Australian Government

BIOREGIONAL ASSESSMENTS

PROVIDING SCIENTIFIC WATER RESOURCE INFORMATION ASSOCIATED WITH COAL SEAM GAS AND LARGE COAL MINES

Context statement for the Arckaringa subregion

Product 1.1 for the Arckaringa subregion from the Lake Eyre Basin Bioregional Assessment

28 July 2015

A scientific collaboration between the Department of the Environment, Bureau of Meteorology, CSIRO, Geoscience Australia and the Government of South Australia

The Bioregional Assessment Programme

The Bioregional Assessment Programme is a transparent and accessible programme of baseline assessments that increase the available science for decision making associated with coal seam gas and large coal mines. A bioregional assessment is a scientific analysis of the ecology, hydrology, geology and hydrogeology of a bioregion with explicit assessment of the potential direct, indirect and cumulative impacts of coal seam gas and large coal mining development on water resources. This Programme draws on the best available scientific information and knowledge from many sources, including government, industry and regional communities, to produce bioregional assessments that are independent, scientifically robust, and relevant and meaningful at a regional scale.

The Programme is funded by the Australian Government Department of the Environment. The Department of the Environment, Bureau of Meteorology, CSIRO and Geoscience Australia are collaborating to undertake bioregional assessments. For more information, visit http://www.bioregionalassessments.gov.au.

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Authorship is listed in relative order of contribution. This product was prepared by the Government of South Australia (see page viii), in collaboration with the Bioregional Assessment Technical Programme (see page x). The Technical Programme defined products and standards, and reviewed this product (see page xii).

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Cover photograph

Hookeys waterhole in Neales catchment, SA. November 2009

Credit: Dale McNeil (South Australian Research & Development Institute)

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The South Australian Department of Environment, Water and Natural Resources (DEWNR) delivered the contextual statements to the OWS as part of its Coal Seam Gas and Coal Mining Water Knowledge program which consisted of three projects: Lake Eyre Basin Rivers Monitoring; Lake Eyre Basin Springs Assessment; and Arckaringa and Pedirka Groundwater Investigations. Technical advice to these projects was provided through reference committees comprising representatives as appropriate of: Bureau of Meteorology; CSIRO Land and Water; Department for Land and Resource Management (NT); Department of Natural Resources and Mines (Queensland); Department of Environment Water and Natural Resources (SA); Department of Science, Information Technology, Innovation, and the Arts (Queensland); Department of State Development (SA); Flinders University; Geoscience Australia; Goyder Institute for Water Research; Lake Eyre Basin Community Advisory Committee; Lake Eyre Basin Rivers Assessment, Department of the Environment; SA Arid Lands Natural Resources Management Board; South Australian Research and Development Institute; The University of Adelaide.

Introduction

The Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) was established to provide advice to the federal Minister for the Environment on potential water-related impacts of coal seam gas (CSG) and large coal mining developments.

Bioregional assessments (BAs) are one of the key mechanisms to assist the IESC in developing this advice so that it is based on best available science and independent expert knowledge. Importantly, technical products from BAs are also expected to be made available to the public, providing the opportunity for all other interested parties, including government regulators, industry, community and the general public, to draw from a single set of accessible information. A BA is a scientific analysis, providing a baseline level of information on the ecology, hydrology, geology and hydrogeology of a bioregion with explicit assessment of the potential direct, indirect and cumulative impacts of CSG and coal mining development on water resources.

The IESC has been involved in the development of *Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources* (the BA methodology; Barrett et al., 2013) and has endorsed it. The BA methodology specifies how BAs should be undertaken. Broadly, a BA comprises five components of activity, as illustrated in Figure 1. Each BA will be different, due in part to regional differences, but also in response to the availability of data, information and fit-for-purpose models. Where differences occur, these are recorded, judgments exercised on what can be achieved, and an explicit record is made of the confidence in the scientific advice produced from the BA.

The Bioregional Assessment Programme

The Bioregional Assessment Programme is a collaboration between the Department of the Environment, the Bureau of Meteorology, CSIRO and Geoscience Australia. Other technical expertise, such as from state governments or universities, is also drawn on as required. For example, natural resource management groups and catchment management authorities identify assets that the community values by providing the list of water-dependent assets, a key input.

The Technical Programme, part of the Bioregional Assessment Programme, will undertake BAs for the following bioregions and subregions:

- the Galilee, Cooper, Pedirka and Arckaringa subregions, within the Lake Eyre Basin bioregion
- the Maranoa-Balonne-Condamine, Gwydir, Namoi and Central West subregions, within the Northern Inland Catchments bioregion
- the Clarence-Moreton bioregion
- the Hunter and Gloucester subregions, within the Northern Sydney Basin bioregion
- the Sydney Basin bioregion
- the Gippsland Basin bioregion.

Technical products (described in a later section) will progressively be delivered throughout the Programme.

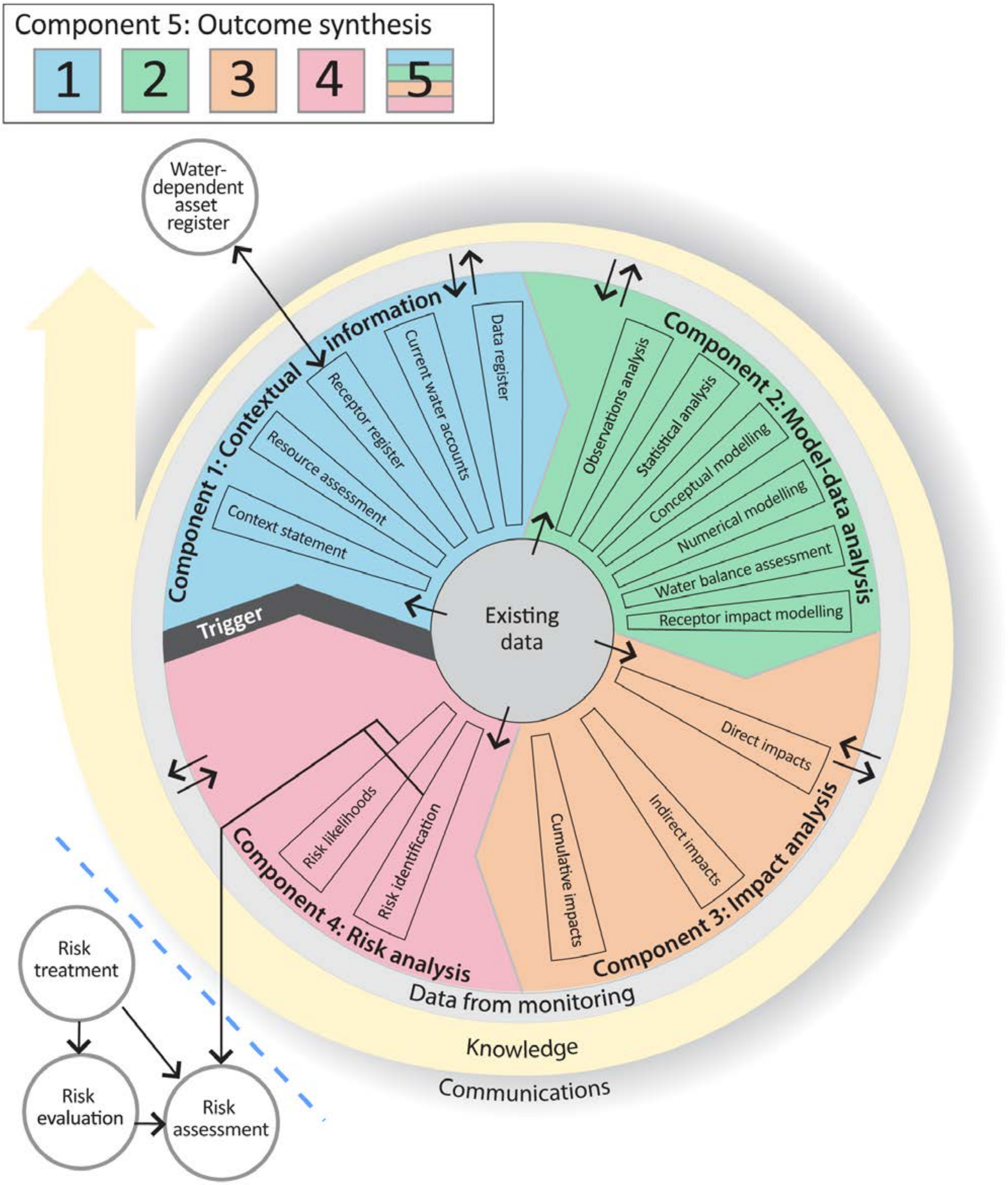

Figure 1 Schematic diagram of the bioregional assessment methodology

The methodology comprises five components, each delivering information into the bioregional assessment and building on prior components, thereby contributing to the accumulation of scientific knowledge. The small grey circles indicate activities external to the bioregional assessment. Risk identification and risk likelihoods are conducted within a bioregional assessment (as part of Component 4) and may contribute activities undertaken externally, such as risk evaluation, risk assessment and risk treatment. Source: Figure 1 in Barrett et al. (2013), © Commonwealth of Australia

Methodologies

For transparency and to ensure consistency across all BAs, submethodologies have been developed to supplement the key approaches outlined in the *Methodology for bioregional assessments of the impact of coal seam gas and coal mining development on water resources* (Barrett et al., 2013). This series of submethodologies aligns with technical products as presented in Table 1. The submethodologies are not intended to be 'recipe books' nor to provide step-by-step instructions; rather they provide an overview of the approach to be taken. In some instances, methods applied for a particular BA may need to differ from what is proposed in the submethodologies – in this case an explanation will be supplied. Overall, the submethodologies are intended to provide a rigorously defined foundation describing how BAs are undertaken.

