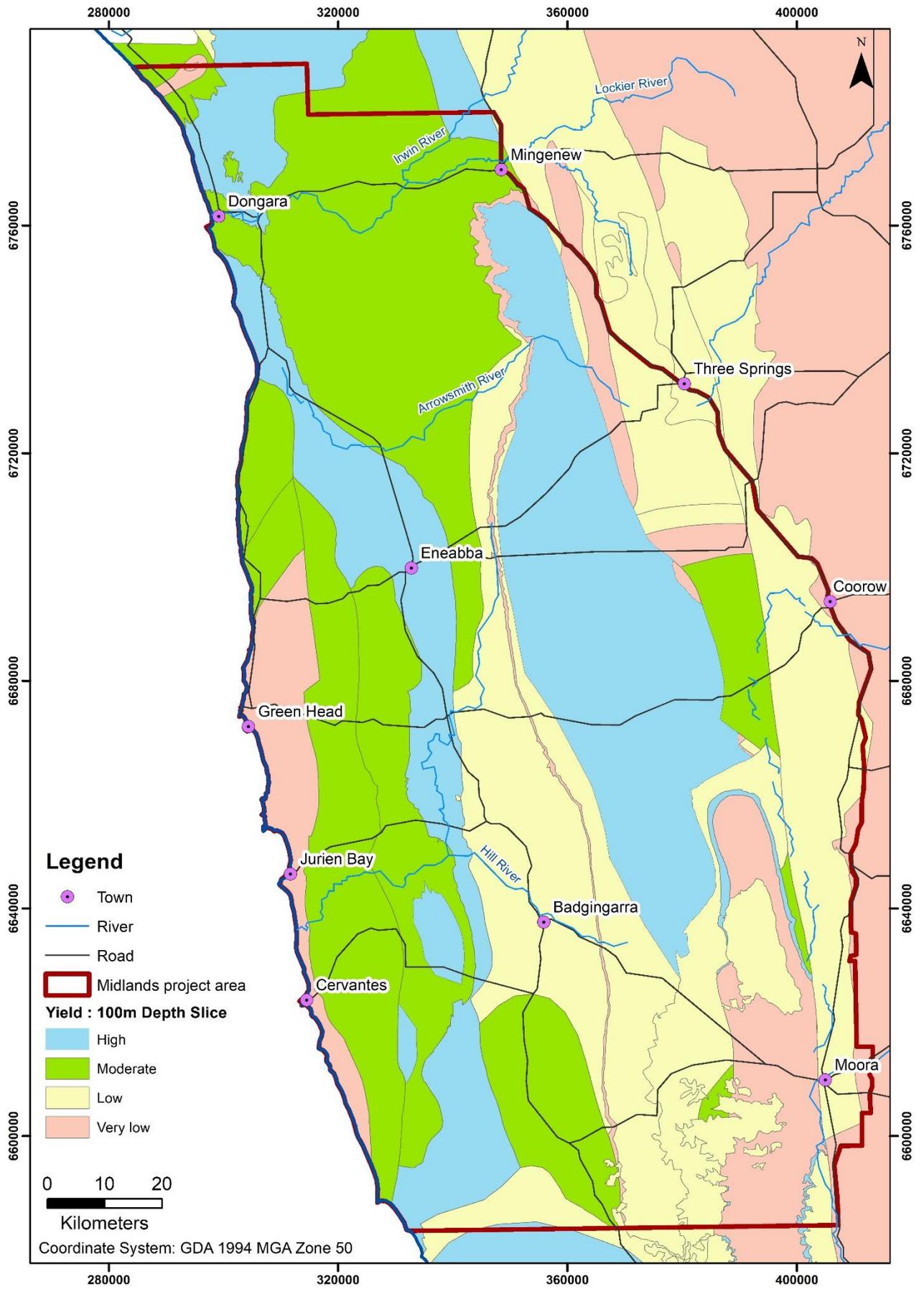


Figure 4-2 Yield potential at the 100 m depth slice.

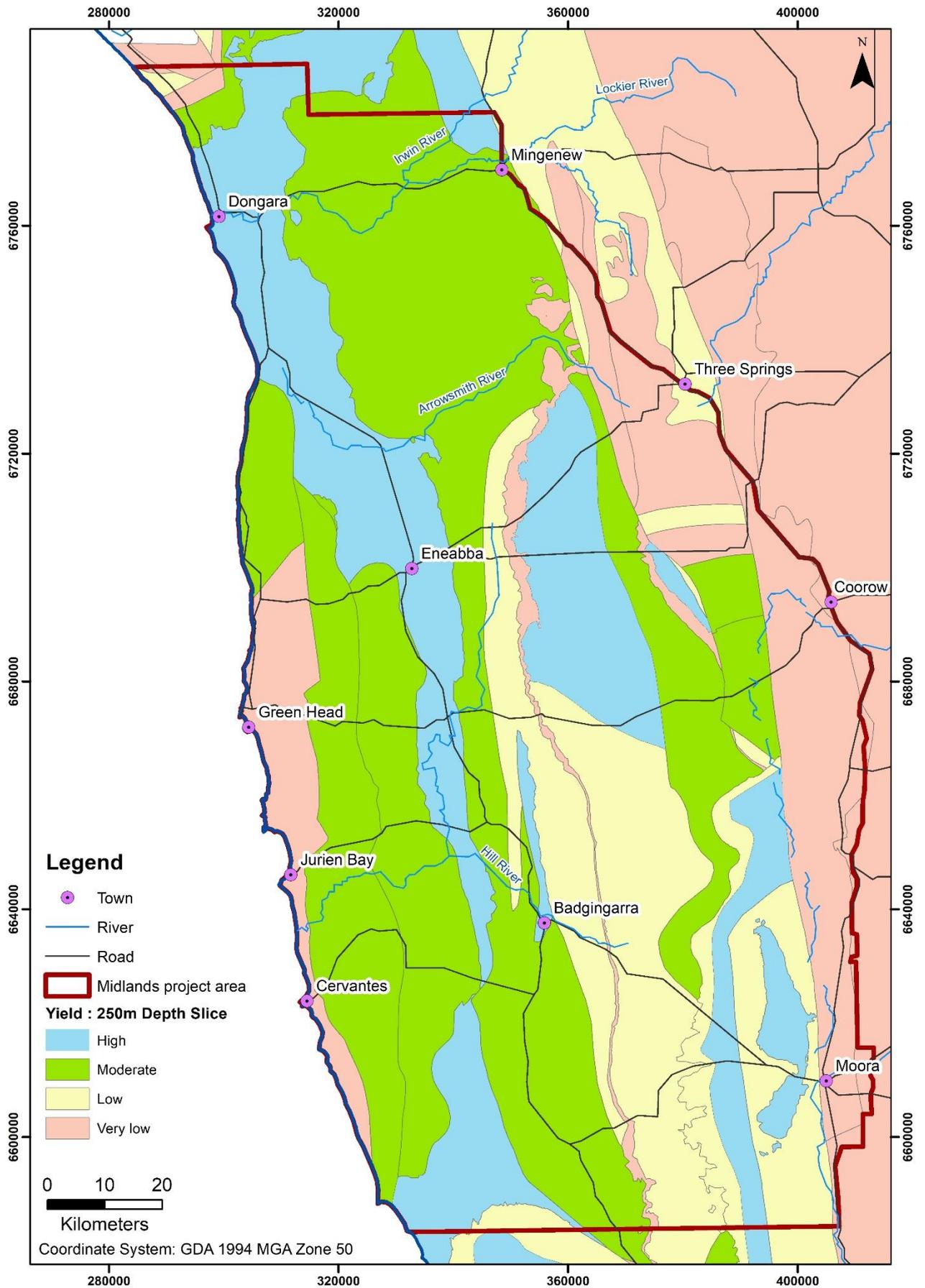


Figure 4-3 Yield potential at the 250 m depth slice.

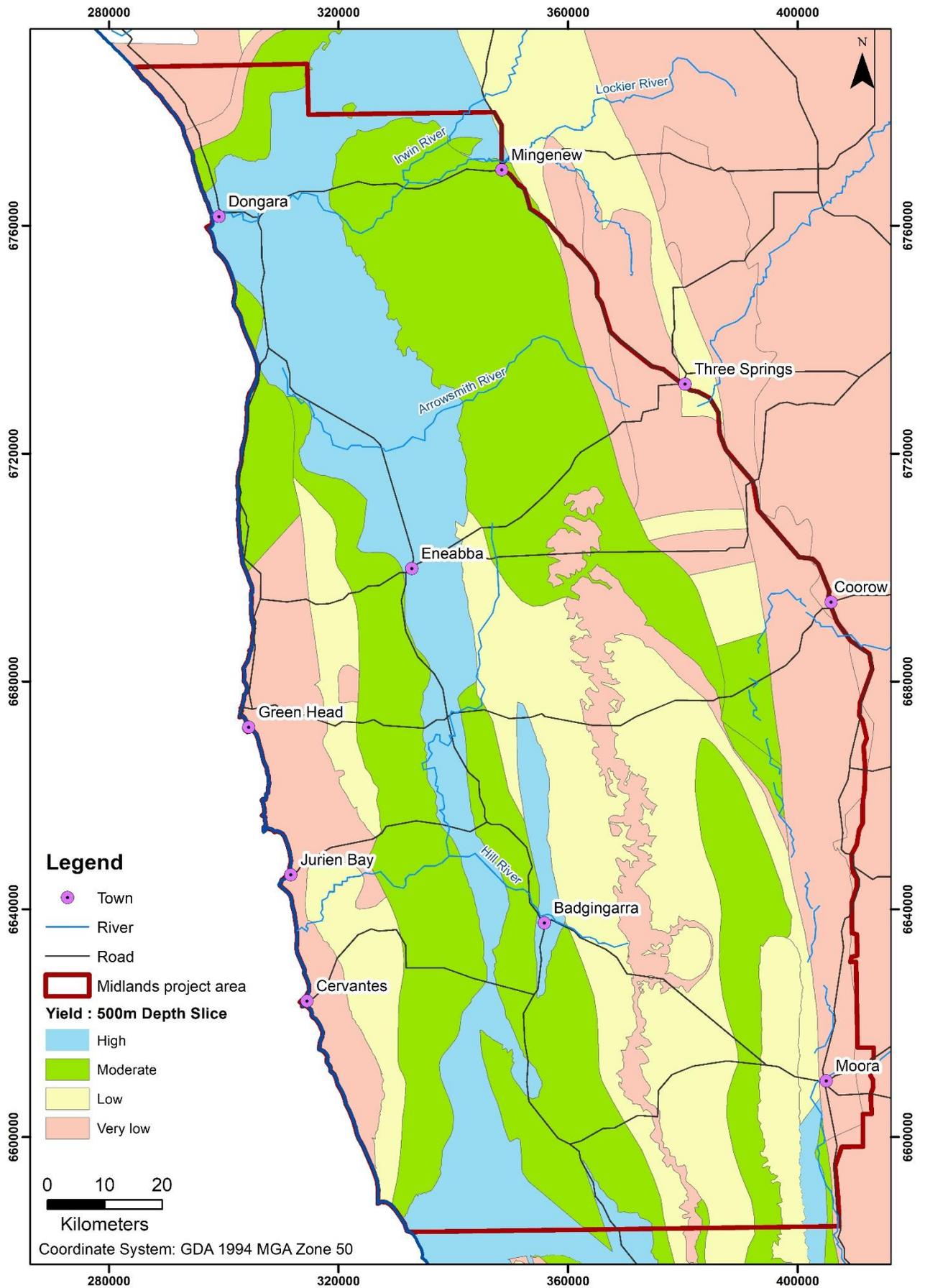


Figure 4-4 Yield potential at the 500 m depth slice.

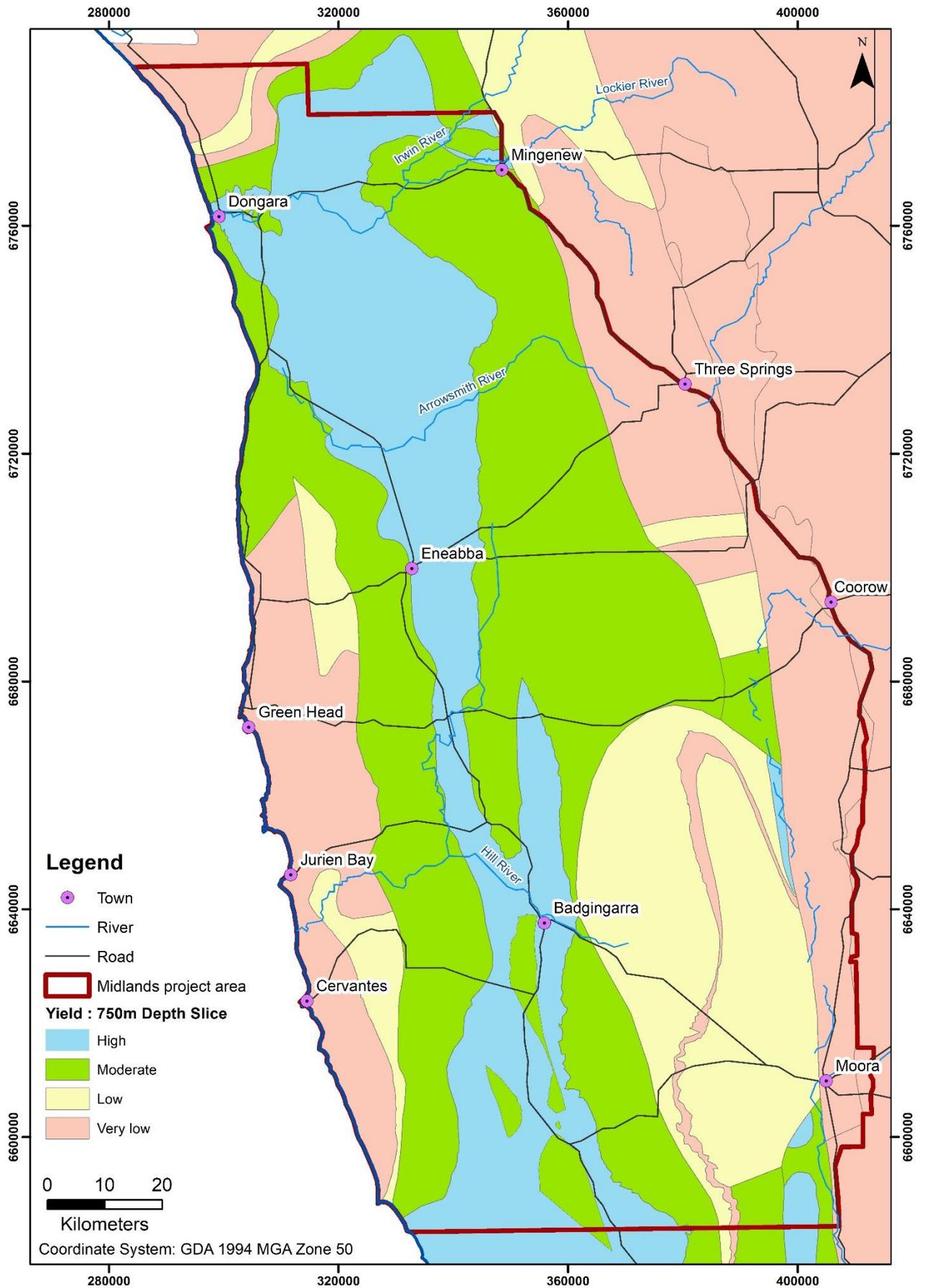


Figure 4-5 Yield potential at the 750 m depth slice.