Table 1 Methodologies and associated technical products listed in Table 2

Code	Proposed title	Summary of content	Associated technical product
M01	*Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources*	A high-level description of the scientific and intellectual basis for a consistent approach to all bioregional assessments	All
M02	*Compiling water-dependent assets*	Describes the approach for determining water-dependent assets	1.3 Description of the water-dependent asset register
M03	*Assigning receptors and impact variables to water-dependent assets*	Describes the approach for determining receptors associated with water-dependent assets	1.4 Description of the receptor register
M04	*Developing a coal resource development pathway*	Specifies the information that needs to be collected and reported in product 1.2 (i.e. known coal and coal seam gas resources as well as current and potential resource developments). Describes the process for determining the coal resource development pathway (reported in product 2.3)	1.2 Coal and coal seam gas resource assessment 2.3 Conceptual modelling
M05	*Developing the conceptual model for causal pathways*	Describes the development of the conceptual model for causal pathways, which summarises how the 'system' operates and articulates the links between coal resource developments and impacts on receptors	2.3 Conceptual modelling
M06	*Surface water modelling*	Describes the approach taken for surface water modelling across all of the bioregions and subregions. It covers the model(s) used, as well as whether modelling will be quantitative or qualitative.	2.6.1 Surface water numerical modelling
M07	*Groundwater modelling*	Describes the approach taken for groundwater modelling across all of the bioregions and subregions. It covers the model(s) used, as well as whether modelling will be quantitative or qualitative. It also considers surface water – groundwater interactions, as well as how the groundwater modelling is constrained by geology.	2.6.2 Groundwater numerical modelling

Code	Proposed title	Summary of content	Associated technical product
M08	*Receptor impact modelling*	Describes how to develop the receptor impact models that are required to assess the potential impacts from coal seam gas and large coal mining on receptors. Conceptual, semi-quantitative and quantitative numerical models are described.	2.7 Receptor impact modelling
M09	*Propagating uncertainty through models*	Describes the approach to sensitivity analysis and quantifying uncertainty in the modelled hydrological response to coal and coal seam gas development	2.3 Conceptual modelling 2.6.1 Surface water numerical modelling 2.6.2 Groundwater numerical modelling 2.7 Receptor impact modelling
M10	*Risk and cumulative impacts on receptors*	Describes the process to identify and analyse risk	3 Impact analysis 4 Risk analysis
M11	*Hazard identification*	Describes the process to identify potential water-related hazards from coal and coal seam gas development	2 Model-data analysis 3 Impact analysis 4 Risk analysis
M12	*Fracture propagation and chemical concentrations*	Describes the likely extent of both vertical and horizontal fractures due to hydraulic stimulation and the likely concentration of chemicals after production of coal seam gas	2 Model-data analysis 3 Impact analysis 4 Risk analysis

Each submethodology is available online at <http://www.bioregionalassessments.gov.au>. Submethodologies might be added in the future.

Technical products

The outputs of the BAs include a suite of technical products variously presenting information about the ecology, hydrology, hydrogeology and geology of a bioregion and the potential direct, indirect and cumulative impacts of CSG and coal mining developments on water resources, both above and below ground. Importantly, these technical products are available to the public, providing the opportunity for all interested parties, including community, industry and government regulators, to draw from a single set of accessible information when considering CSG and large coal mining developments in a particular area.

The information included in the technical products is specified in the BA methodology. Figure 2 shows the information flow within a BA. Table 2 lists the content provided in the technical products, with cross-references to the part of the BA methodology that specifies it. The red rectangles in both Figure 2 and Table 2 indicate the information included in this technical product.

This technical product is delivered as a report (PDF). Additional material is also provided, as specified by the BA methodology:

- all unencumbered data syntheses and databases
- unencumbered tools, model code, procedures, routines and algorithms
- unencumbered forcing, boundary condition, parameter and initial condition datasets
- the workflow, comprising a record of all decision points along the pathway towards completion of the BA, gaps in data and modelling capability, and provenance of data.

The PDF of this technical product, and the additional material, are available online at http://www.bioregionalassessments.gov.au.

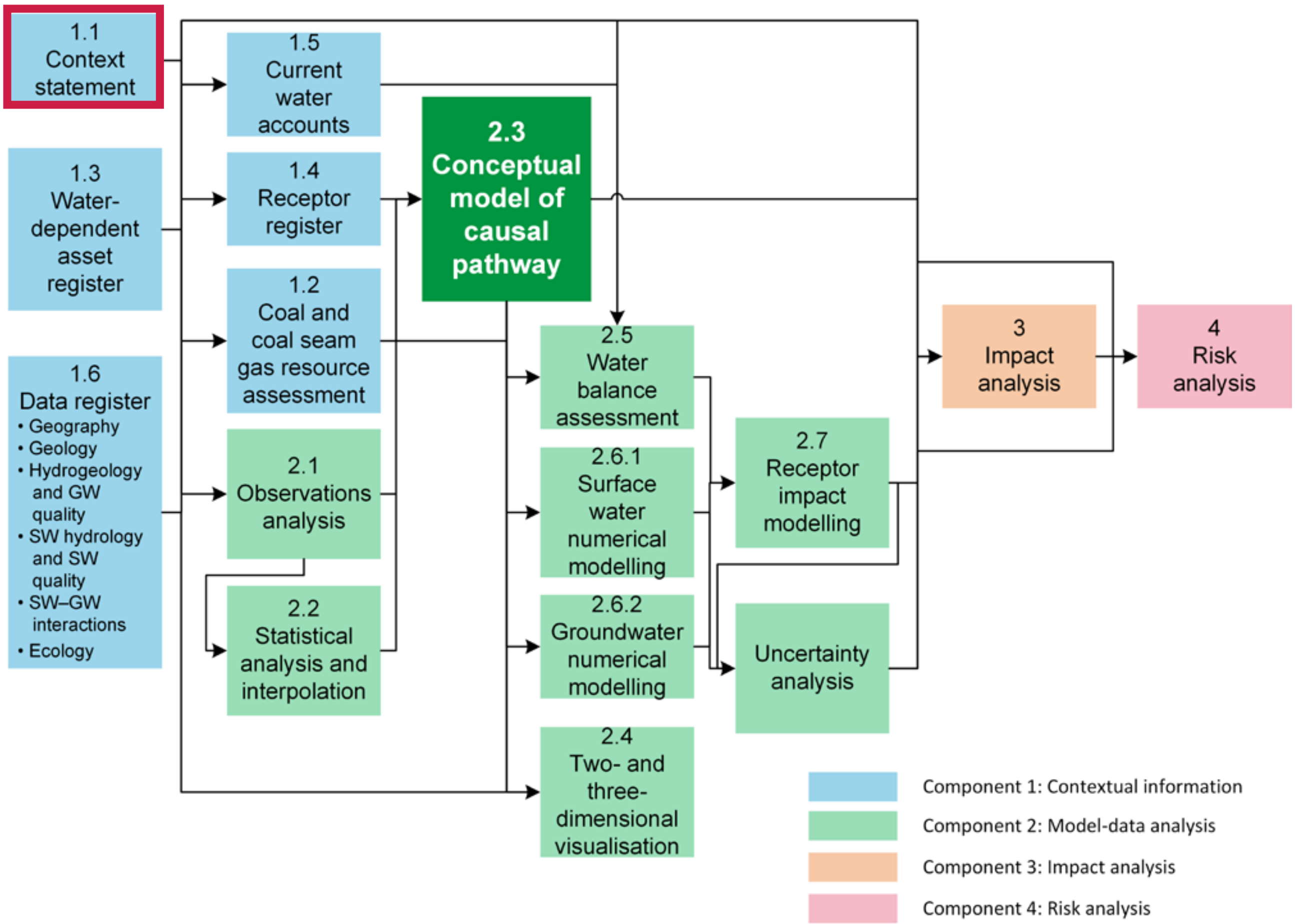

Figure 2 The simple decision tree indicates the flow of information through a bioregional assessment

The red rectangle indicates the information included in this technical product.

Table 2 Technical products being delivered as part of the Lake Eyre Basin Bioregional Assessment

For each subregion in the Lake Eyre Basin Bioregional Assessment, technical products are delivered online at http://www.bioregionalassessments.gov.au, as indicated in the 'Type' columna. Other products – such as datasets, metadata, data visualisation and factsheets – are provided online.

Component	Product code	Title	Section in the BA methodology[b]	Type[a]
Component 1: Contextual information for the Arckaringa subregion	1.1	Context statement	2.5.1.1, 3.2	PDF, HTML
	1.2	Coal and coal seam gas resource assessment	2.5.1.2, 3.3	Cross-reference
	1.3	Description of the water-dependent asset register	2.5.1.3, 3.4	PDF, HTML, register
	1.4	Description of the receptor register	2.5.1.4, 3.5	Cross-reference
	1.5	Current water accounts and water quality	2.5.1.5	Cross-reference
	1.6	Data register	2.5.1.6	Register
Component 2: Model-data analysis for the Arckaringa subregion	2.1-2.2	Observations analysis, statistical analysis and interpolation	2.5.2.1, 2.5.2.2	Cross-reference
	2.3	Conceptual modelling	2.5.2.3, 4.3	Cross-reference
	2.5	Water balance assessment	2.5.2.4	Cross-reference
	2.6.1	Surface water numerical modelling	4.4	Cross-reference
	2.6.2	Groundwater numerical modelling	4.4	Cross-reference
	2.7	Receptor impact modelling	2.5.2.6, 4.5	Not produced
Component 3: Impact analysis for the Arckaringa subregion	3-4	Impact analysis	5.2.1	Cross-reference
Component 4: Risk analysis for the Arckaringa subregion		Risk analysis	2.5.4, 5.3	
Component 5: Outcome synthesis for the Lake Eyre Basin bioregion	5	Outcome synthesis	2.5.5	PDF, HTML

[a]The types of products are as follows:
- 'PDF' indicates a PDF document that is developed by the Lake Eyre Basin Bioregional Assessment using the structure, standards, and look and feel specified by the programme.
- 'HTML' indicates the same content as in the PDF document, but delivered as webpages.
- 'Register' indicates controlled lists that are delivered using a variety of formats as appropriate.
- 'Cross-reference' indicates material that does not use the same structure, standards, and look and feel specified by the programme. This material is typically developed externally or through aligned research projects funded by the Department of the Environment. A webpage links to this material and explain how it fits into the Assessment.
- 'Not produced' indicates that the product was not developed. A webpage explains why and points to relevant submethodologies (Table 1).

[b]*Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources* (Barrett et al., 2013)

About this technical product

The following notes are relevant only for this technical product.

- The context statement is a collation of existing information and thus in some cases figures are reproduced from other sources. These figures were not redrawn for consistency (with respect to 'look and feel' as well as content), and the resolution and quality reflects that found in the source.
- All reasonable efforts were made to provide all material under a Creative Commons Attribution 3.0 Australia Licence.
- All maps created as part of this BA for inclusion in this product used the Albers equal area projection with a central meridian of 141.0° East for the Lake Eyre Basin bioregion and two standard parallels of –18.0° and –36.0°.
- Contact bioregionalassessments@bom.gov.au to access metadata (including copyright, attribution and licensing information) for all datasets cited or used to make figures in this product. At a later date, this information, as well as all unencumbered datasets, will be published online.

References

Barrett DJ, Couch CA, Metcalfe DJ, Lytton L, Adhikary DP and Schmidt RK (2013) Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources. A report prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development through the Department of the Environment. Department of the Environment, Australia. Viewed 10 November 2015, http://www.iesc.environment.gov.au/publications/methodology-bioregional-assessments-impacts-coal-seam-gas-and-coal-mining-development-water.

1.1 Context statement for the Arckaringa subregion

The context statement brings together what is currently known about the geography, ecology, hydrology, geology and hydrogeology of a subregion or bioregion. It provides baseline information that is relevant to understanding the regional context of water resources and water-dependent assets, which might be impacted by coal and coal seam gas development. Information is collated that is relevant to interpret the impact analysis, risk analysis and outcomes of the bioregional assessment.

The context statement includes materially relevant characteristics of a subregion or bioregion that are needed to adequately interpret output from ecological, surface water and groundwater datasets and models, and from this develop improved knowledge of whole-of-system functioning.

No new analysis or modelling is presented in the context statement; rather it draws on existing information. Thus, some figures are reproduced from other sources and the look and feel of these external figures is not consistent with those produced in the bioregional assessment. Likewise, results from different sources may use different methods or inconsistent units.

1.1.1 Bioregion

The Arckaringa subregion is part of the Lake Eyre Basin bioregion (Figure 3). The Lake Eyre Basin bioregion covers an area of approximately 1.31 million km^2 of central and north-eastern Australia, including parts of Queensland, NSW, SA and the NT (Figure 3). The Lake Eyre Basin bioregion incorporates the whole of the Kati Thanda – Lake Eyre surface drainage basin as well as portions of several adjacent surface drainage catchments. The main areas of interest within the Lake Eyre Basin bioregion are principally those underlain by four separate coal-bearing geological basins – the Pedirka and Arckaringa basins in the west, and the Galilee and Cooper basins in the east.

The Galilee, Cooper, Pedirka and Arckaringa basin areas each define subregions within Lake Eyre Basin bioregion. Each of these subregions will be the subject of a bioregional assessment.

1.1.1.1 Definitions used

The Arckaringa subregion is located entirely in SA (Figure 4), and is defined by the extent of the Arckaringa geological basin (see Section 1.1.1 for further detail). The subregion spans an area of about 82,505 km^2 and extends west beyond the Kati Thanda – Lake Eyre surface drainage catchment into the Gairdner surface drainage catchment. The whole of the Arckaringa geological basin is though included within the Lake Eyre Basin bioregion.

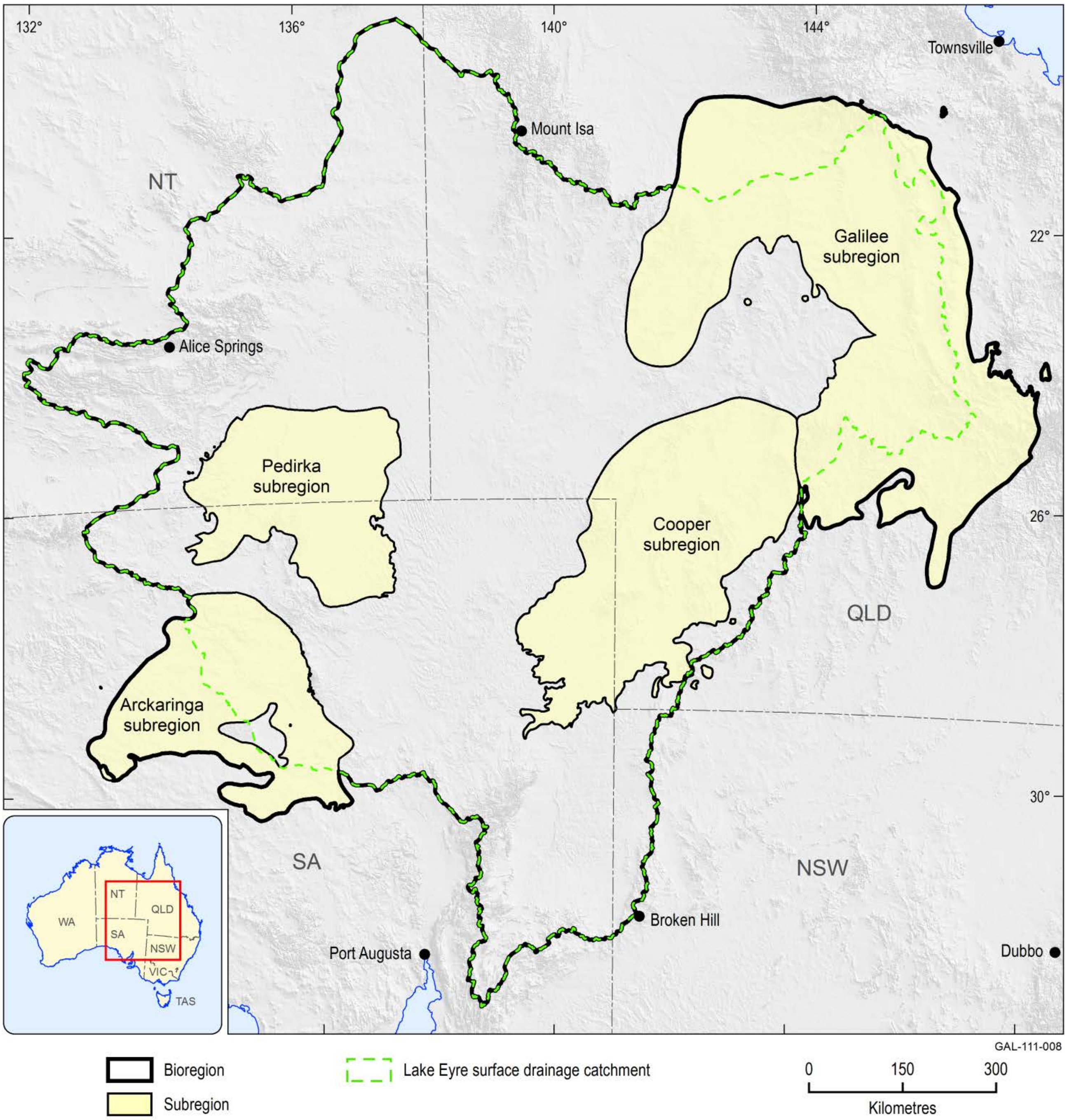

Figure 3 Lake Eyre Basin bioregion and subregions

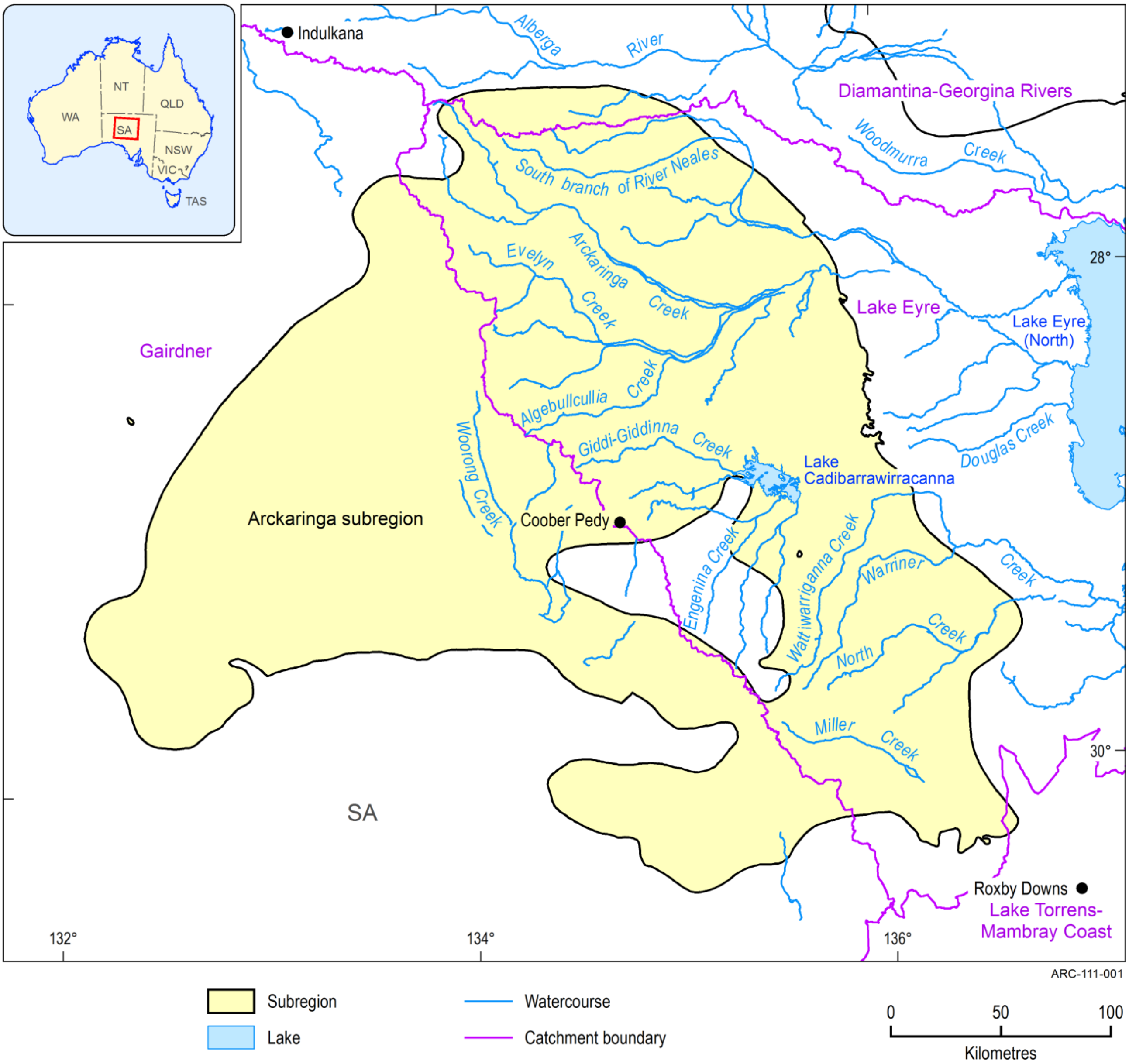

Figure 4 Arckaringa subregion showing surface water catchments

1.1.2 Geography

Summary

The Arckaringa subregion is located in northern SA, approximately 600 km north-northwest of Adelaide. The Arckaringa subregion is composed of a largely flat-lying, desert landscape of sand dunes and gibber planes and vegetation adapted to surviving in an arid climate.