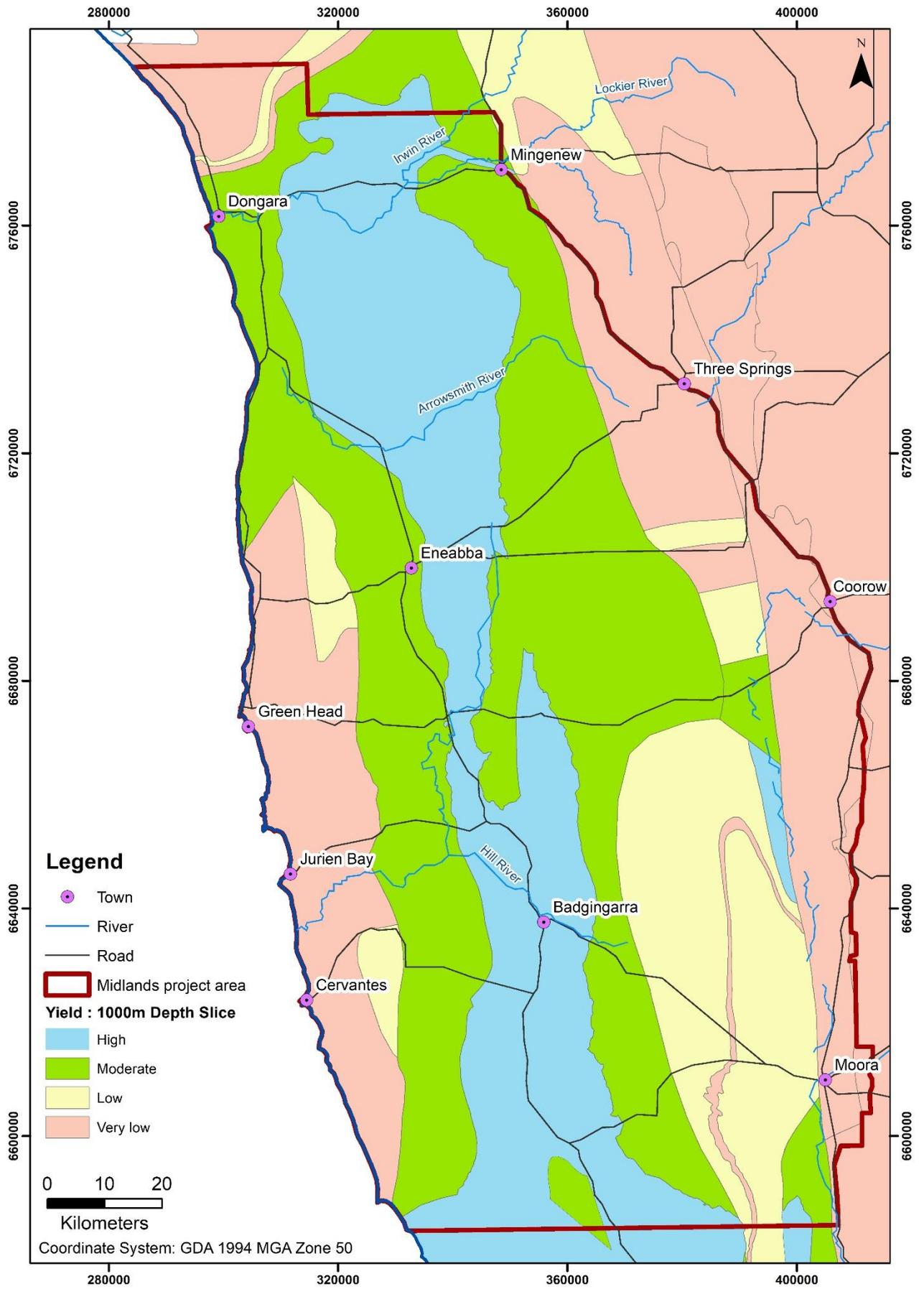


Figure 4-6 Yield potential at the 1000 m depth slice.

## 5 Salinity

Low salinity groundwater is critical for irrigated horticulture activities. Although various crops may be able to tolerate a diverse range on water salinities, groundwater of high salinity (more than about 1500 mg/L TDS) can be taken as being too saline for consideration.

Groundwater salinity distribution for each of the depth slices is based on salinity mapping presented in the Bulletin for each of the aquifer units. A single salinity map for each depth slice is produced by combining the salinity associated with each aquifer unit across the slice. Groundwater salinity is then classified into the ranges: <500, 500–1000, 1000–1500, 1500–3000, 3000–7000, 7000–14000, and >14000 mg/L. For most aquifers, groundwater salinity is sufficiently uniform vertically through each unit that spatial mapping of groundwater salinity from the Bulletin can be applied to the full thickness. Significant vertical change in groundwater salinity does occur through the Yarragadee Formation owing to its great thickness, and parts of the Carnac Formation within the Parmelia Group mainly owing to lithology changes.

The salinity distributions of each depth slice have been adapted for the Yarragadee Formation and Parmelia Group to account for vertical changes within these aquifers. These adaptations were based on measured groundwater salinity from monitoring bores and downhole resistivity geophysical logs to determine the appropriate area for each salinity range. There is a general regional trend of increasing groundwater salinity with greater depth through the Yarragadee Formation and Carnac Formation, although salinity does decrease with depth beneath parts of the Arrowsmith Region north of Badgingarra through Unit D of the Yarragadee Formation. There is little need for resolving salinity in the aquitards, as these are assumed to be too saline and unproductive for development.

Groundwater salinity distribution for each of the depth slices is shown in Figures 5-1 to 5-6. The main limitation for this interpretation is the distribution of boreholes and depth of the monitoring intervals. Most the deep data relate to the borehole lines and there can be large distances between the lines of up to 50 km in places.

Classification of salinity ranges utilised for the prospectivity mapping is based on DPIRD irrigation guidelines ([www.agric.wa.gov.au/fruit/water-salinity-and-plant-irrigation](http://www.agric.wa.gov.au/fruit/water-salinity-and-plant-irrigation)), and are categorised as follows:

- Less than 500 mg/L is very good with no loss of crop yield;
- 500 to 1000 mg/L is good with minor loss of crop yield;
- 1000 to 1500 mg/L is marginal with some loss in crop yield;
- Greater than 1500 mg/L is unsuitable with increased loss in crop yield.

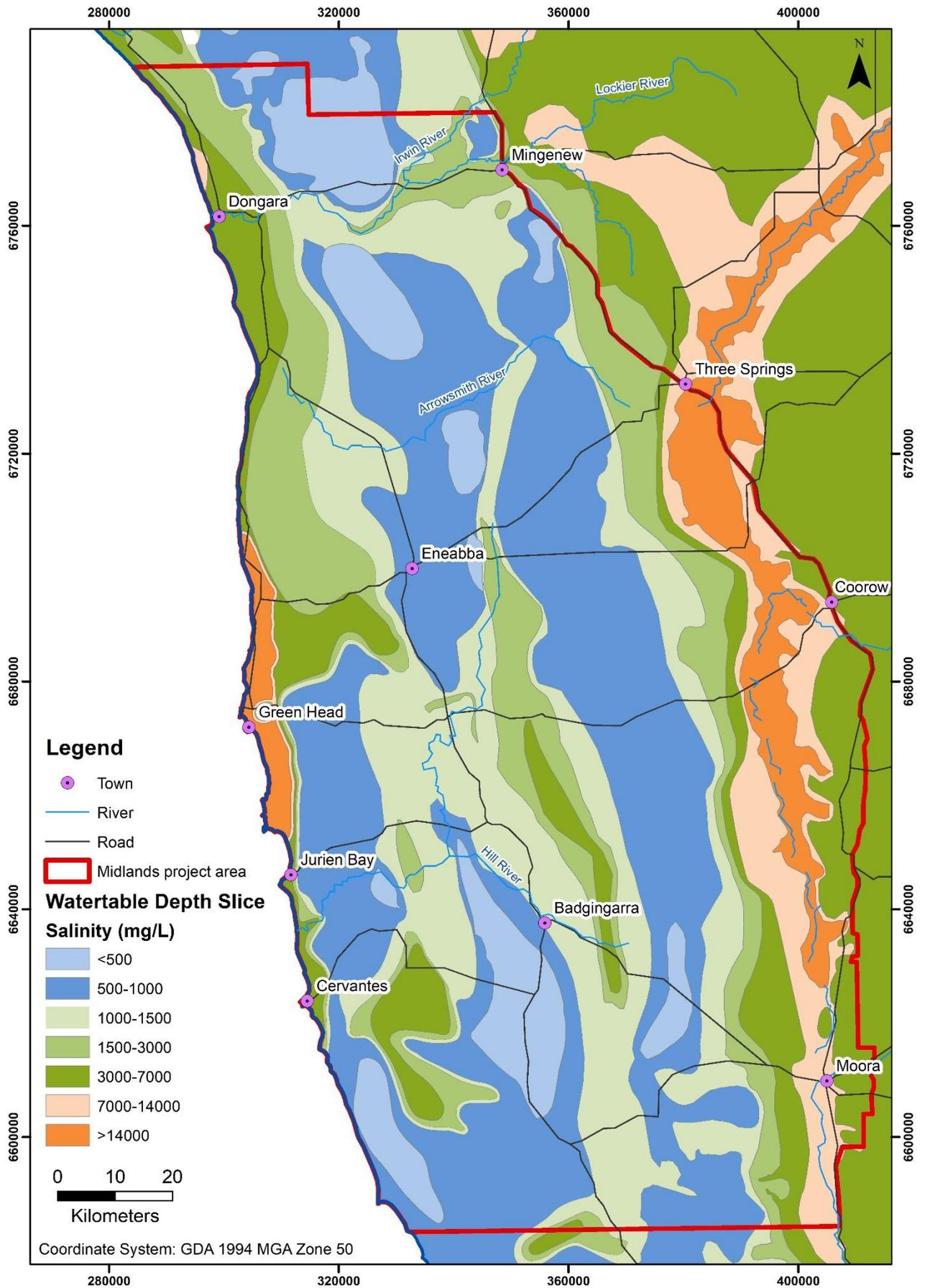


Figure 5-1 Groundwater salinity at the watertable.

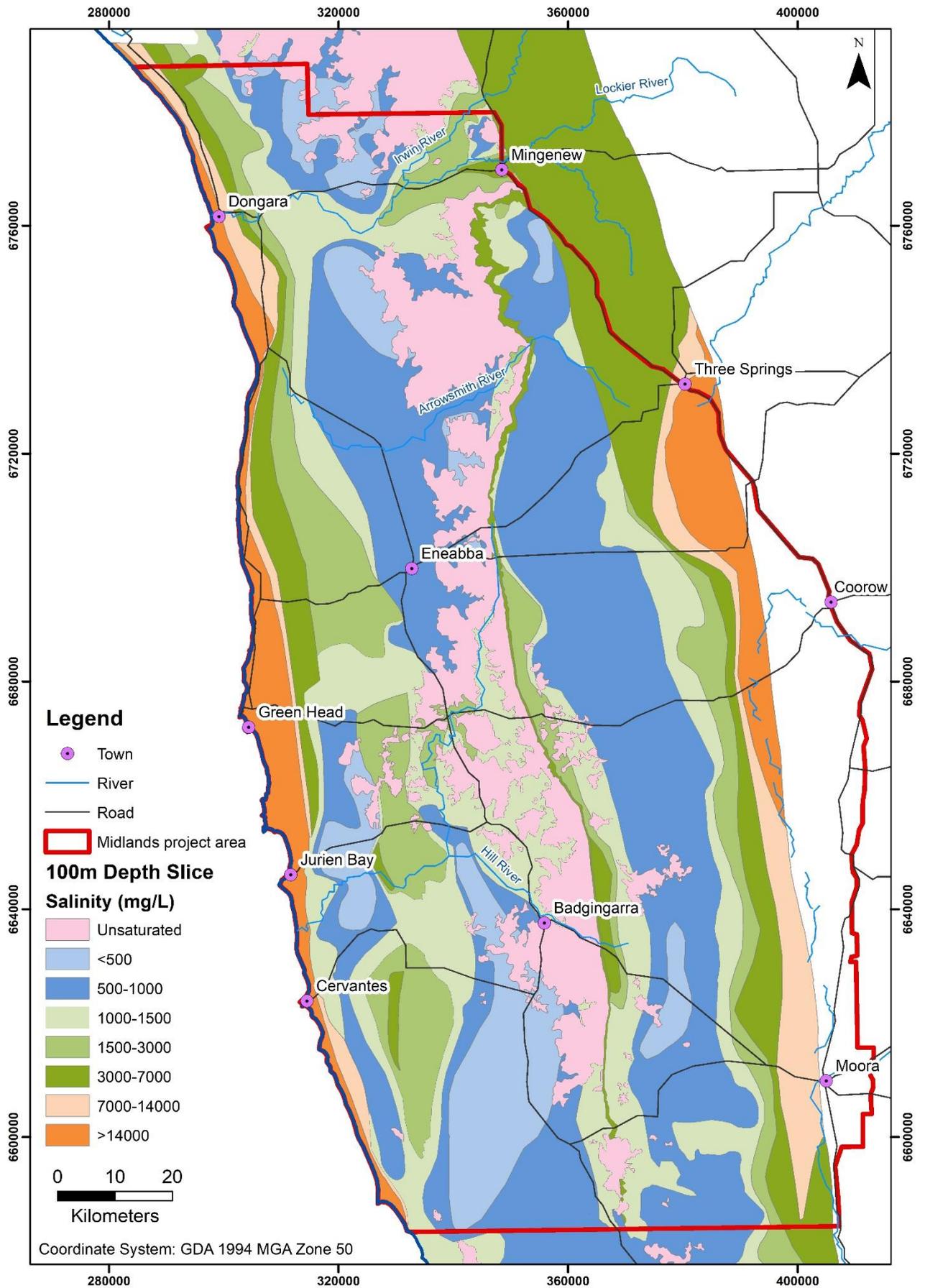


Figure 5-2 Groundwater salinity at the 100 m depth slice.

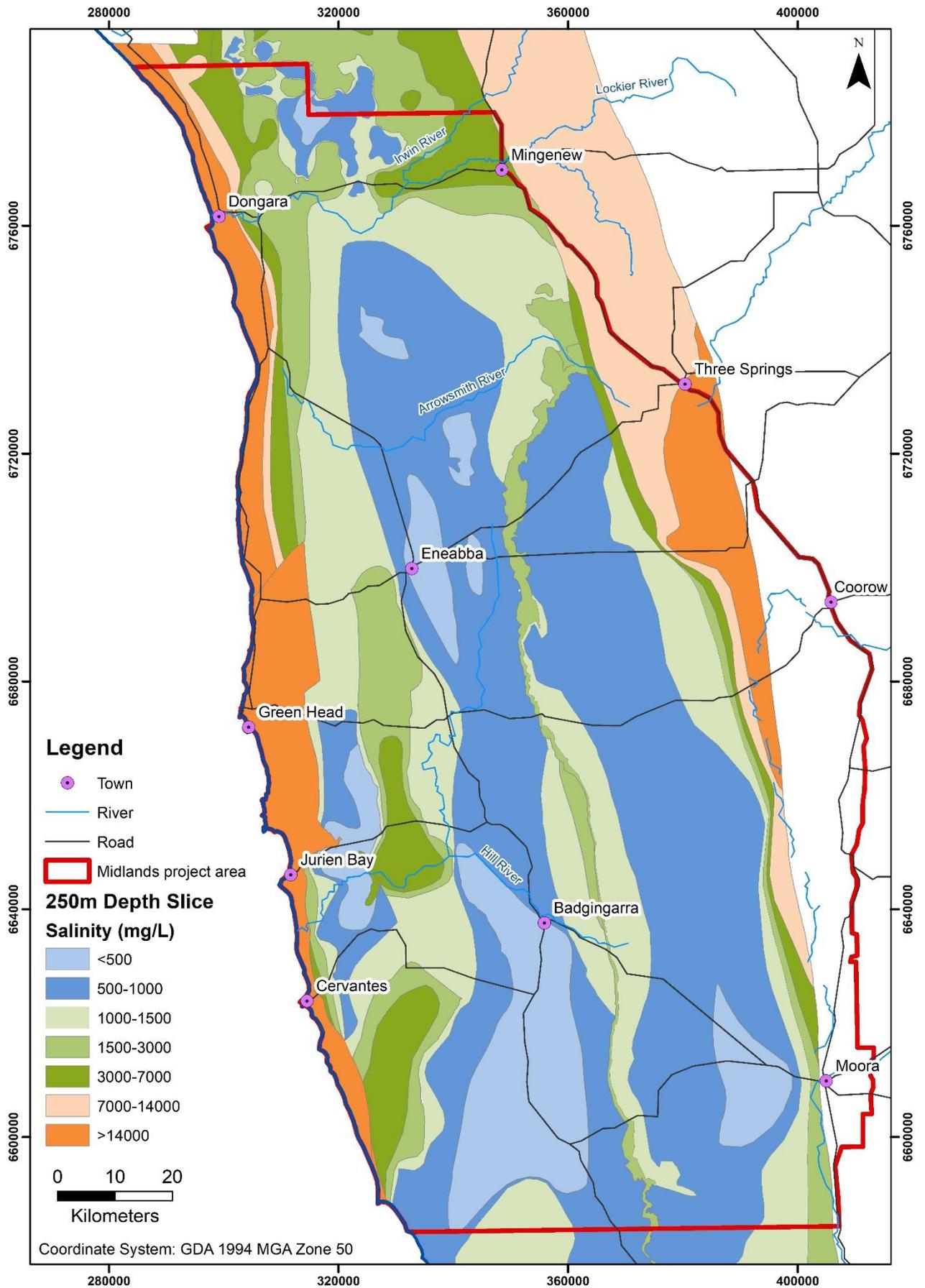


Figure 5-3 Groundwater salinity at the 250 m depth slice.