Coober Pedy is the largest town within the subregion, with a population of approximately 2000 people. Other towns of significance immediately outside the subregion include Roxby Downs, Marla and Oodnadatta. Parts of the Maralinga Tjarutja and the Pitjantjatjara, Yankunytjatjara and Ngaanyatjarra (or Anangu) Indigenous freehold lands are situated within the subregion.

The pastoral industry represents the predominant land use across the subregion, while mining and tourism are increasingly becoming important industries.

With respect to water use in the Arckaringa subregion, the majority of water supply is derived from groundwater as surface water resources are small and unreliable. Of the groundwater supplies present, most is taken from the Great Artesian Basin (GAB), with some supplies derived from the underlying Arckaringa Basin.

The climate of central Australia is generally arid. Central Australian weather is dominated by persistent high pressure systems, which have an important influence on temperatures in the subregion. Any rainfall the subregion receives predominantly comes from weak winter cold fronts originating from the Southern Indian Ocean or sporadic summer monsoon rainfall that originates in northwest Australia; rainfall for the region averages 150 mm/year, although this can vary significantly from year to year.

1.1.2.1 Physical geography

The Arckaringa subregion is located in northern SA (Figure 5), approximately 600 km north-northwest of Adelaide and 400 km south of Alice Springs. The subregion area is based on the subsurface extent of the Arckaringa geological basin (Arckaringa Basin), which covers an area of approximately 100,000 km^2. The subregion is bordered by a series of ranges, ridges and plateaux that includes the Gawler Ranges to the south and south-west, the Ooldea Ranges to the south-west and west, the Everard Ranges and Central Australian Plateau to the west, the Bitchera Ridge to the north, the Peake and Denison Inlier (Denison and Davenport Range) to the east and the Stuart Shelf to the south-east. A low-rising escarpment of silcrete-capped Cretaceous sediments called the Stuart Range transects the Arckaringa Basin from south to north. The Stuart Range is of particular importance to the Arckaringa subregion as it marks the western limit of the Kati Thanda – Lake Eyre hydrological basin.

Aeolian-driven erosion as described by Mabbutt (1977) is an important process shaping the physiology of the region. Consequently, the topography of the Arckaringa subregion is largely flat-lying, with dominant landscape features controlled by longitudinal and lunette dune fields or gravelly (‘gibber’) plains and tablelands. These environments support perennial grasses and sparse chenopod, samphire or saltbush shrubland vegetation (Marla-Oodnadatta Soil Conservation Board, 2002). Ground elevation across the subregion ranges between 20 mAHD and 380 mAHD. Additionally, anastomosing channels that form wide, gently sloped valleys, swales and floodplains also provide topographic variability. These environments support stands of coolabah, Gidgee and small areas of River Red Gum vegetation (Marla-Oodnadatta Soil Conservation Board, 2002).

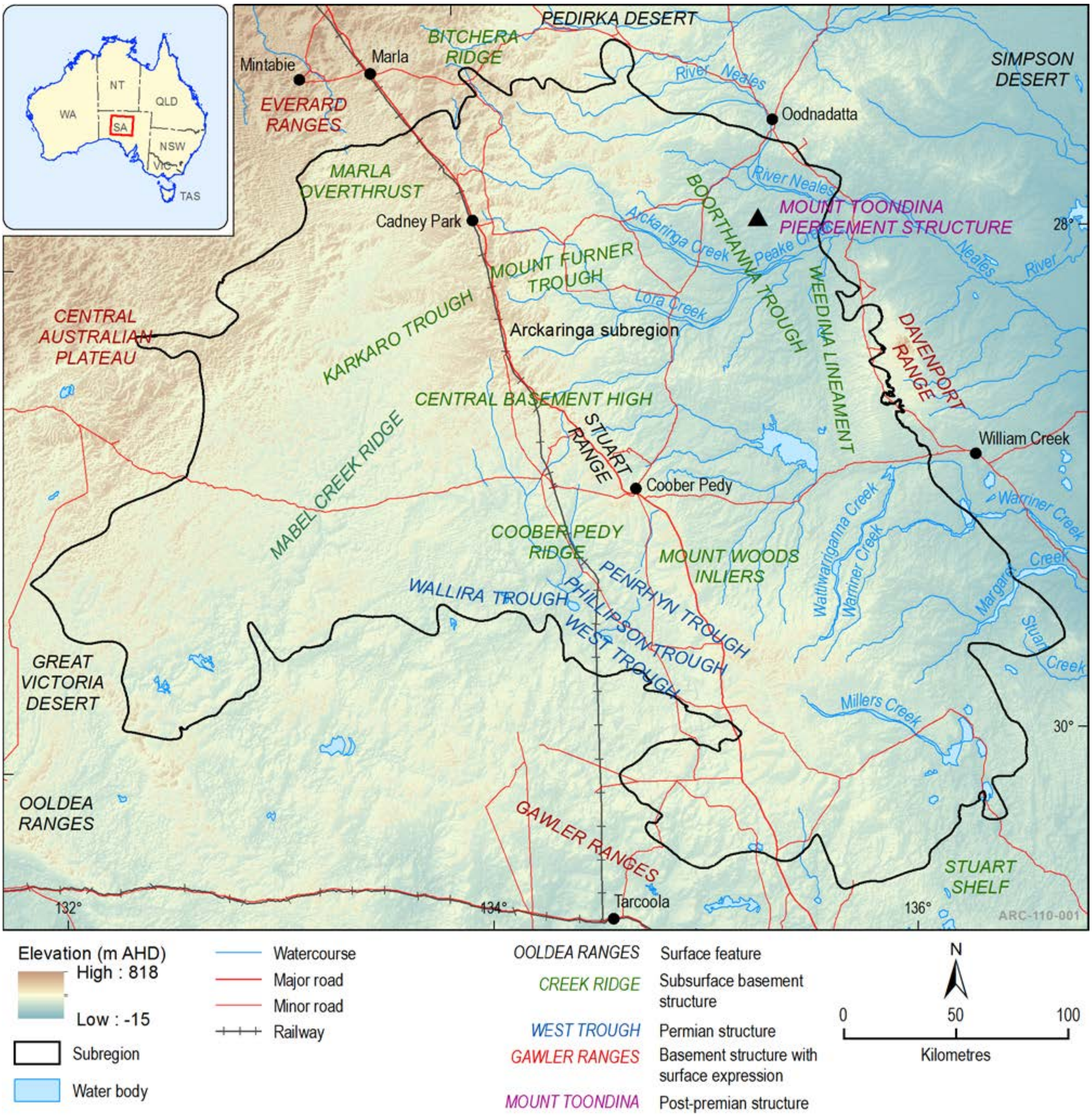

Figure 5 Physical geography of the Arckaringa subregion

The subregion boundary used in this and following maps is a more detailed representation (than that used in the preceeding maps) based on the extent of the Pedirka geological basin

1.1.2.2 Human geography

The Arckaringa subregion includes the Local Government Area of Coober Pedy and portions of Indigenous freehold lands, including the Maralinga Tjarutja and the Pitjantjatjara, Yankunytjatjara and Ngaanyatjarra (or Anangu) lands. Coober Pedy is the largest town within the subregion, with a population of approximately 2000 people. Other towns of significance immediately outside the subregion include Roxby Downs (population ~3600), Marla (population ~100) and Oodnadatta (population ~300). The population density across the Arckaringa subregion is <0.1 persons/km^2 (ABS, 2007).

1.1.2.2.1 Land use

The pastoral industry represents the predominant land use across the Arckaringa subregion (Figure 6) being established soon after European exploration of the region (Smerdon et al., 2012). There is a primary focus of beef-cattle production, while some sheep production occurs in the vicinity of Coober Pedy and the southern and central regions of the Arckaringa subregion.

In recent times, mining has become an important industry in the subregion, although activity remains restricted in geographic extent. Opal mining occurs within the Coober Pedy Proclaimed Precious Stones Field, while copper, gold and iron ore are mined towards the south-eastern corner of the Arckaringa Basin at the Prominent Hill, Peculiar Knob, and Cairn Hill mining operations (Wohling et al., 2012).

Tourism is an important activity in the region, although, like mining, only covers a small geographical extent. Tourism is largely concentrated along the main transport routes, towns and conservation parks. A number of conservation parks are located within and in close proximity to the Arckaringa subregion; these include the Wabma Kadarbu, Kati Thanda – Lake Eyre and Witjira National Parks (NP), the Simpson Desert Regional Reserve (RR) and Tallaringa Conservation Park (CP), and the Mount Willoughby Indigenous Protection Area (IPA). Specific tourist attractions within the subregion include Coober Pedy and its opal mining industry, the breakaways, the Painted Desert, Great Artesian Basin (GAB) springs and historical infrastructure associated with the Old Ghan Railway and Overland Telegraph Line. The subregion also contains numerous sites of Indigenous significance. The Woomera Prohibited Area (WPA) overlaps the southern portion of the Arckaringa subregion (Keppel et al., 2013; Smerdon et al., 2012; Wohling et al., 2012).

1.1.2.2.2 Water use

Surface water resources within the subregion are small in volume and unreliable in supply; Sibenaler (2010) describes the use of surface water as generally limited to opportunistic pastoral industry supplies and roof runoff harvested via tank systems for domestic purposes. Consequently the majority of water supplies for the region are sourced from groundwater, with the GAB being the primary source.

According to SAAL NRMB (2009), the primary users of GAB groundwater in the South Australian portion of the GAB outside of springs and wetlands included stock and domestic and the mining and petroleum industries. Future projections suggest that groundwater use by the mining, petroleum and energy production industries may increase (Fluin et al., 2009).

SAAL NRMB (2009) suggested that GAB springs provided the single largest 'demand' for GAB groundwater resources within their area of jurisdiction; while the volume of water to springs was expected to remain similar going forward, increases in water demand from extractive industries suggested that it would no longer be the largest 'user' of groundwater resources into the future. It should be noted that management of GAB springs in the general vicinity of the Arckaringa subregion is based upon groundwater pressures within the GAB aquifer in the vicinity of springs, rather than through volume allocation. Consequently such comparisons between springs and commercial groundwater abstractions should be qualitative only.

Currently the single largest known user of groundwater resources from Arckaringa Basin aquifers is the Prominent Hill Mining operation, which has licences to extract up to 26.6 ML/day from two borefields located within the south-eastern corner of the Arckaringa Basin (SKM, 2009).

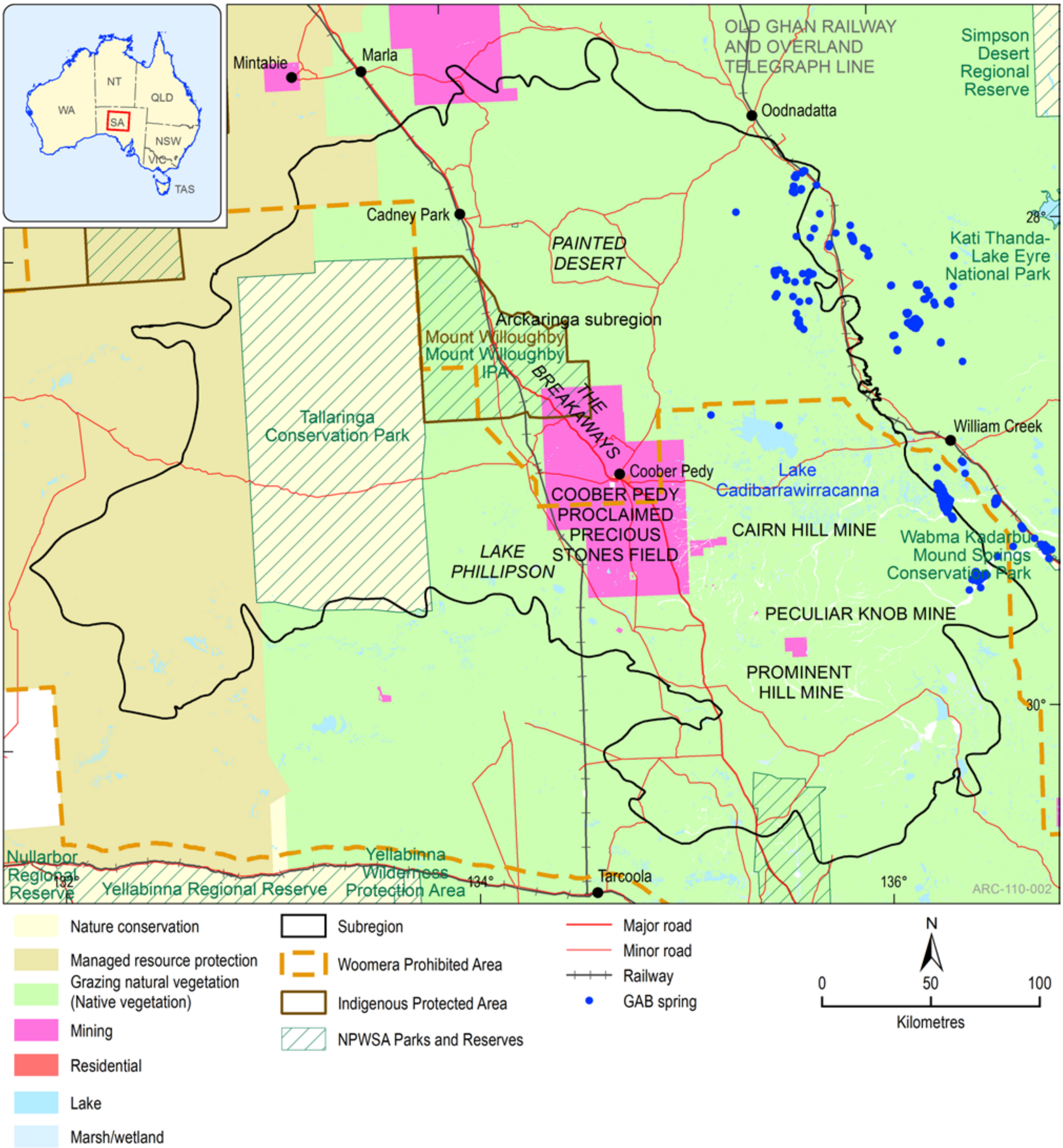

Figure 6 Land use and human geography of the Arckaringa subregion

1.1.2.3 Climate

The climate of the Arckaringa subregion has been described by Allan (1990) and McMahon et al. (2005) as arid; while Stern et al. (2000), using a modified version of the Köppen climate scheme, describes the region as 'desert'. Weather in the subregion tends to be dominated by persistent high pressure systems; the location of the dominant high pressure system is an important influence on temperature in the region. Average maximum peak-summer monthly temperatures range between 35 °C and 38 °C, although daily maximums are regularly above 40 °C. In contrast, the minimum peak-winter monthly temperatures range from 5 °C to 6 °C, although daily minimums may drop below 0 °C, with monthly averages shown in Figure 7.

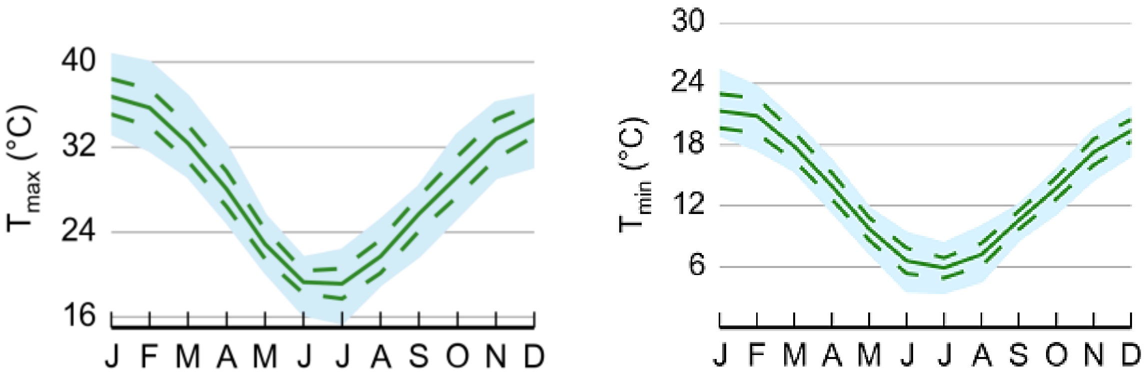

Figure 7 Monthly maximum and minimum temperature

Source: Bioregional Assessment Programme (2014)

Mean annual rainfall varies between 130 and 170 mm across the majority of the region, with higher totals in excess of 200 mm found in the higher reaches of the Stuart Range and Denison and Davenport Range (Figure 8). Averaged across the region, the long term mean annual rainfall is 153 mm. The variability of rainfall over the subregion is both spatially and temporally among the highest in Australia (Allan, 1985). Key rainfall events in the subregion range from convective thunderstorms with limited spatial extent, but often with high intensities, to large transient depressions of tropical origin (Allan, 1985; Croke et al., 1999) that result in regional flooding. Although the majority of rainfall in the Arckaringa subregion occurs in the summer months, significant winter rains are not uncommon (Costelloe et al., 2005). This can be seen in Figure 9 where although there is little variation in the mean monthly precipitation depth, the extremes of rainfall in the summer months are very significant.