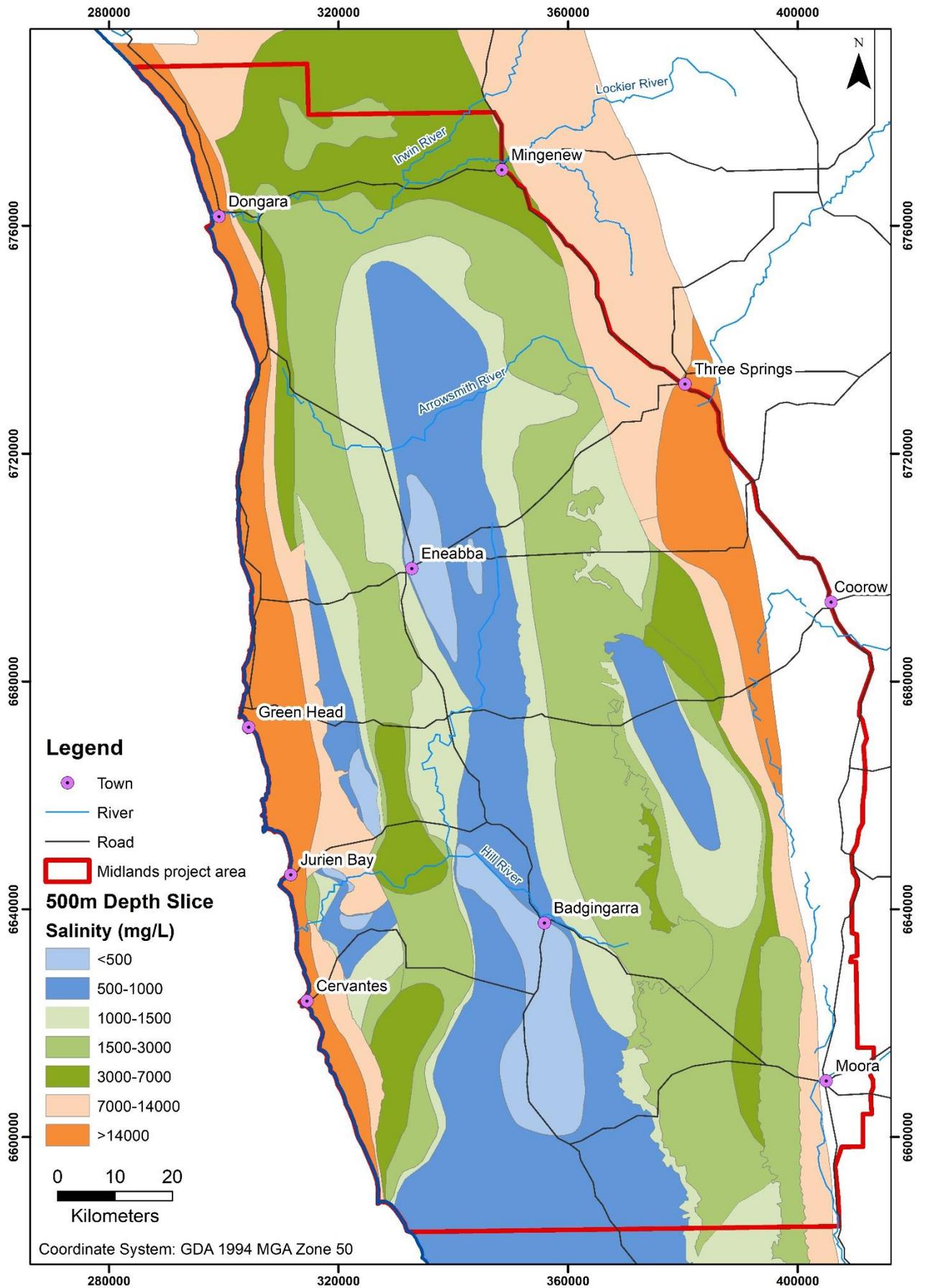


Figure 5-4 Groundwater salinity at the 500 m depth slice.

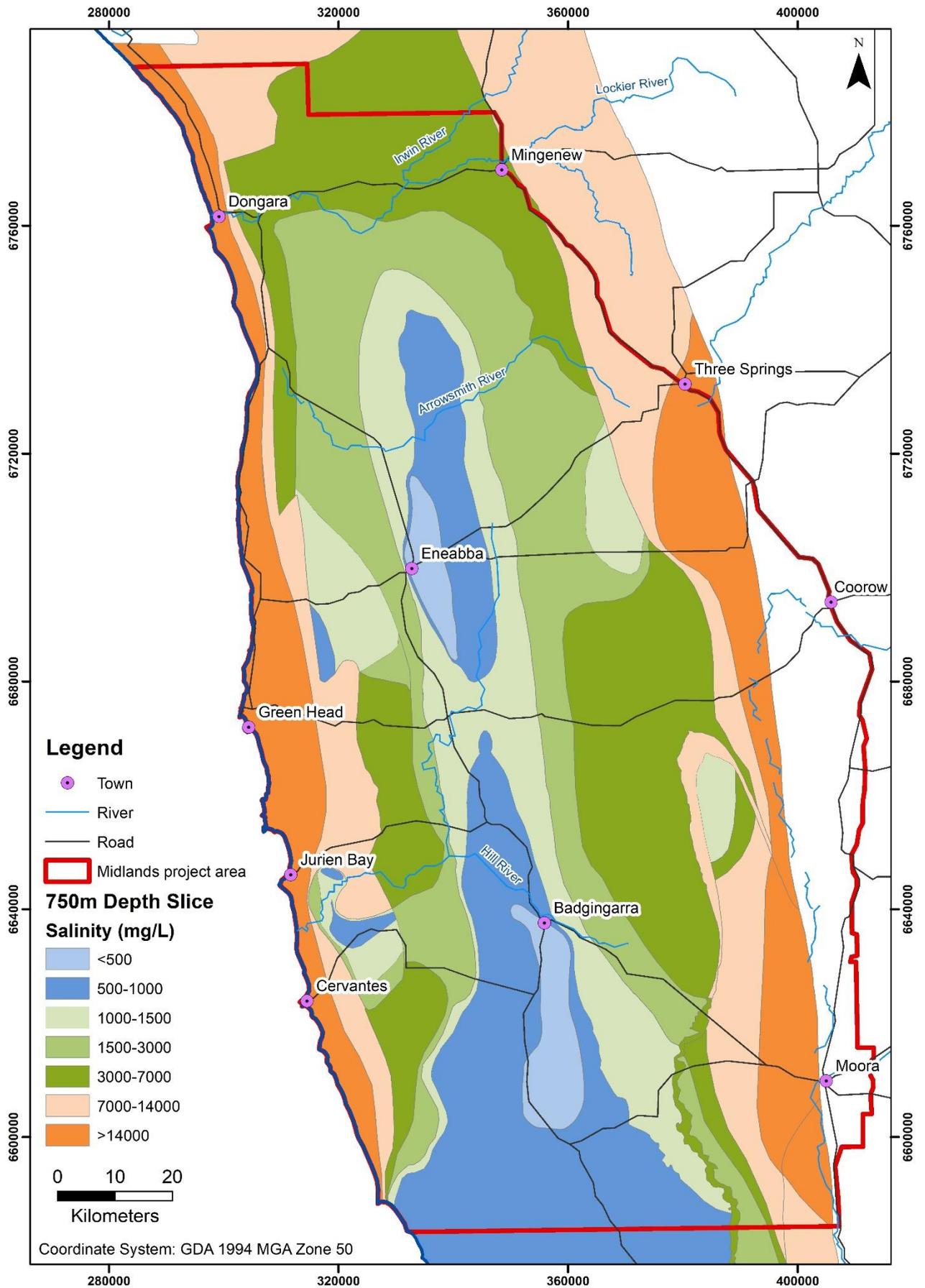


Figure 5-5 Groundwater salinity at the 750 m depth slice.

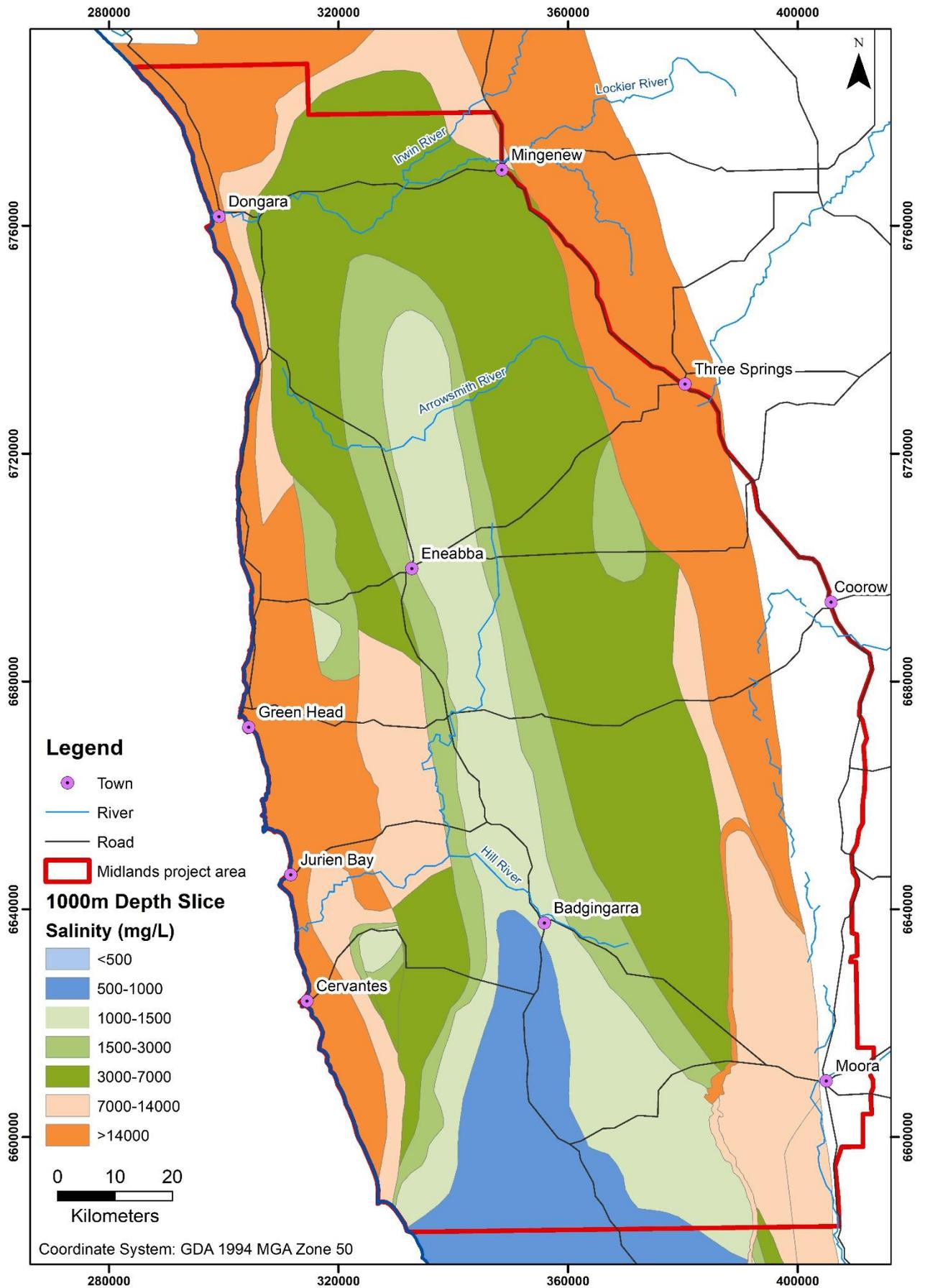


Figure 5-6 Groundwater salinity at the 1000 m depth slice.

## 6 Depth to groundwater

Depth to groundwater (either as watertable or a potentiometric surface) is an important factor for the prospectivity of water supplies, as deeper groundwater can more expensive to drill and pumping costs are higher. Areas with a shallow groundwater depth will also need to consider potential interactions with Groundwater Dependent Ecosystems (GDEs).

Irrigation experts should be consulted regarding the economics of water levels for pumping from bores, but indicatively less than 25 m depth below ground level (bgl) is ideal for abstraction but there is high potential of hydraulic connection with GDEs where the level is less than approximately 10 m; 25 to 50 m bgl is good with less influence on GDEs; 50 to 75 m is marginal owing to high pumping costs; and greater than 75 m bgl is often uneconomic. The likely drawdown within a pumping bore will also need to be considered, as this is in addition to the starting depth to water and will add further to pumping costs. Pumping drawdown within a bore is dependent mainly on the pumping rate and aquifer permeability (as well as bore efficiency), with typical drawdown levels of 25 to 40 m, but it is highly variable between locations.

Watertable elevations for the superficial / unconfined aquifers and potentiometric heads for the confined aquifers have been mapped within the Bulletin. The depth to groundwater across the project area has been estimated using a DEM (digital elevation model) compared to the water level elevation. The depth to groundwater for each of the depth slices is presented by Figures 6-1 to 6-6. These water level depths refer to the anticipated depth of water that would be found within a bore at the approximate depth of the slice, which may be different from the depth at which water is first intersected, which represents the watertable.

The potentiometric head within confined aquifers can be different to the watertable due to a vertical hydraulic gradient through the aquifers. This is most notable beneath the Arrowsmith Region and Dandaragan Plateau, where downward decreasing potentiometric heads result in a deeper water level at greater depths, while within the deeper valleys upward hydraulic gradients may exist so that water levels become shallower at greater depths.

The watertable is mostly less than 10 m depth beneath the Swan Coastal Plain where it is associated with extensive areas of wetlands, except beneath coastal dunes where the watertable is much deeper. A deep watertable and potentiometric head that can be well in excess of 100 m is extensive beneath the Arrowsmith Region and parts of the Dandaragan Plateau, but is shallower within river valleys.

Beneath the Dandaragan Plateau, there is a large difference in water levels between the Leederville–Parmelia aquifer and the underlying Yarragadee aquifer. Water levels in the Leederville–Parmelia aquifer can be around 100 m higher than in the Yarragadee aquifer. Beneath the Dandaragan Plateau, the water level for each depth slice has accounted for whether the Leederville–Parmelia or Yarragadee aquifers are present – for progressively deeper depths the Yarragadee aquifer extends further eastward and the extent of Parmelia Group reduces.

Water level depths are classified as:

- Less than 25 m – Highly prospective;
- 25 to 50 m – Moderately prospective;
- 50 to 75 m – Low prospectivity;
- Greater than 75 m – Uneconomic / not prospective.