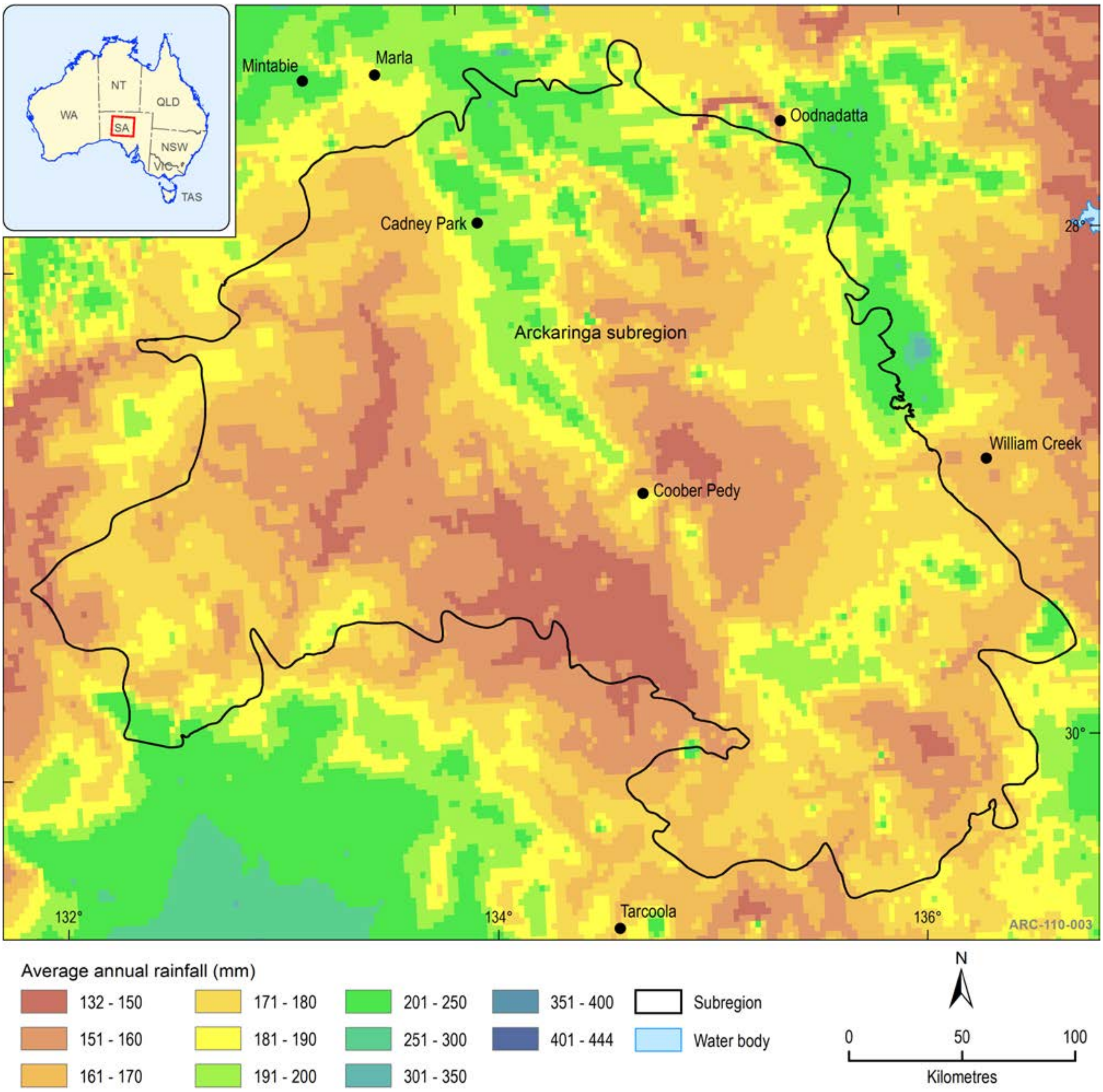

Figure 8 Mean annual rainfall in the Arckaringa subregion

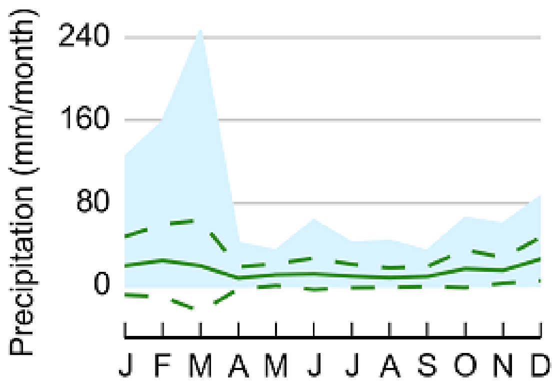

Figure 9 Monthly precipitation depths

Source: Bioregional Assessment Programme (2014)

Table 3 shows rainfall summaries for selected sites in the Arckaringa subregion, with their locations shown in Figure 10. Of note is that the influence of summer monsoonal rains seems to diminish towards the south of the region. The northernmost site, Oodnadatta, receives over 40% of its annual total in the summer months (December – February). Further south, Coober Pedy, receives around 35% of annual falls in the same period and the southernmost site, Tarcoola, (Bulginna) only 28% in that period. These observations highlight the complexities inherent in water resource modelling in this area.

Table 3 Rainfall summary for selected sites in the Arckaringa subregion

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
017043 Oodnadatta Airport 1939 – present; Elevation: 113 m													
Mean rainfall (mm)	23.4	32.4	14.3	11.0	12.6	11.1	9.8	7.8	10.0	13.9	13.3	17.2	176.6
016007 Coober Pedy 1921 – present; Elevation: 213 m													
Mean rainfall (mm)	15.0	20.1	12.6	6.1	12.4	12.3	7.0	7.8	8.0	13.3	11.1	15.1	140.8
016003 Tarcoola (Bulginna) 1931 – present; Elevation: 168 m													
Mean rainfall (mm)	14.4	19.6	15.0	7.8	10.9	11.6	8.0	11.3	9.6	15.4	12.7	14.9	151.1

As seen in Figure 11 and Figure 12, mean annual point potential evapotranspiration (PET) and pan evaporation increase on a general north-east gradient, with PET varying from 2150 mm in the south-west to 2750 mm in the north-east. Pan evaporation ranges from 2620 mm to 3200 mm along the same axis, with a small area of high evaporation in the south-west corner of the region.

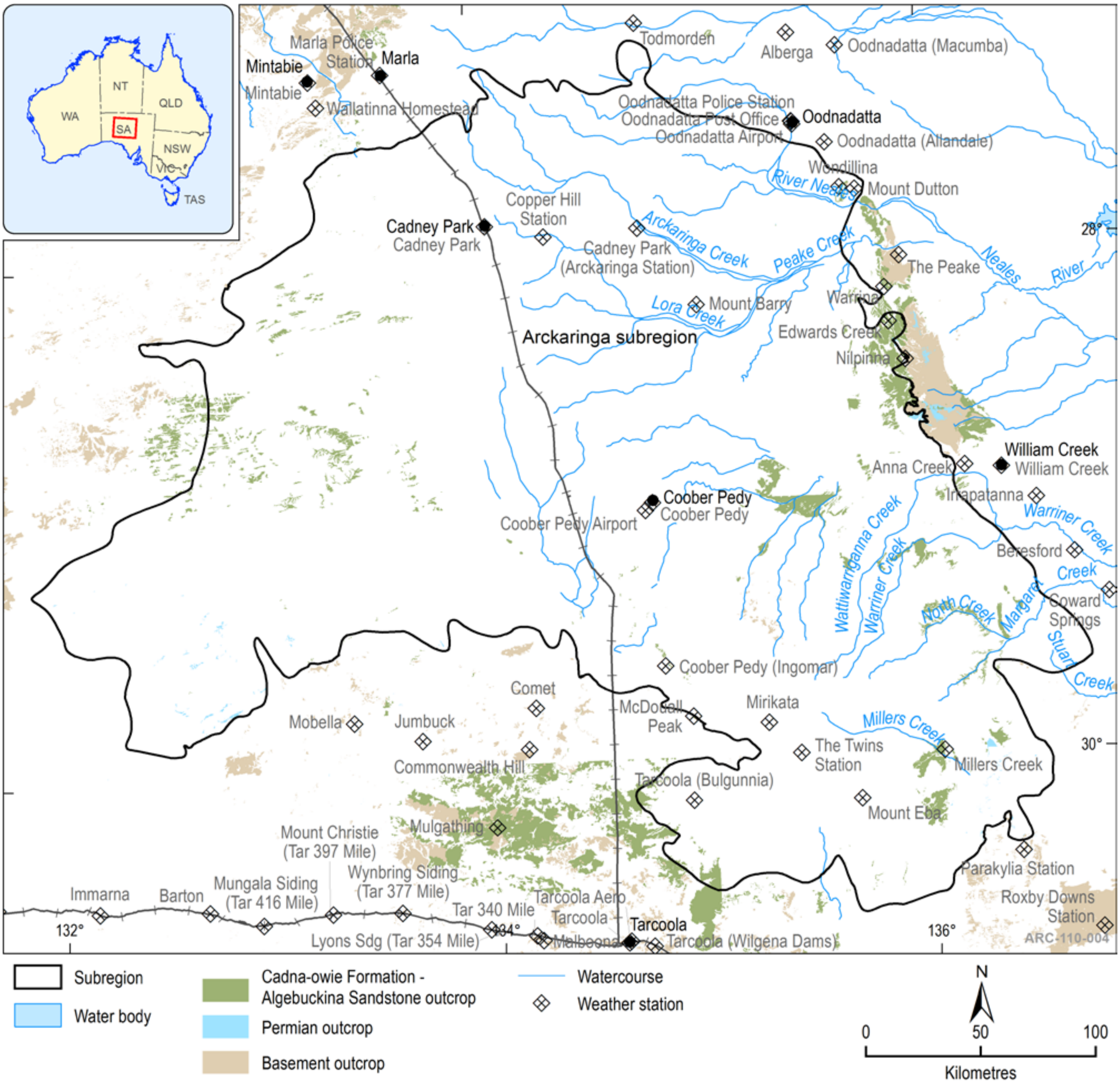

Figure 10 Location of weather monitoring stations in the Arckaringa subregion

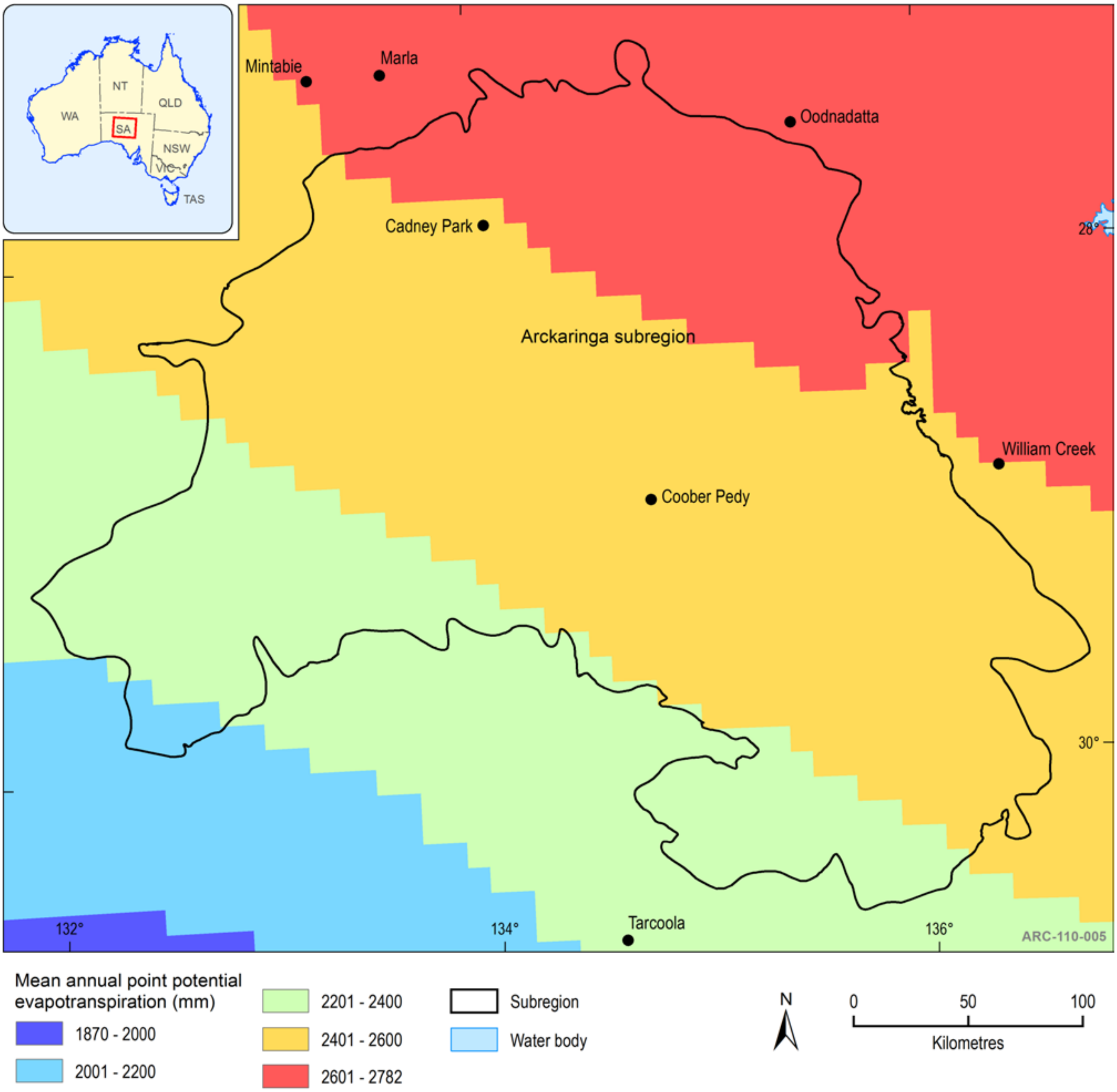

Figure 11 Mean annual point potential evapotranspiration in the Arckaringa subregion

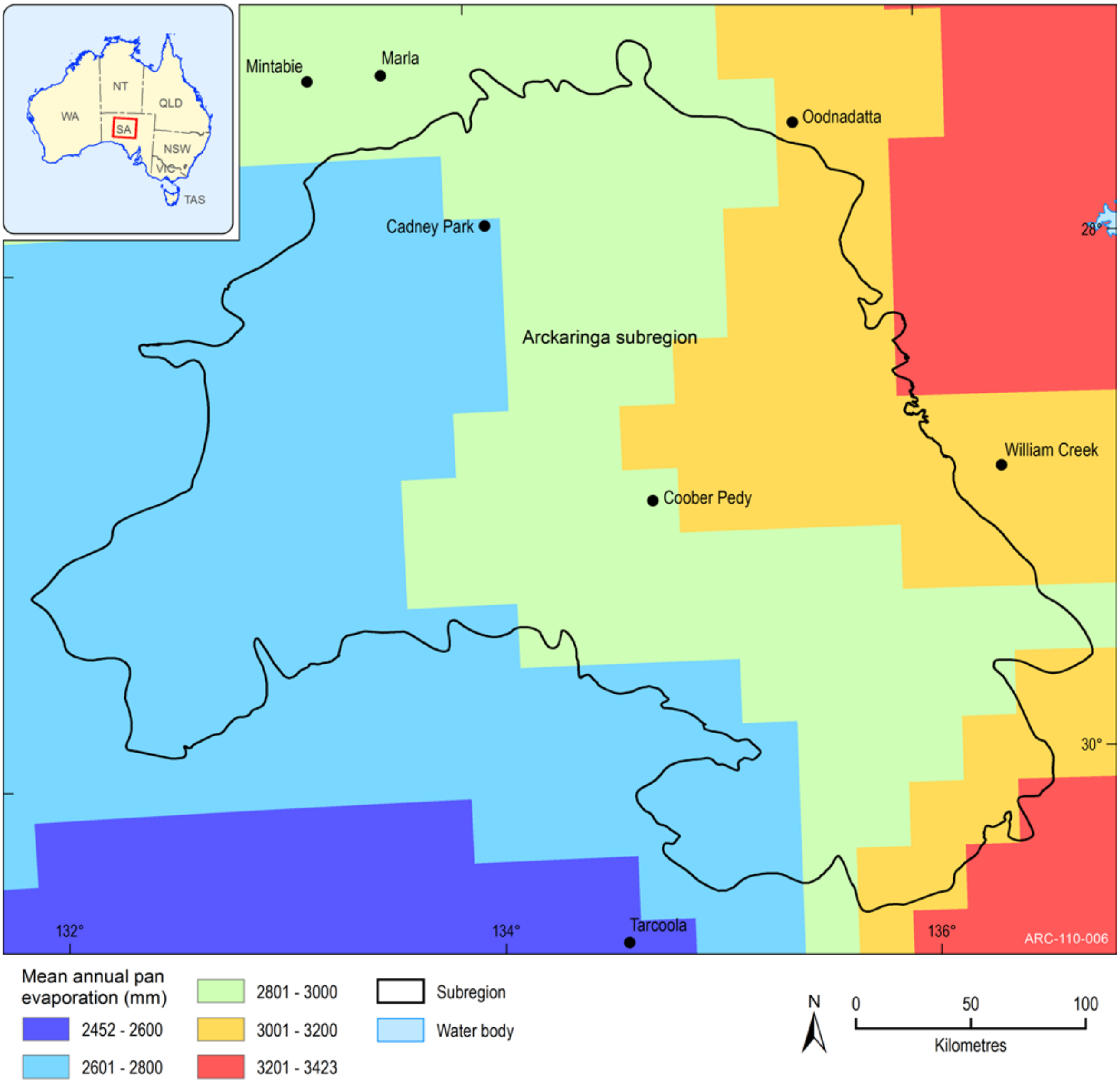

Figure 12 Mean annual pan evaporation in the Arckaringa subregion

Until recently, there has been no dedicated research towards assessing the impacts of a changing climate over the Arckaringa subregion. Information produced through the Australian Climate Change Science Program has demonstrated that it is very likely that mean annual rainfall totals will decrease in future and that mean temperatures will increase. These findings are summarised in Figure 13 and Figure 14 respectively. It can be seen that median annual rainfall totals may fall by between 5% and 20% in the Arckaringa subregion by 2050, with temperatures increasing by 1 to 2.5 °C by the same time horizon.

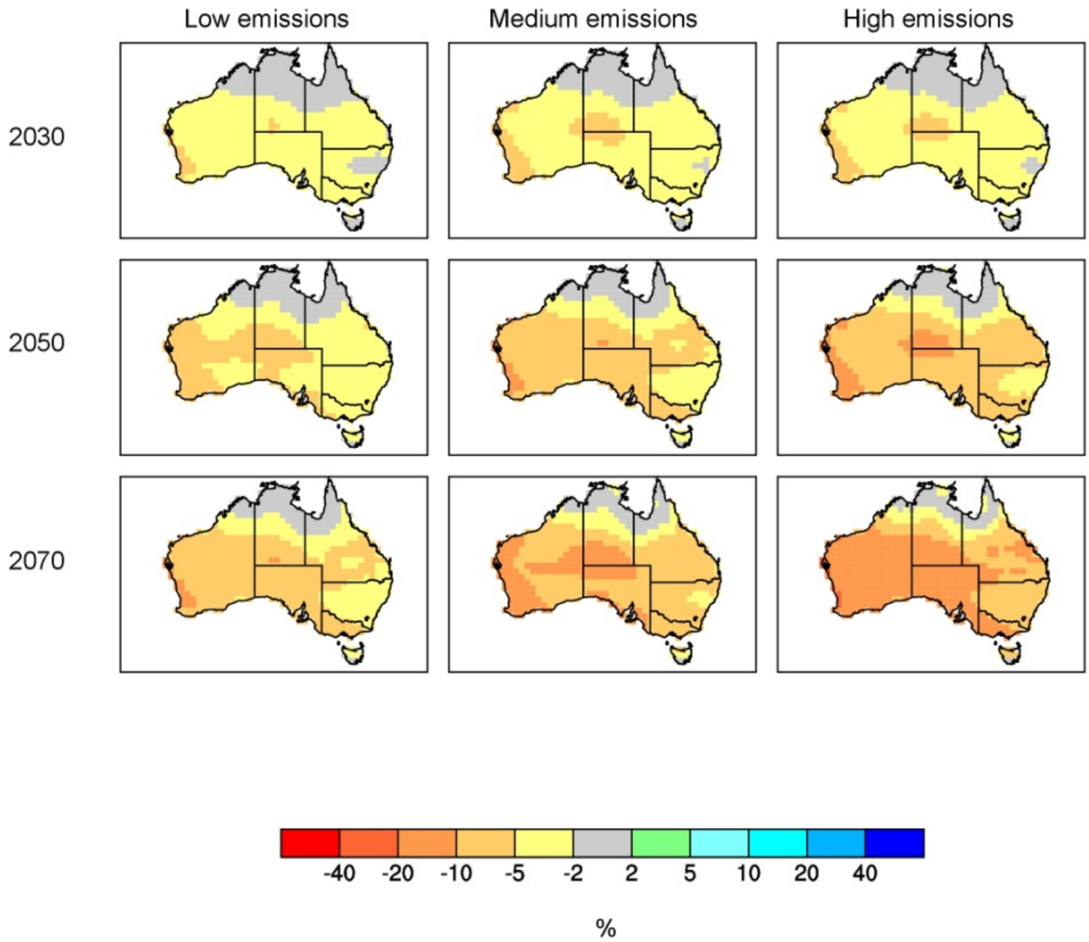

Figure 13 Percentage change in median annual rainfall totals from the baseline (1990) case for three future time horizons and three emissions scenarios