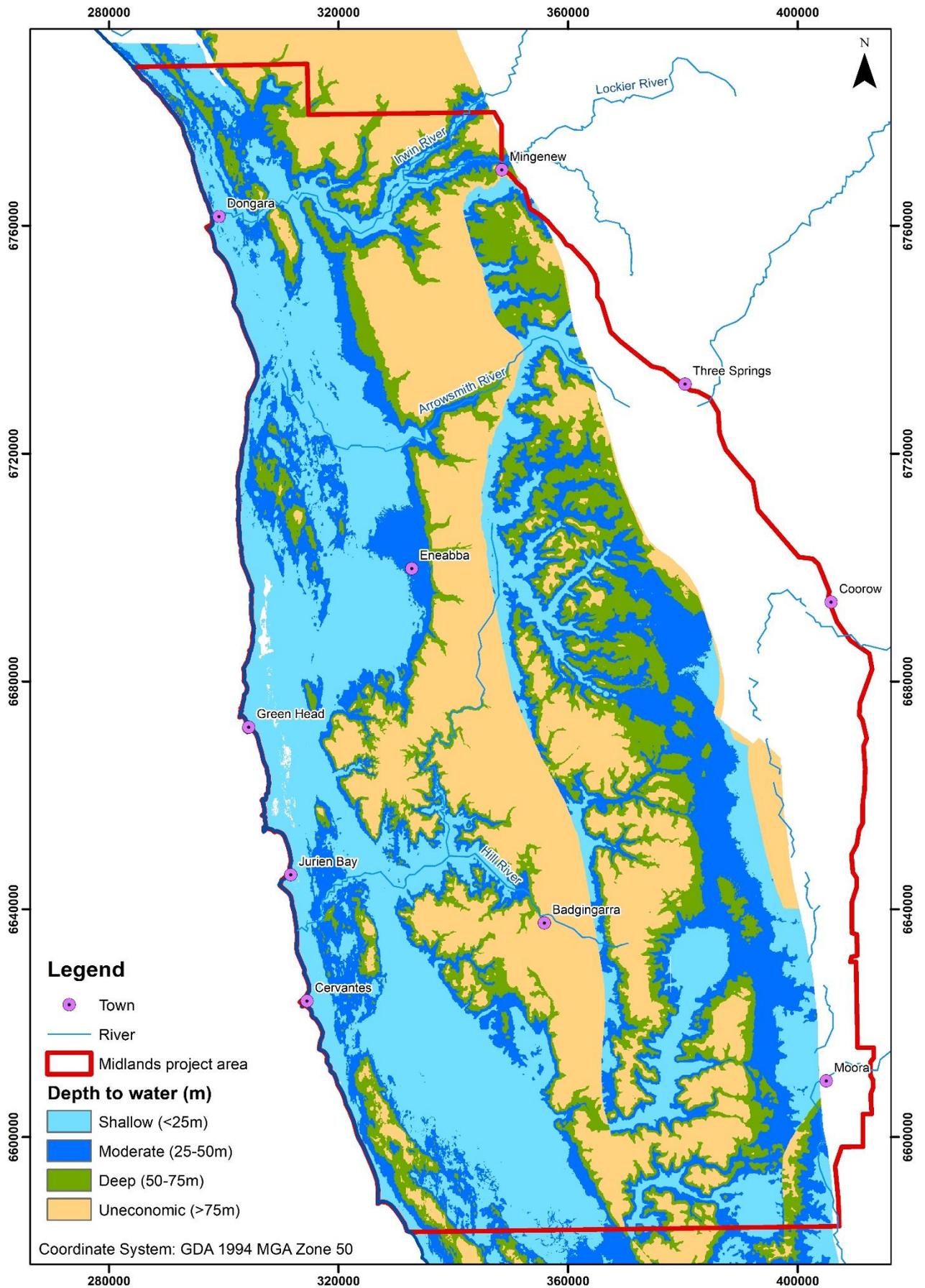


Figure 6-1 Depth to watertable.

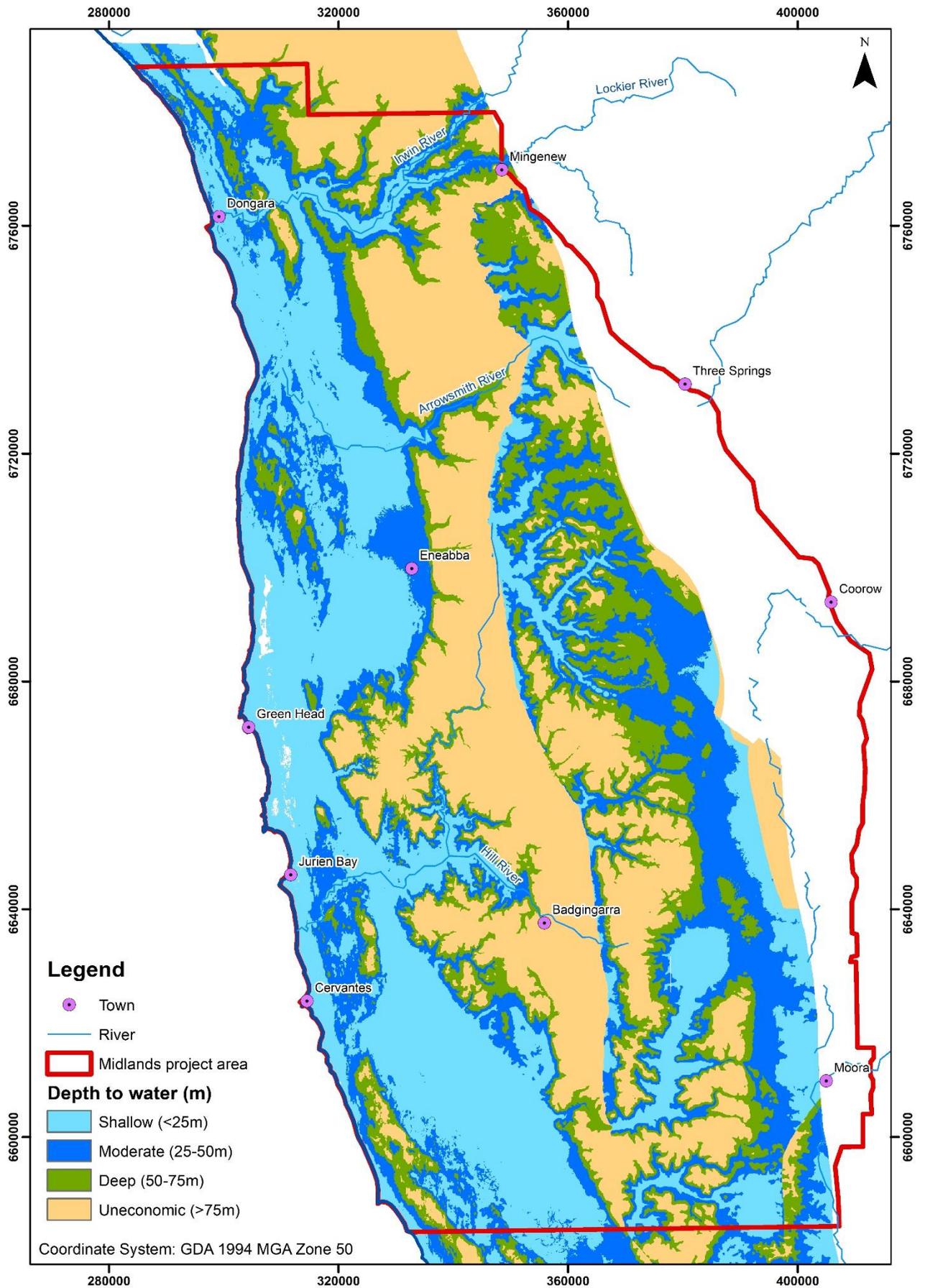


Figure 6-2 Water level depth for the 100 m depth slice.

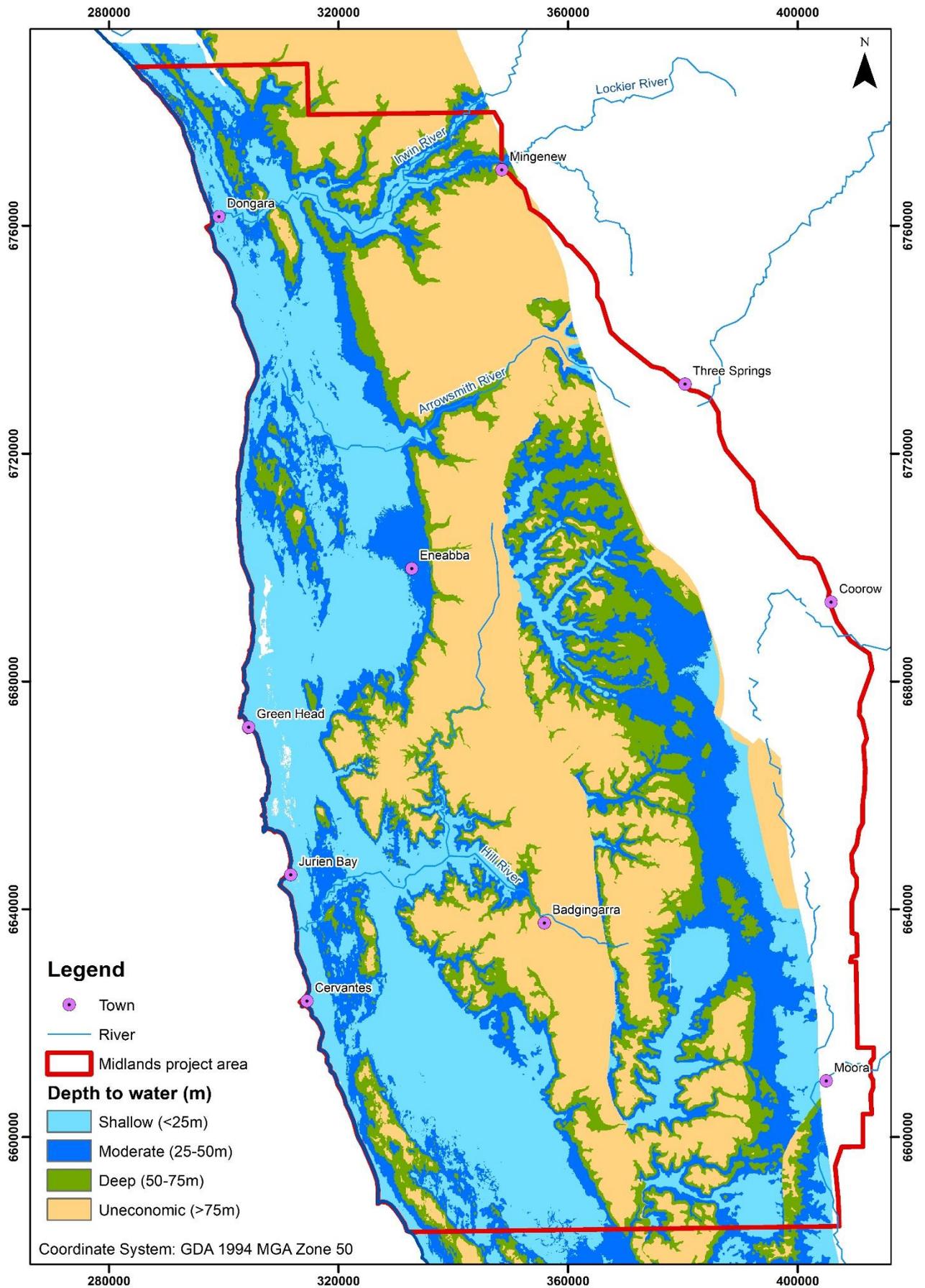


Figure 6-3 Water level depth for the 250 m depth slice.

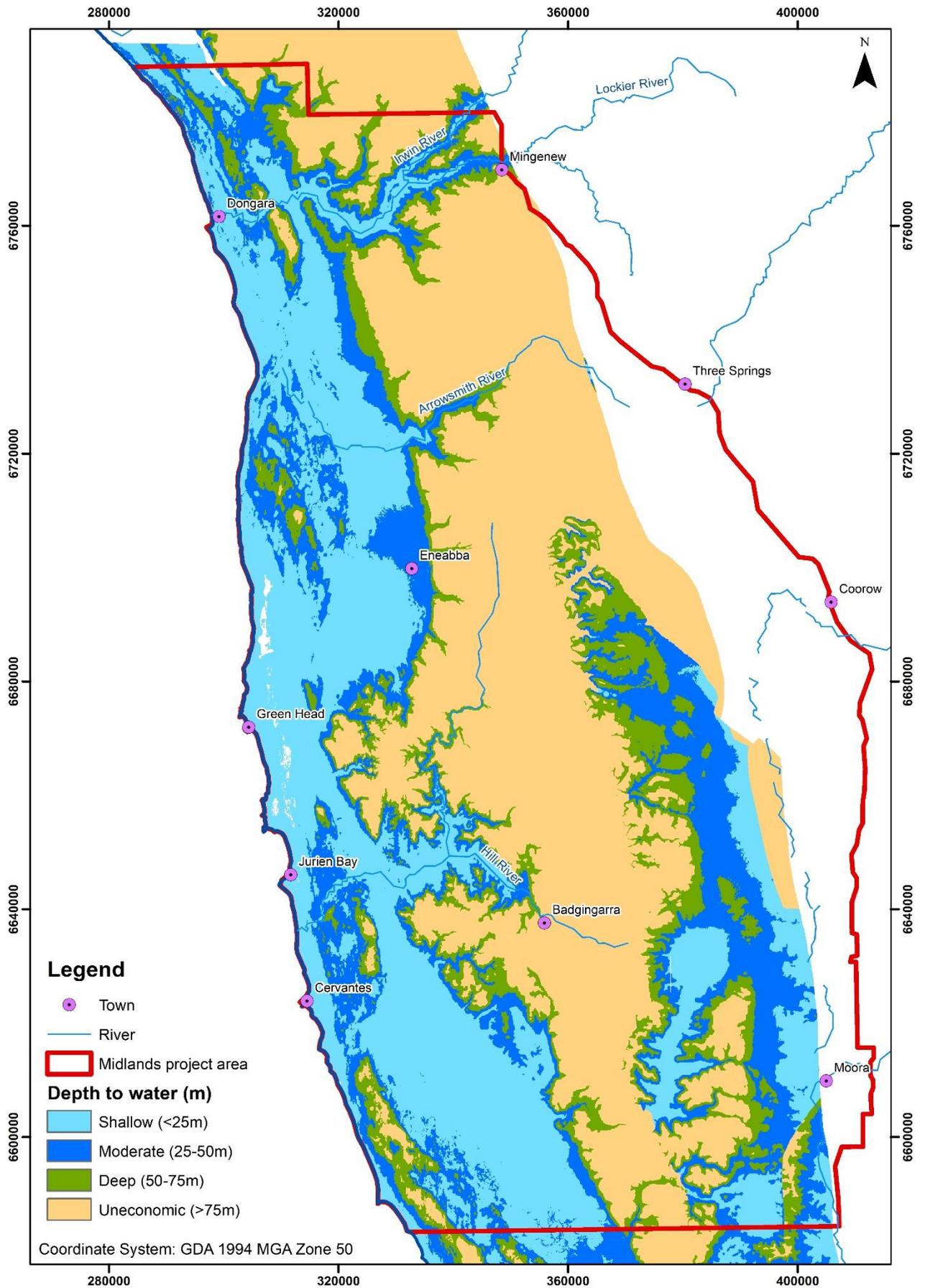


Figure 6-4 Water level depth for the 500 m depth slice.

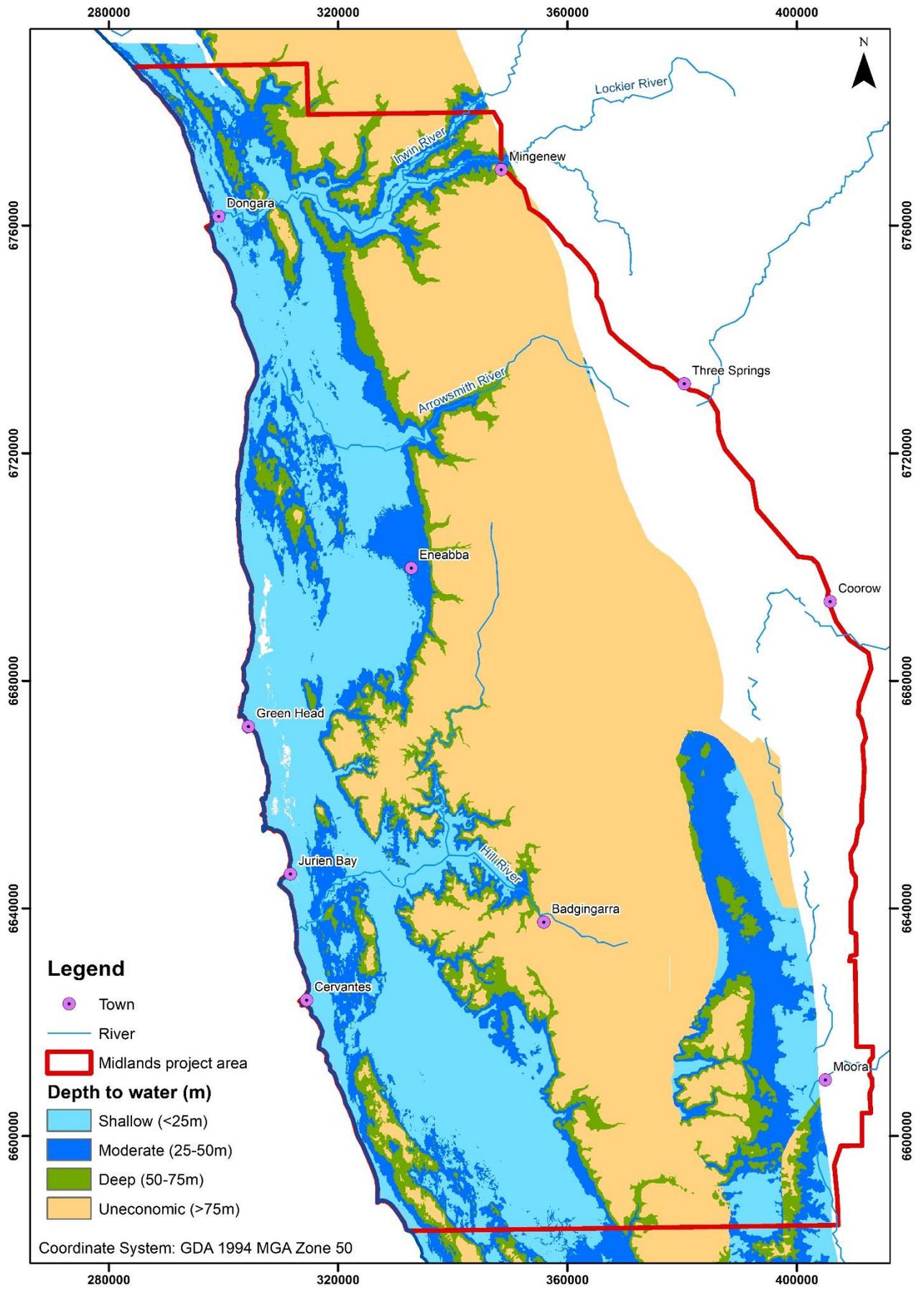


Figure 6-5 Water level depth for the 750 m depth slice.

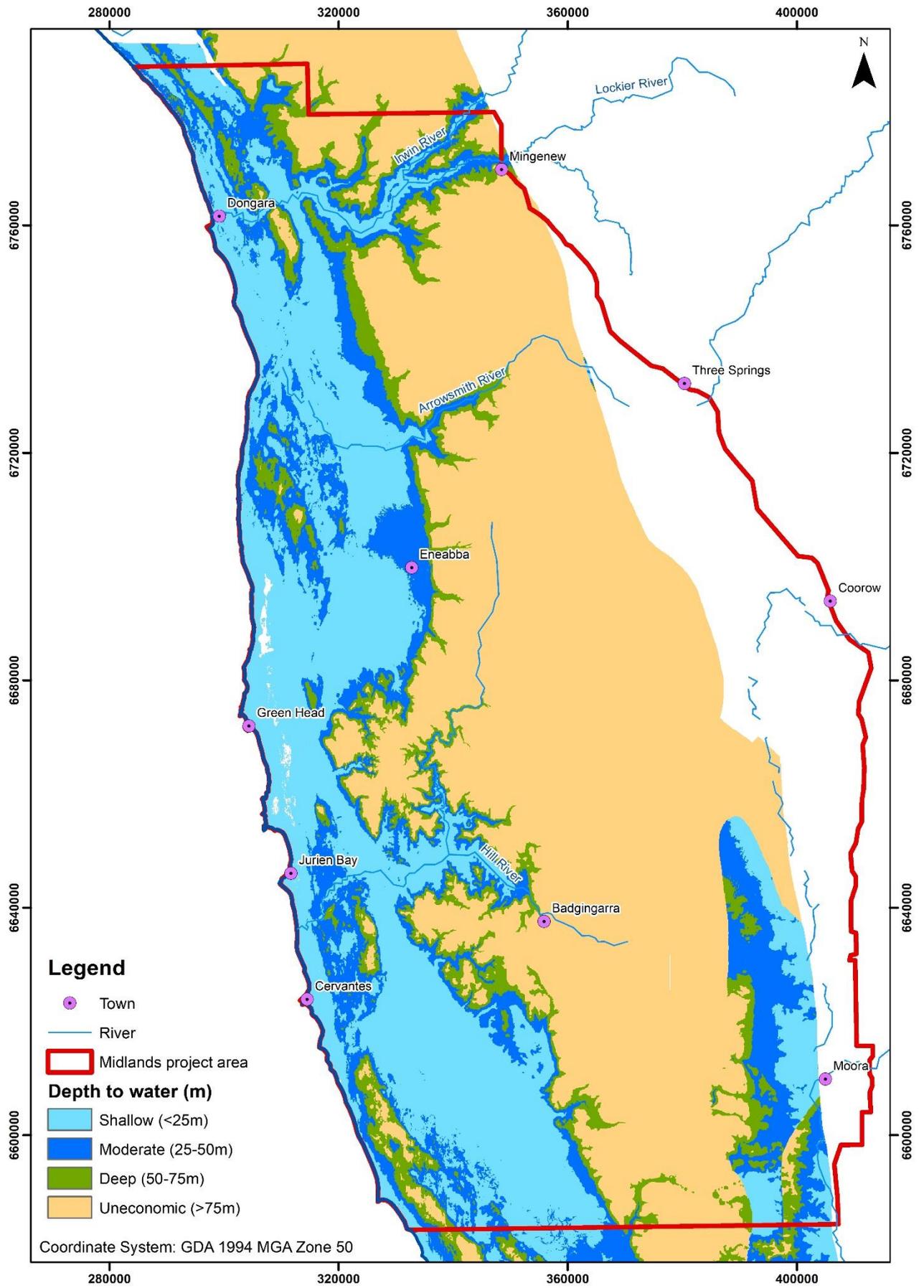


Figure 6-6 Water level depth for the 1000 m depth slice.

## 7 Groundwater prospectivity

Prospectivity for each depth slice is derived by combining the yield, salinity and water level depth classifications. Groundwater prospectivity reflects worst of the three attributes for an area. Yield and salinity prospectivity has been initially derived, followed by the depth to water level condition. A prospectivity chart is presented by Figure 7-1, which shows the relation between each of the parameter classifications in the derivation of groundwater prospectivity. The derived groundwater prospectivity for each of the depth slices is presented in Figures 7-2 to 7-7.

The prospectivity classification is as follows:

- Highly prospective represents shallow water level with salinity < 500 mg/L within a high yielding aquifer;
- Prospective represents water levels in the range up to 50 m bgl, groundwater salinity is <1000 mg/L and it is at least a moderate yielding aquifer;
- Marginal represents water levels up to 75 m depth, groundwater salinity is up to 1500 mg/L, and the aquifer is low yielding or better; and
- Unprospective has at least one attribute that is either a water level > 75 m depth, groundwater salinity > 1500 mg/L TDS or is a very low yielding aquitard.

From the watertable to depths of about 250 m, there are prospective areas associated with the superficial aquifer (namely Tamala Limestone and Bassendean Sands), Lesueur Sandstone near Jurien Bay, valleys over the Leederville-Parmelia on the Dandaragan Plateau, and the Yarragadee aquifer near Eneabba, Hill River (west of Badgingarra) and towards the south of the project area (west of Cataby). At depths of greater than 500 m, there are limited and more restricted areas of prospectivity associated with the Yarragadee aquifer near Eneabba, beneath the Hill River to the west of Badgingarra, and west of Cataby.

The most prospective area of groundwater resource development is the Yarragadee aquifer to the west of Cataby; however, this resource is currently being utilised by large allocations for the mineral sands operations at Cooljarloo and Cataby. There is a small area of prospectivity beneath the Hill River to the west of Badgingarra; however, most of the land is protected within Nature Reserves and National Parks. There is also prospectivity in the Yarragadee aquifer near Eneabba with this groundwater resource being previously developed by the minerals sands industry and capable of providing high-yielding supplies of low-salinity groundwater.

There are large areas of marginal prospectivity to unprospective across the project area. This highlights that not all parts of the northern Perth Basin are prospective for groundwater resource development and that care should be taken to thoroughly understand the regional hydrogeology prior to considering any horticulture operation.

Depending on water supply requirements of a particular activity, the relevance of each groundwater attribute may vary so that more locations could be considered as prospective. In this instance, maps associated with the aquifer yield, groundwater salinity and depth should be consulted individually to identify potential locations of suitable water supplies. For example, where the economics of an activity allow for greater pumping depths, larger areas of the Yarragadee Formation beneath the Arrowsmith Region become prospective west of Badgingarra and north of Eneabba.

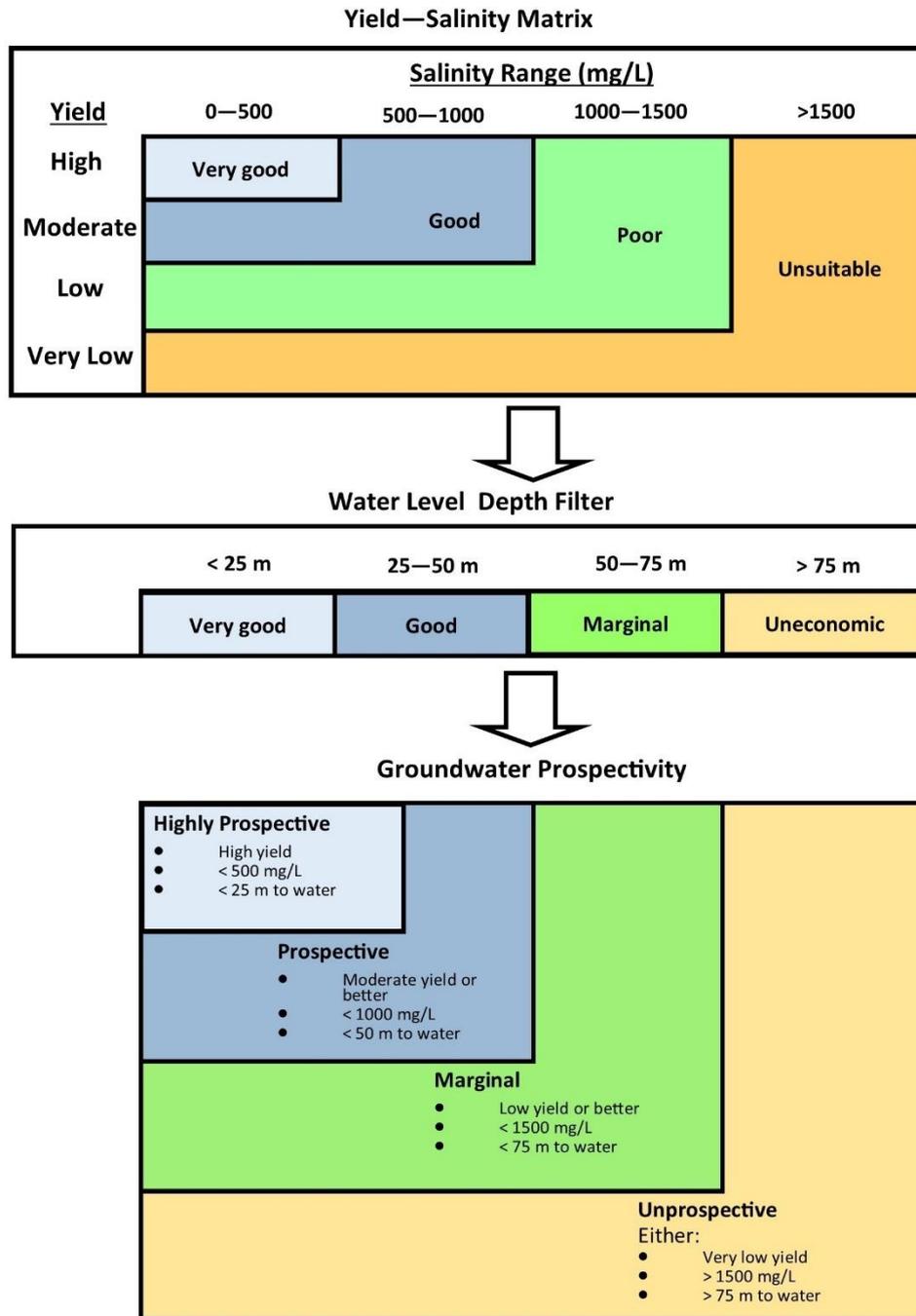


Figure 7-1 Prospectivity chart.

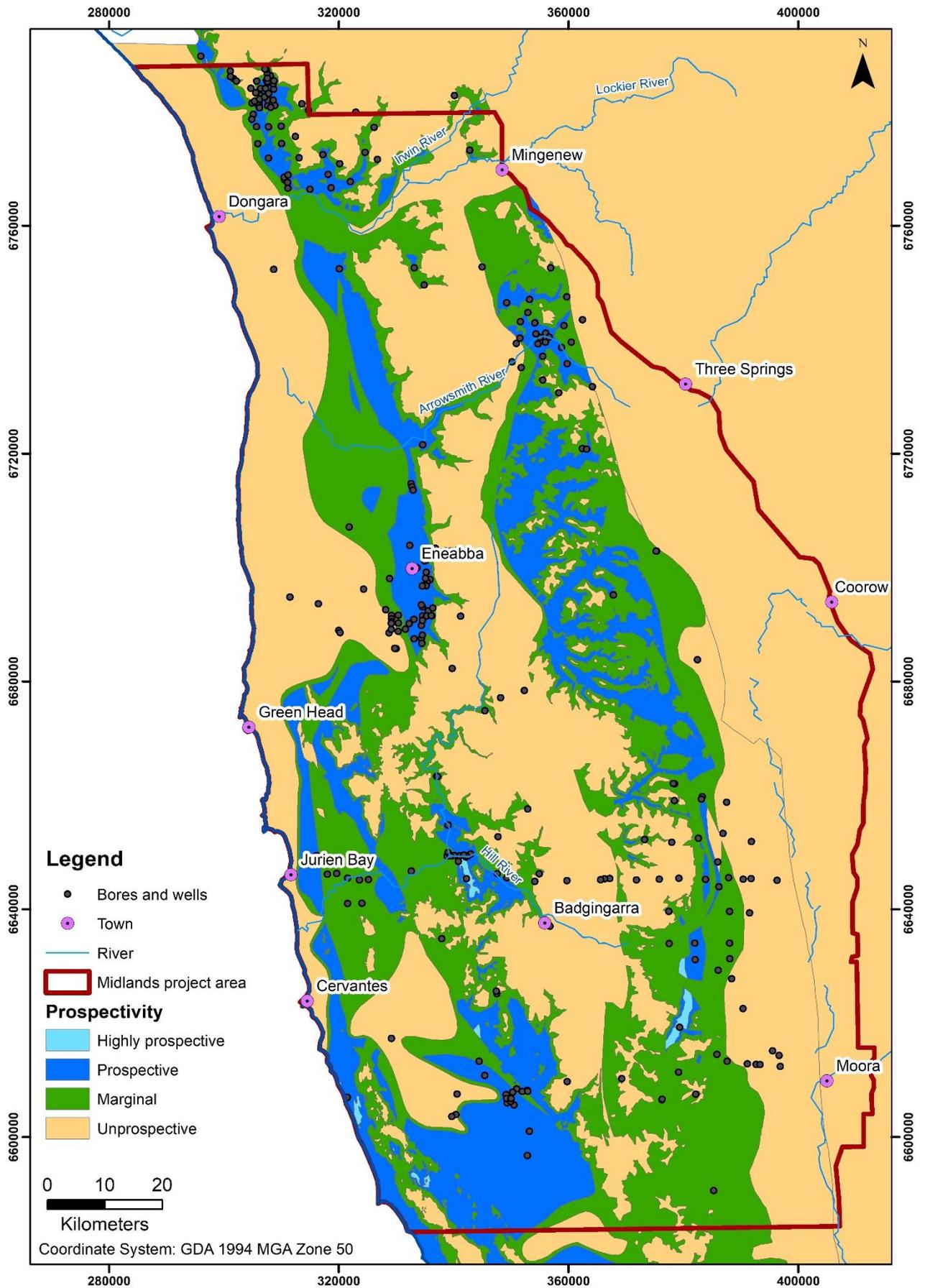


Figure 7-2 Groundwater prospectivity at the watertable.

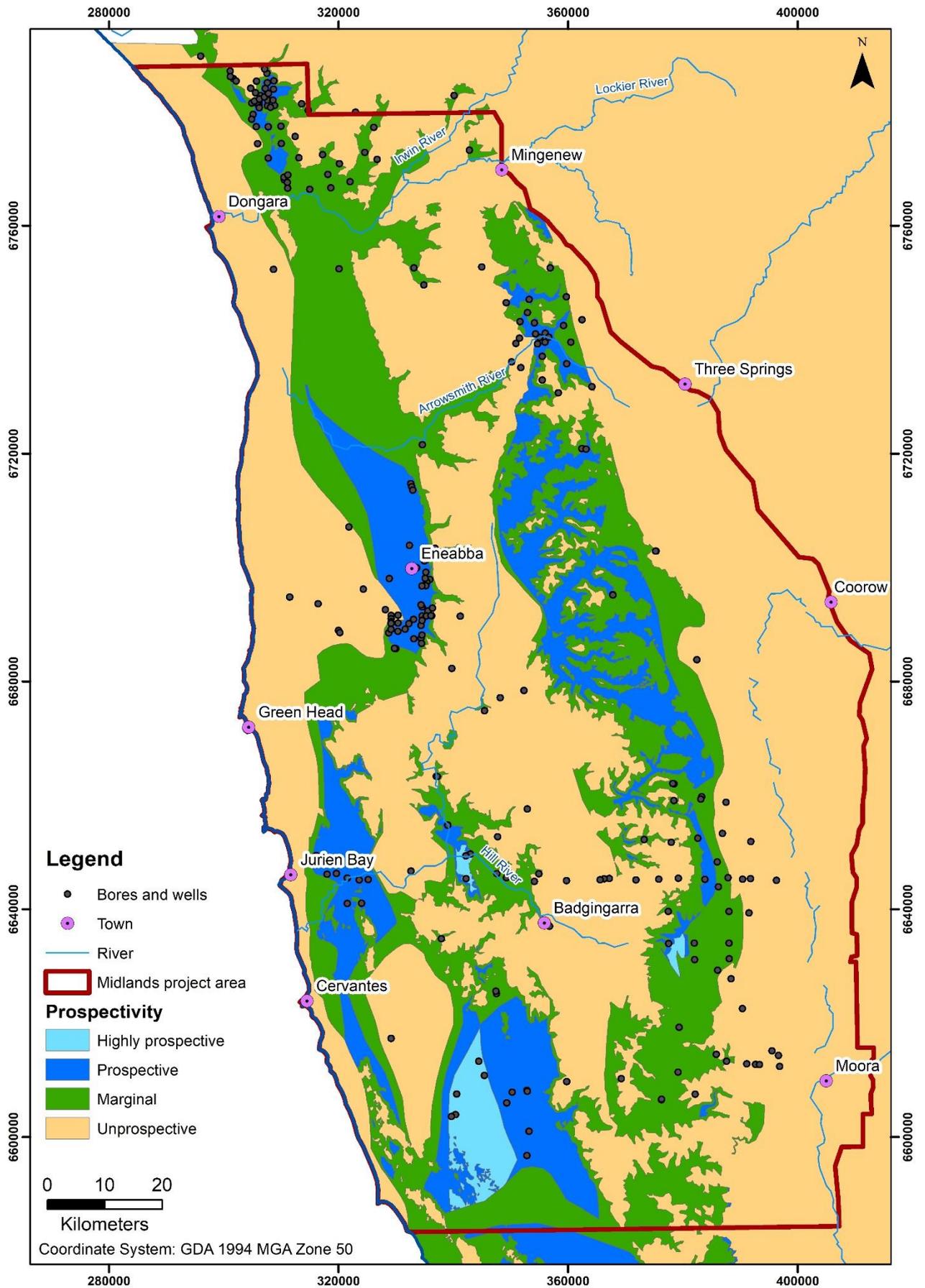


Figure 7-3 Groundwater prospectivity for the 100 m depth slice.

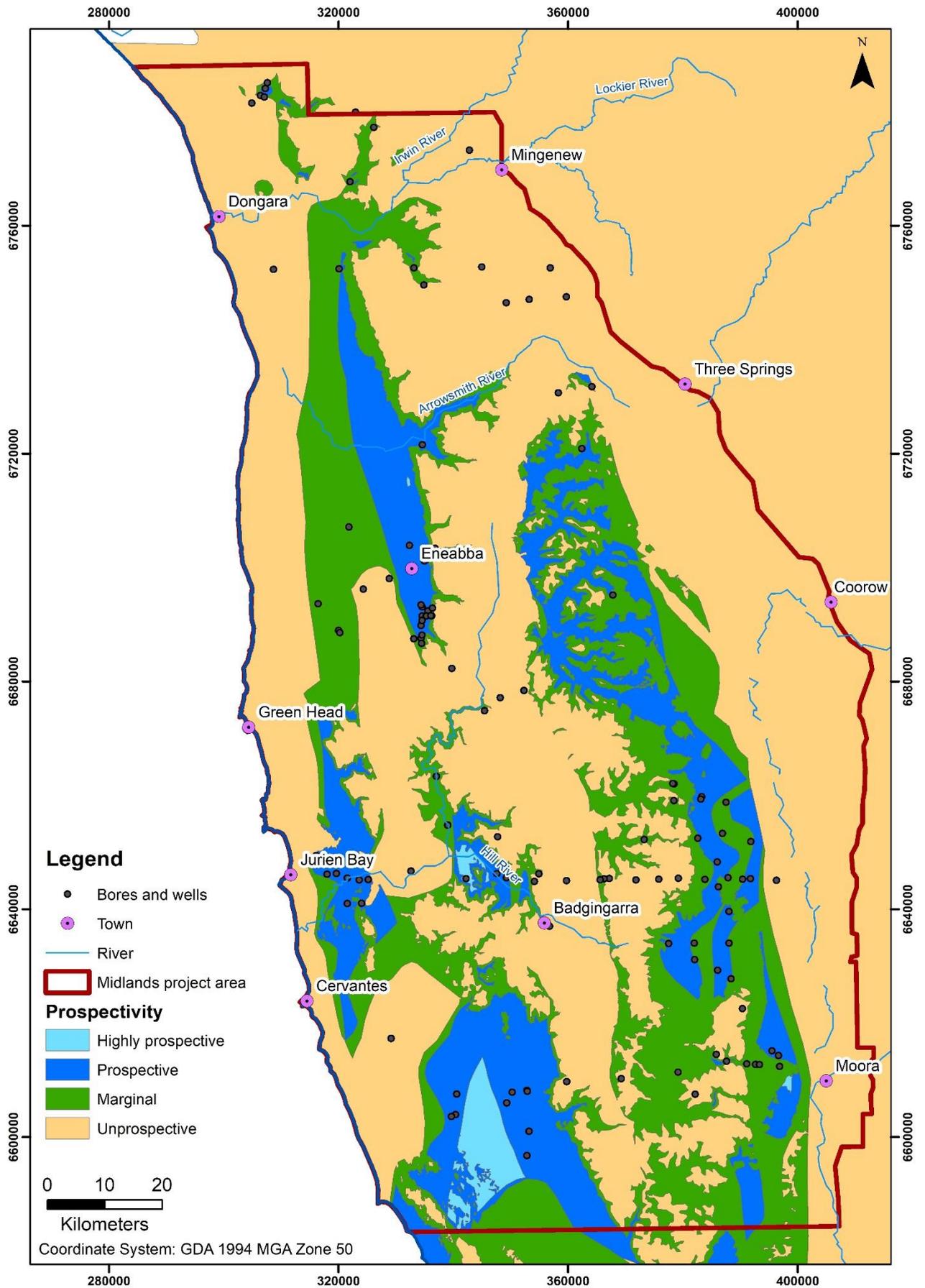


Figure 7-4 Groundwater prospectivity for the 250 m depth slice.

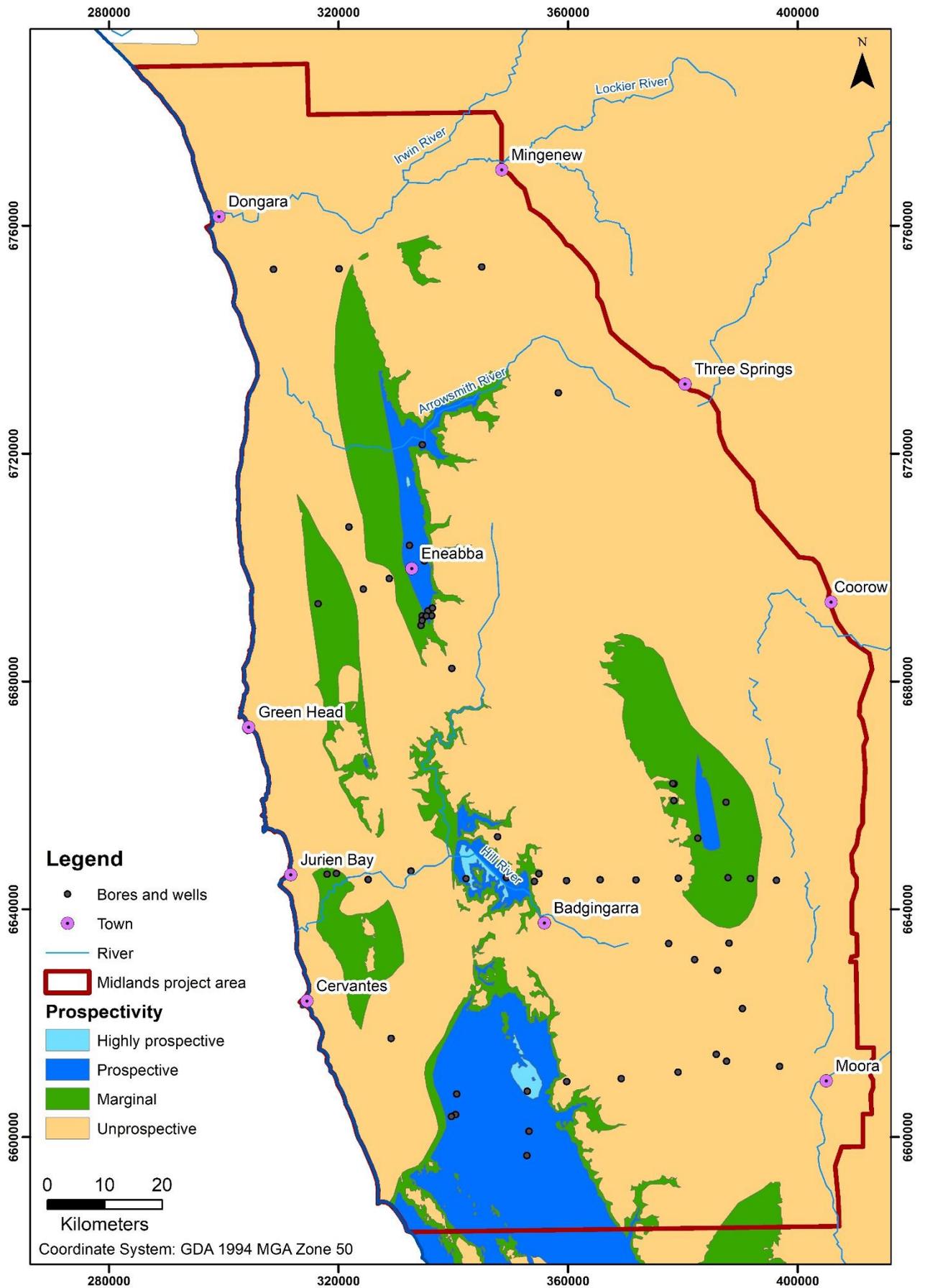


Figure 7-5 Groundwater prospectivity for the 500 m depth slice.

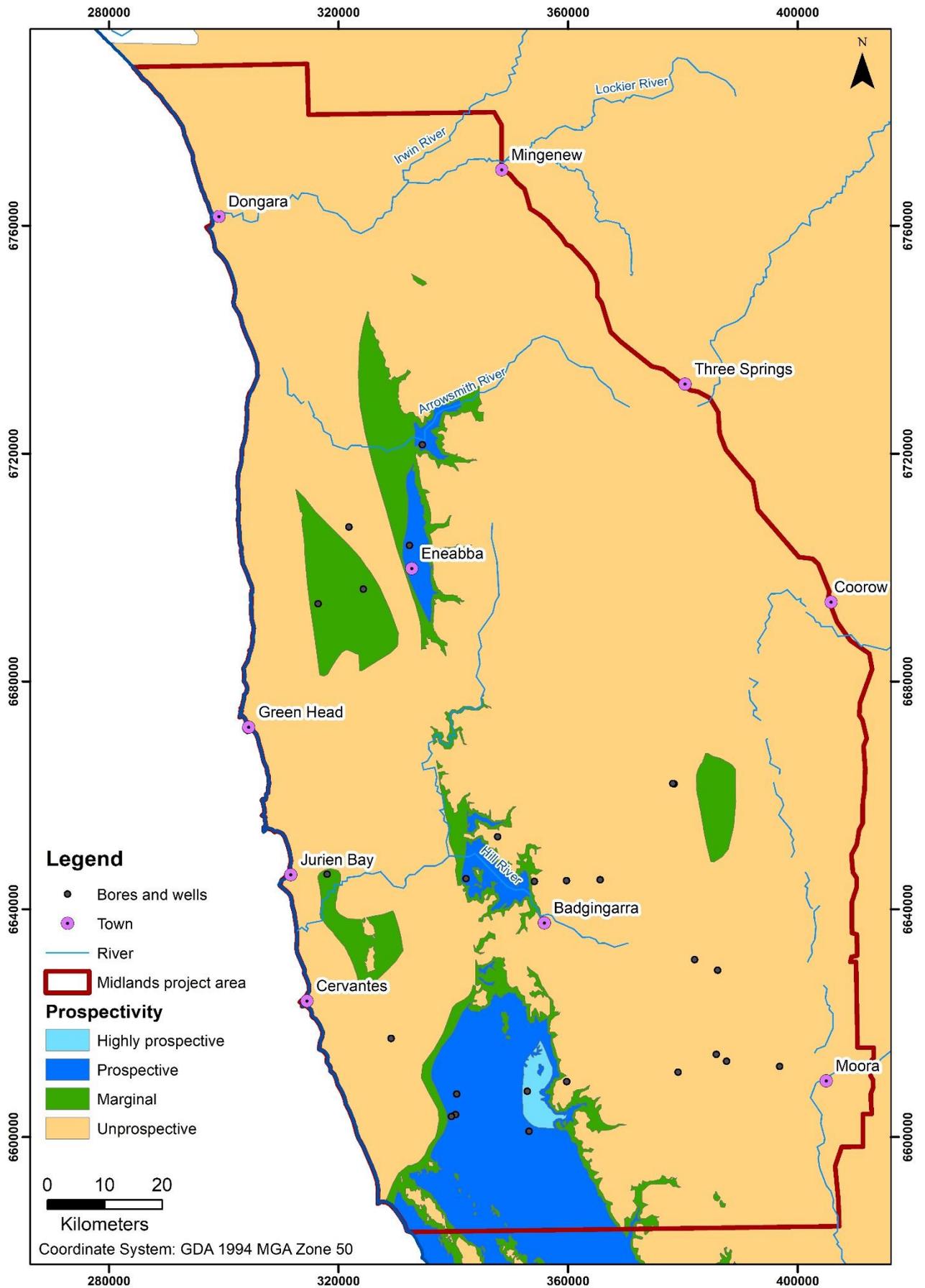


Figure 7-6 Groundwater prospectivity for the 750 m depth slice.

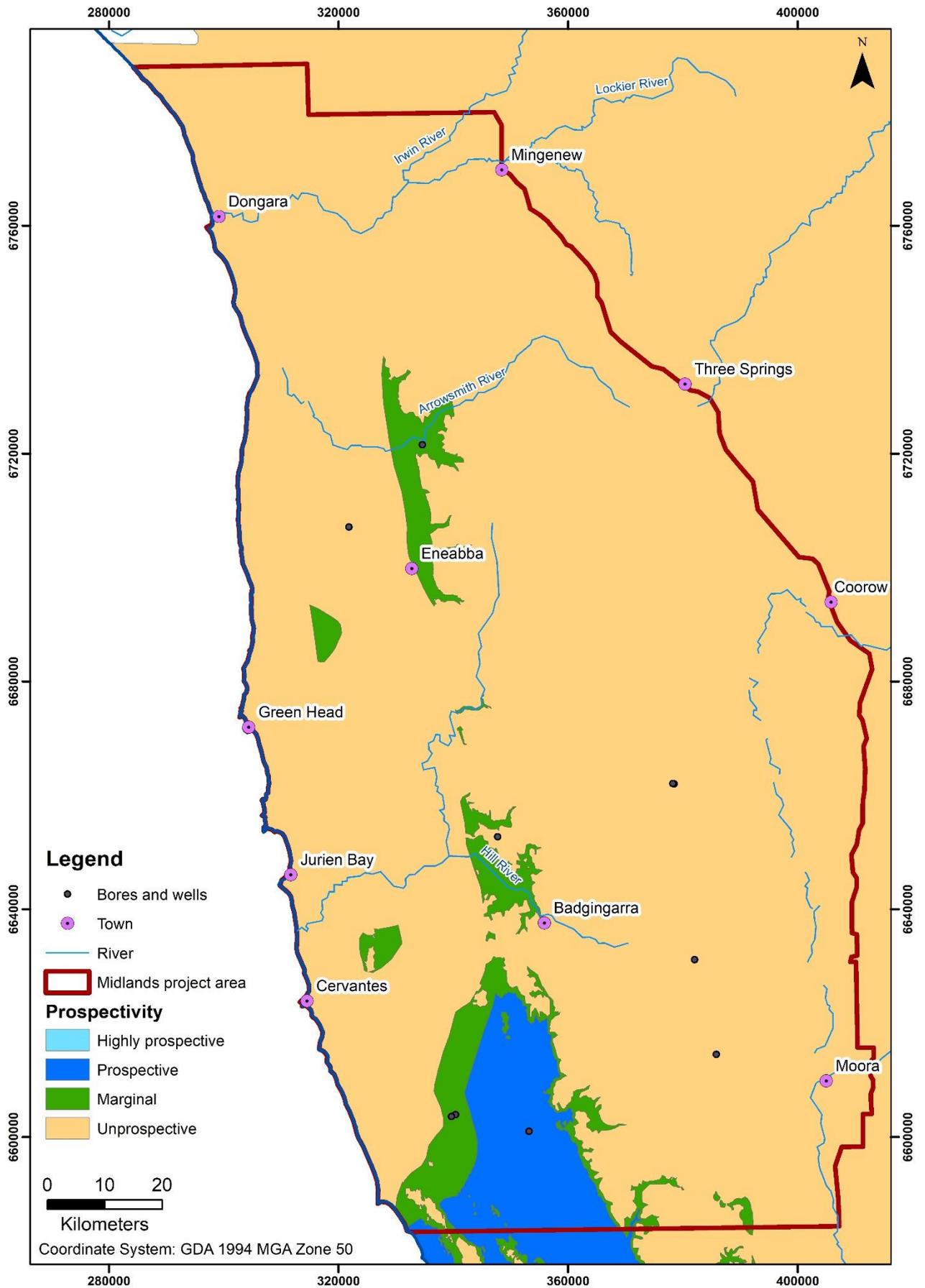


Figure 7-7 Groundwater prospectivity for the 1000 m depth slice.

## 8 Level of confidence

The accuracy of the interpretation for this mapping project is dependent upon the distribution and quality of the point bore and well data. The areas with the greatest concentration of bores and wells are likely to have a higher level of confidence; whereas, areas with fewer bores will have a lower confidence due to the interpretive extrapolation over larger distances. The shallower depths are reached by a greater number of drilled holes, so consequently there is greater confidence of groundwater conditions for the shallower depth slices. Data collected can differ depending on the purpose of the drilled hole. The different hole types are principally government bores drilled for investigation and monitoring purposes, water supply bores (town and private irrigation or mining) and petroleum wells. Figure 8-1 shows the distribution of bores and wells for each depth slice in the project area.

Generally, holes drilled for water supply bores have good water yield and salinity data, but often provide basic geological information, while petroleum wells may have good geological data but have limited water quality data. Although a large number of petroleum wells have been drilled into the basin, particularly in the northern-most portion, most of these wells did not collect data until below potentially suitable aquifer levels and therefore have not contributed to the prospectivity mapping. The most comprehensive data comes from the government monitoring bores.

The most reliable data about the deeper groundwater resources were obtained from exploratory drilling and monitoring bore installation associated with the five deep east–west borehole lines that were drilled about 50 km apart to depths of up to 800 m. These are, in order from north to south: the Dongara Line, Eneabba Line, Watheroo Line, Moora Line, and Gillingarra Line. Boreholes were completed for long-term water level and salinity monitoring where possible, and many sites included multiple bores screened at different depths and in different aquifers.

This understanding of the deeper groundwater resources has been recently complemented by a series of four deep bore lines across the Swan Coastal Plain between Guilderton and Wedge Island to the west and the Gingin Scarp to the east. A total of 29 bores were installed at 12 sites to a maximum depth of 1022 m (Tuffs, 2016). This drilling program focused on the Leederville and Yarragadee aquifers, improving groundwater monitoring and refining the hydrogeological conceptualisation between the Gingin, Gillingarra and Moora deep bore lines.

There have been a number of investigations in the shallow aquifers of the Swan Coastal Plain between Guilderton in the south and Geraldton in the north. More than 200 shallow monitoring bores have been installed, as part of these investigations.

Within both the shallow and deep groundwater resources, numerous investigations have been undertaken as part of town water supply development. Drilling and monitoring information on each of these sources has been collected by the Water Corporation and its predecessors (Public Works Department and Water Authority of Western Australia). There have also been groundwater investigations by mining companies and private developers for irrigated agriculture with a range of shallow and deep production bores being installed.

The degree of confidence in prospectivity mapping is generally greater for areas categorised as Unprospective. This is especially the case east of the Darling Fault which lies outside

the Perth Basin and is underlain by low yielding units with high groundwater salinity. There is also a degree of uncertainty about the boundary of prospectivity classifications, where the actual groundwater conditions representative of one category may extend further than mapped into an adjoining area. Confidence in the prospectivity classification improves further away from a classification boundary.

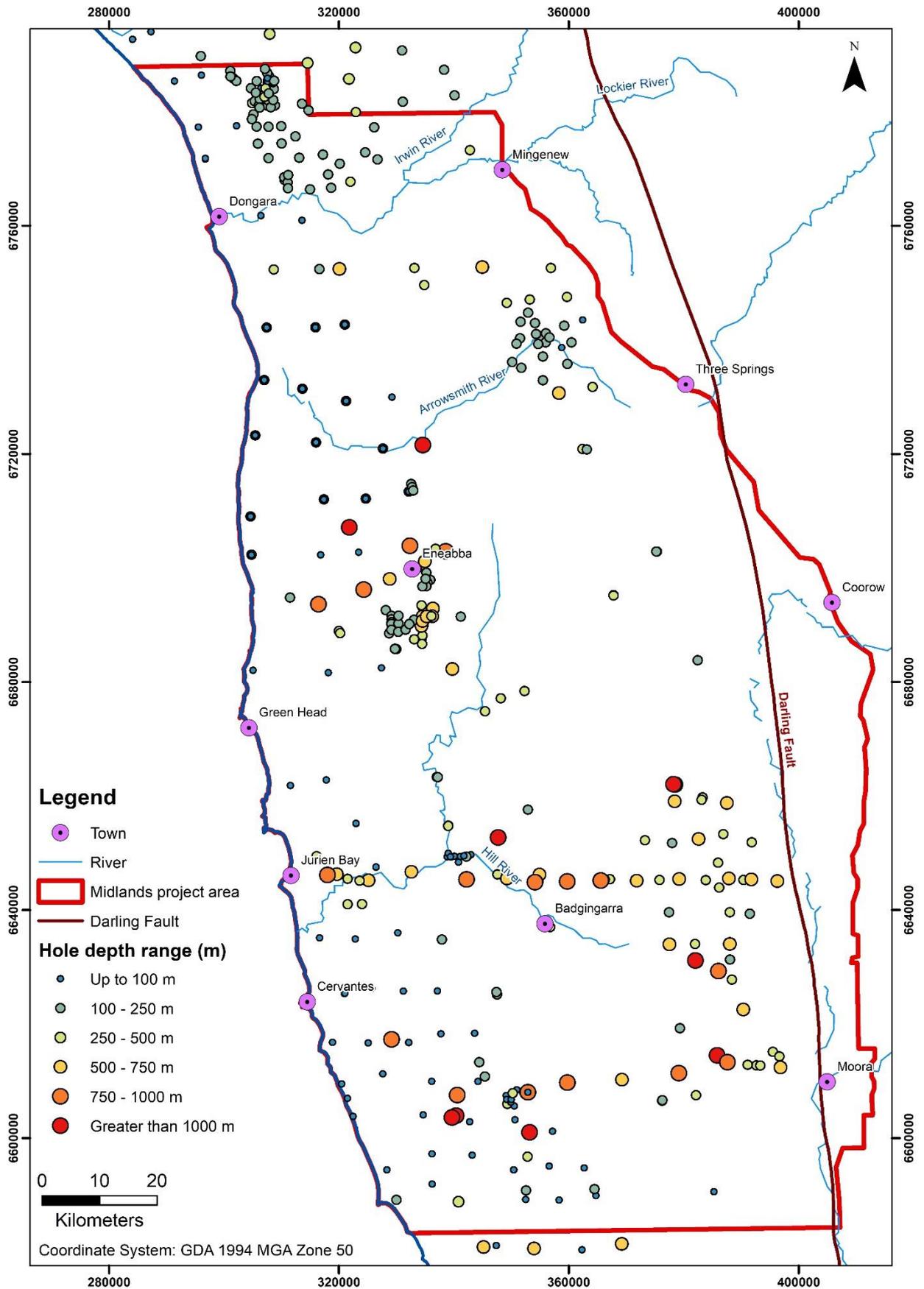


Figure 8-1 Bore and well distribution for the watertable depth slice.

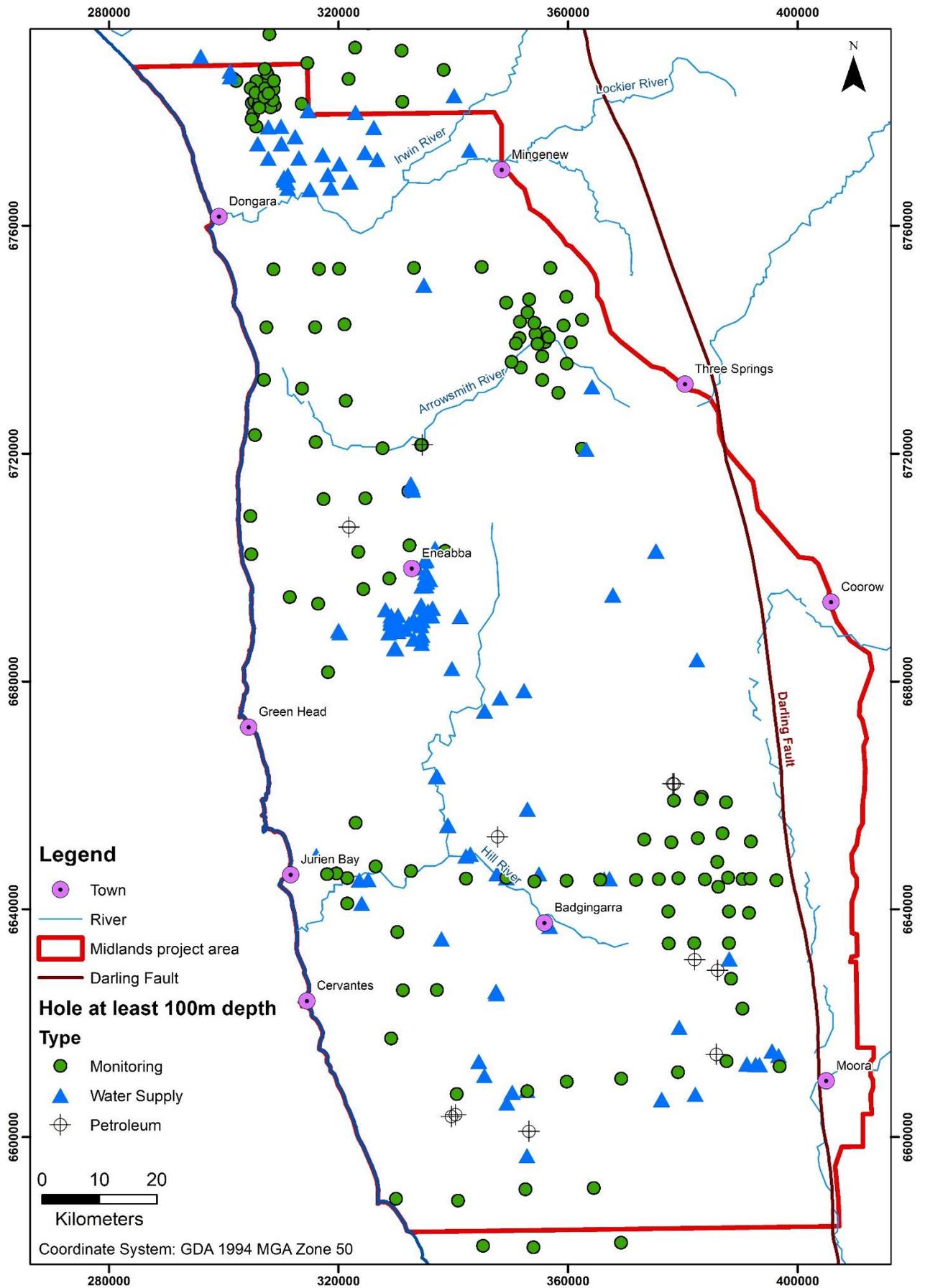


Figure 8-2 Bore and well distribution for the 100 m depth slice.

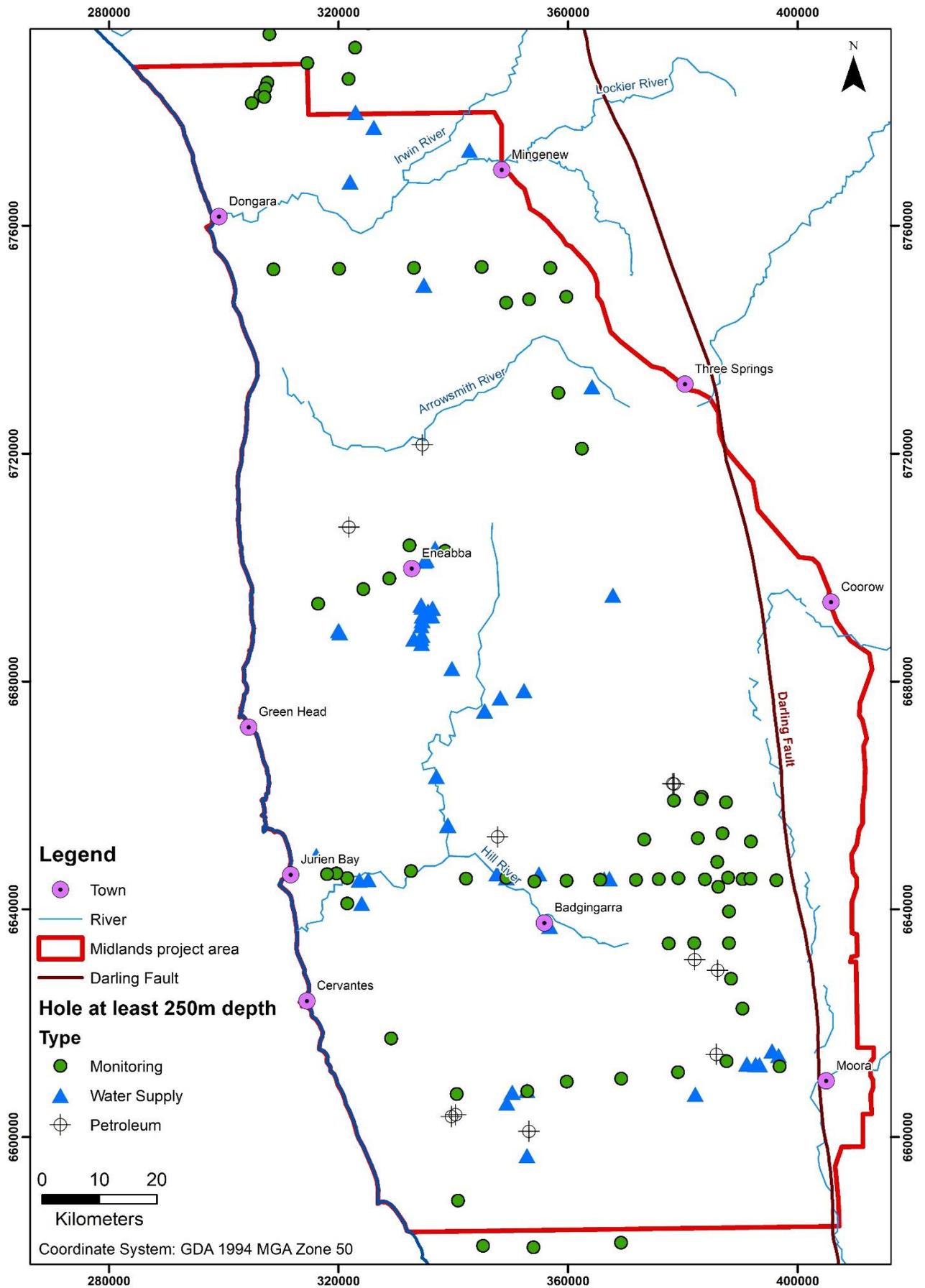


Figure 8-3 Bore and well distribution for the 250 m depth slice.

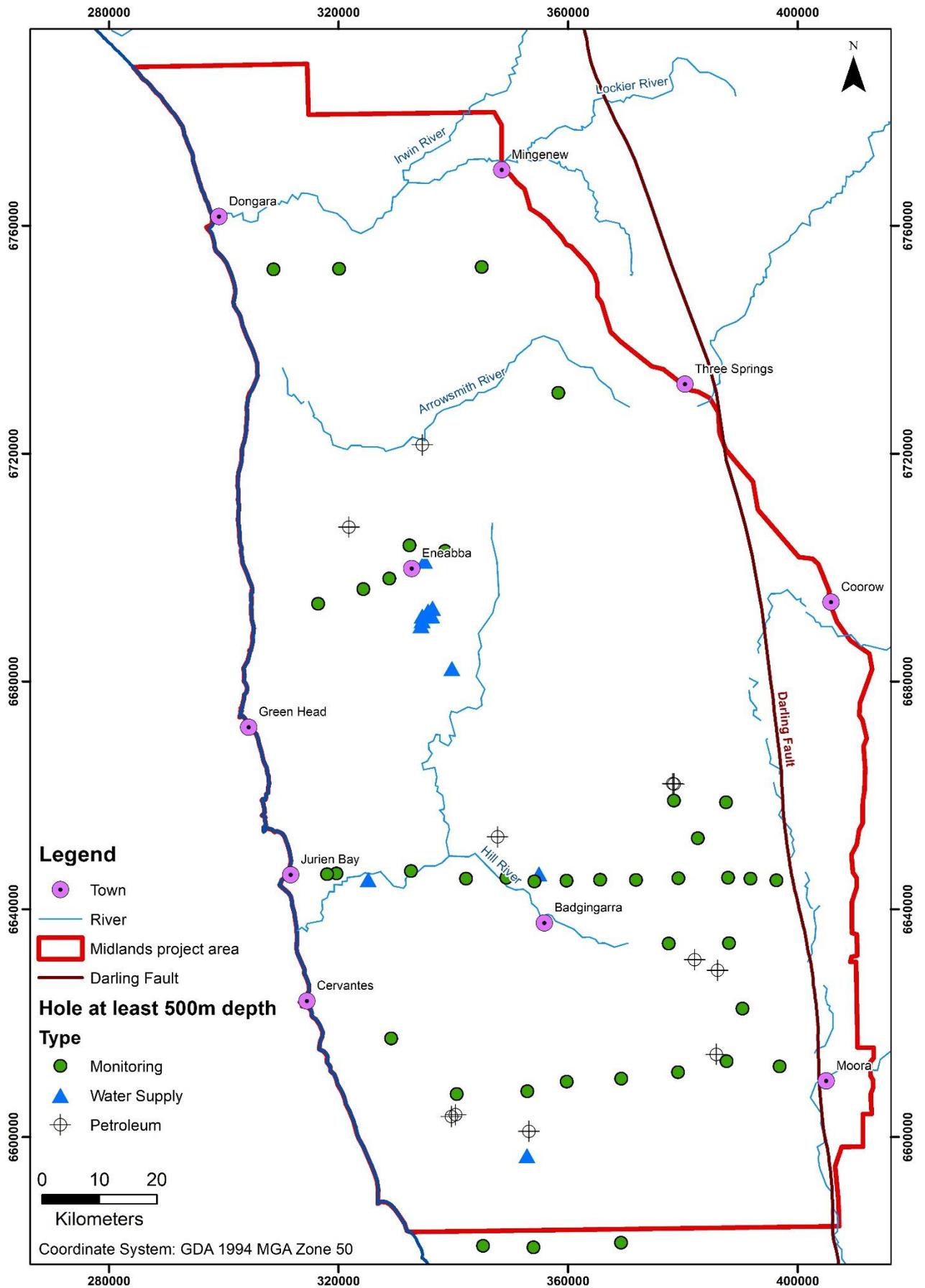


Figure 8-4 Bore and well distribution for the 500 m depth slice.

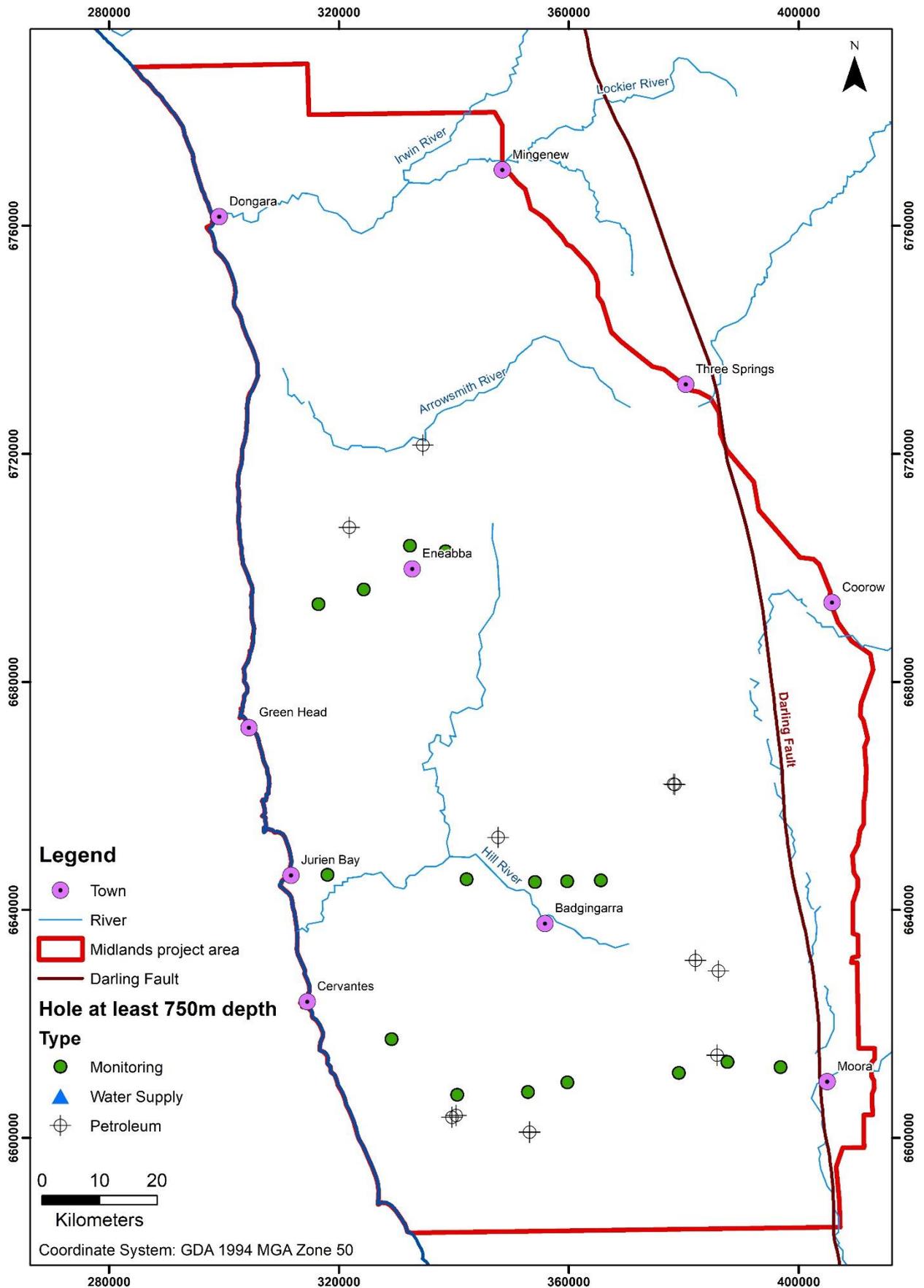


Figure 8-5 Bore and well distribution for the 750 m depth slice.

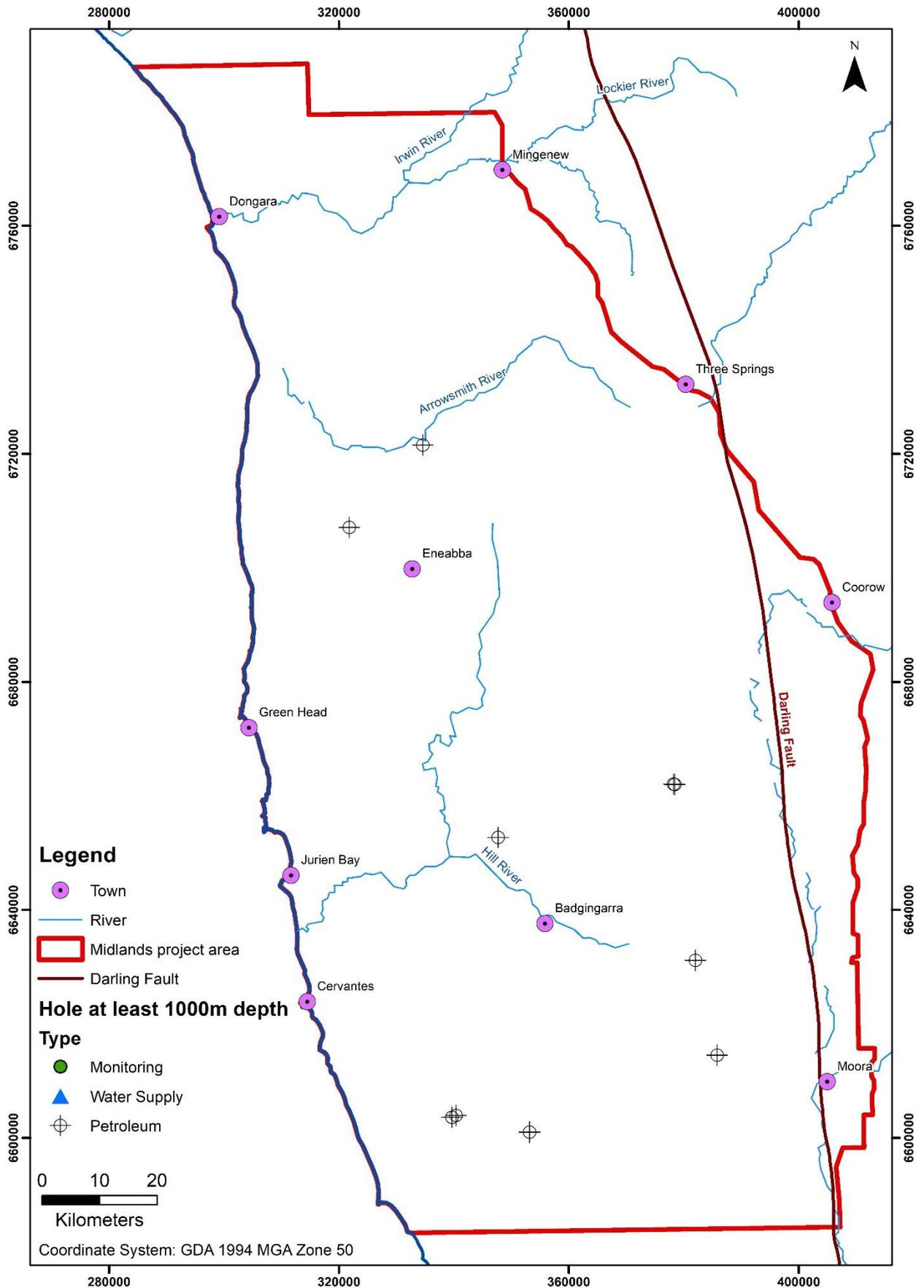


Figure 8-6 Bore and well distribution for the 1000 m depth slice.

## 9 Conclusions

As there has been no previous attempt to develop a groundwater prospectivity layer for the groundwater resources in Western Australia, an original methodology was progressively developed through ongoing discussion and review. The focus was resolving the physical and hydrogeological attributes associated with the groundwater resource, being hydrostratigraphy (major and minor aquifer types and aquitards), groundwater salinity, aquifer yield potential and depth to watertable. Anthropogenic attributes such as resource allocation and GDEs could be assessed subsequently as additional constraints to pumping groundwater.

Prospectivity for each depth slice was derived by combining the yield, salinity and water level depth classifications. Yield and salinity prospectivity has been derived, before being adjusted for the depth to water level. The resultant dataset enables the user to understand groundwater prospectivity for a range of depth slices for any locality within the project area.

From the watertable to depths of about 250 m, prospective areas are associated with the superficial aquifer (namely Tamala Limestone and Bassendean Sands), Lesueur Sandstone near Jurien Bay, incised parts of the Leederville-Parmelia on the Dandaragan Plateau, and the Yarragadee aquifer near Eneabba, Hill River (west of Badgingarra) and towards the south of the project area (west of Cataby). At depths of greater than 500 m, there are limited and more restricted areas of prospectivity associated with the Yarragadee aquifer near Eneabba, beneath the Hill River to the west of Badgingarra, and west of Cataby.

There are large areas of marginal prospectivity to unprospective across the Midlands area. This highlights that not all parts of the northern Perth Basin are prospective for groundwater resource development and that care should be taken to thoroughly understand the regional hydrogeology prior to considering any horticulture operation.

The dataset will be useful for landowners and developers highlighting the opportunities and risks for accessing groundwater resources. It is envisaged that the final groundwater prospectivity and HQAL datasets will be combined to identify land parcels with suitable water and soil conditions across the entire project area. There is also scope for the dataset to be populated into the on-line regional GIS mapping tool (refer to <http://narvis.com.au/>) developed by Northern Agricultural Catchment Committee (NACC).

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