Source: CSIRO et al. (2007a)

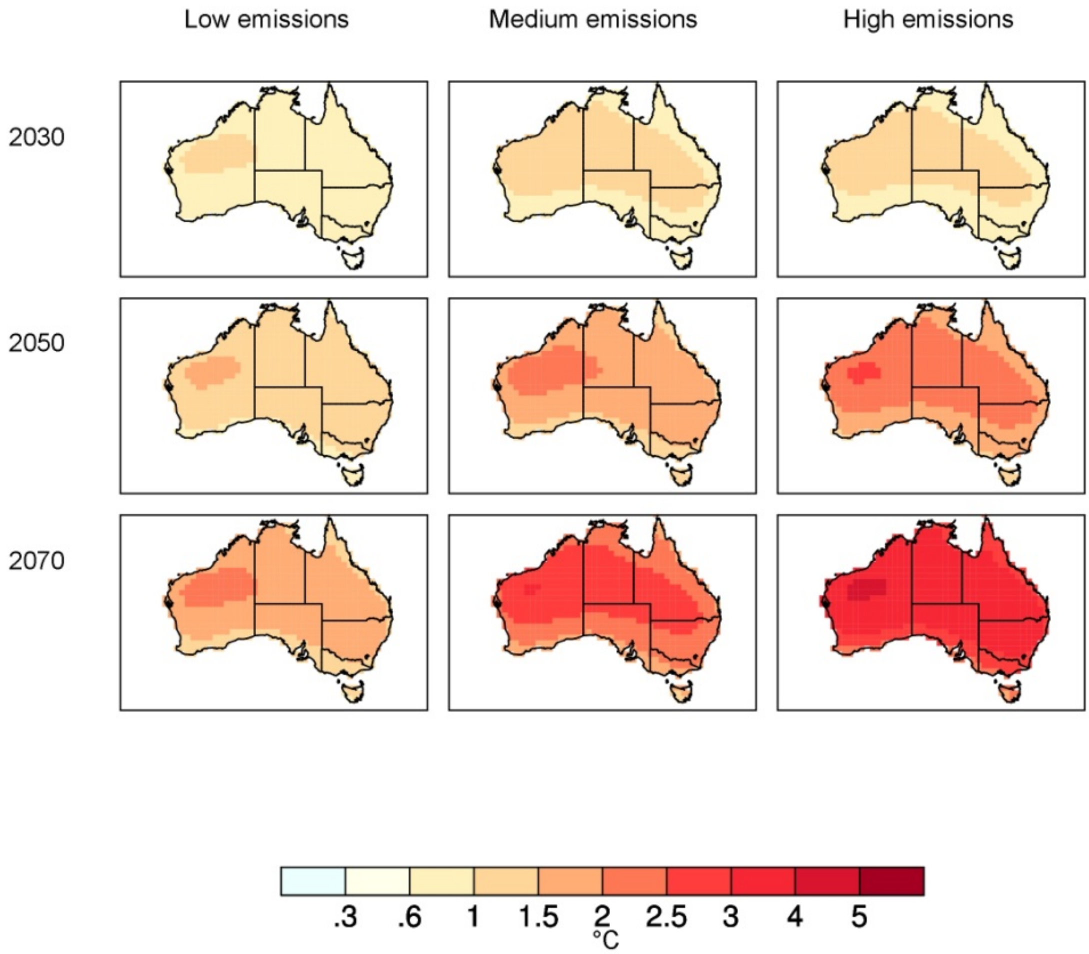

Figure 14 Percentage change in median average temperature from the baseline (1990) case for three future time horizons and three emissions scenarios

Source: CSIRO et al. (2007b)

Recently, the South Australian Government, through its Impacts of Climate Change on Water Resources Project, has undertaken an analysis of groundwater recharge, surface water runoff and rainfall intensity data in the South Australian Arid Lands Natural Resources Management (SAALNRM) Region to determine the potential impact of climate change on the principal water resources of the region (Gibbs et al., 2012). The SAALNRM Region contains most of the north-east of SA, running from the borders with the NT and Queensland to the north and east, with its western boundary around 100 km west of Coober Pedy and southernmost point around 300 km below the most southern point of the Arckaringa subregion, thereby bisecting and containing much of the Arckaringa subregion. This report found that rainfall decreases of the kind suggested by CSIRO et al. (2013) across the NRM region would lead to even more significant decreases in annual runoff totals, in the order of a 1% decline in annual rainfall representing a 2% decline in annual runoff. Gibbs et al. (2012) also determined that in the Neales-Peake catchment (cf Section 1.1.5.1.1), the length of time between flow events increased in line with rainfall declines, (i.e. a 10% reduction in annual rainfall led to a 10% increase in average length of dry periods) a statistic potentially more important given the intermittent nature of flow events in the subregion.

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1.1.3 Geology

Summary

The Arckaringa Basin is a roughly horseshoe-shaped sedimentary basin containing predominantly Late Carboniferous and Early Permian sedimentary rocks. The basin is composed of a series of deep troughs that partially ring basement unit rocks that occur close to the surface. The surface geology of the Arckaringa subregion is largely composed of sedimentary rocks associated with the Eromanga Basin with occurrences of the Bulldog Shale typical. Wind-blown sediments associated with the current–day desert landforms are also common, although sediments associated with rivers, lakes and springs are restricted in extent.

There are three main geological formations within the Arckaringa Basin: the Boorthanna, Stuart Range and Mount Toondina formations. The Boorthanna Formation is the oldest of the three and consists of an upper unit composed of marine sediments grading from silt to boulders and a lower unit contains glacial sediments that vary from sandy to bouldery claystone to gravel. The Stuart Range Formation consists of mudstone, siltstone, and organic-rich shale. The Mount Toondina Formation is the youngest of the three and is composed of an upper sequence of grey carbonaceous shale and coal with interbeds of sandstone and siltstone and a lower sequence of marine shale and mudstone. Very little outcrop of Arckaringa Basin strata occur.

Directly overlying most of the Arckaringa Basin is the Eromanga Basin, which is synonymous with the Great Artesian Basin (GAB) in SA. In the Arckaringa subregion, the primary aquifer units are the Cadna-owie Formation and Algebuckina Sandstone with primary confining layers including the Bulldog Shale, Oodnadatta Formation and lateral equivalents within the Rolling Downs Group. Overlying the Eromanga Basin are the most recent phases of sedimentation primarily deposited in episodic river and lake environments. Underlying the Arckaringa Basin are rocks of the Warburton and Officer Basins and crystalline basement sequences. The potential for inter-basin connectivity between the Arckaringa Basin and the overlying Great Artesian Basin is thought to be largely influenced by the occurrence of confining layers, the development of former river valleys and the extent of faulting.

The shape and structure of the Arckaringa Basin was formed over a series of major tectonic events that have taken place since the Proterozoic. Additionally, valleys formed by glaciers prior to the deposition of Arckaringa Basin strata may have also influenced basin architecture. Deposition in the Arckaringa Basin appears to have ceased during the Early Permian. The Arckaringa Basin contains thick, extensive Permian coal measures comprising a number of discrete deposits within the upper Mount Toondina Formation. There are currently seven defined coal deposits of potential economic significance. In addition, the Arckaringa subregion is subject to conventional hydrocarbon and shale oil and gas exploration.

1.1.3.1 Geological structural framework

The Arckaringa Basin is an intracratonic basin containing predominantly Late Carboniferous to Early Permian sedimentary rocks. A number of depocentres are located around a basement high (Coober Pedy Ridge, Mabel Creek Ridge and Central Basin High) associated with the Mount Woods Inlier (Figure 15). These depocentres include the Boorthanna Trough, located along the eastern margin of the basin; the Wallira, West, Penrhyn and Phillipson troughs, located near the southern margin, and the Karkaro and Mt Furner troughs in the northern half of the basin. The Arckaringa Basin is bound to the east by the Peake and Denison Inlier (Denison and Davenport Range), to the south by the Gawler Ranges and Stuart Shelf and to the north and west by the Officer Basin. Troughs and bordering inliers in the vicinity of the eastern margin coincide with a series of north-west regional structures associated with the Torrens Hinge Zone and the northern extension of the Adelaide Fold Belt. The south-western margin is coincident with the Karari Fault Zone (Figure 15).

The western Arckaringa Basin is thin, geologically simple and only moderately faulted while the eastern Arckaringa Basin is deep and geologically complex. Additionally, the base of the Permian strata displays a complex, glacially-scoured surface with significant erosional relief. Cretaceous and Jurassic units of the Eromanga Basin overlie the majority of the Arckaringa Basin (Figure 16 and Figure 17). The Eromanga Basin regional unconformity displays evidence for major incision and erosion, particularly within the northern and north-western Arckaringa Basin, where paleochannel development is evident (Figure 16). Additionally, there is seismic evidence of gentle tilting, low angle truncation and erosion of upper Mount Toondina Formation coals below the base of this unconformity (Figure 16 and Figure 17).

The Arckaringa Basin is underlain by early Cambrian, Proterozoic and Archean rocks inclusive of the Stuart Shelf and in part by strata of the Warburton Basin and Officer Basin (Figure 15). The Proterozoic and Archean rocks are primarily composed of metasedimentary and igneous units and underlie the central and southern Arckaringa Basin. The Warburton Basin and Officer Basin are large sedimentary basins primarily of Cambrian to Devonian-age. The Warburton Basin occupies large portions of north and north-east SA and southern NT, whereas the Officer Basin occupies large portions of western SA and eastern WA (Gravestock et al., 1995; Radke, 2009).

Current intra-plate tectonic activity is interpreted to be a function of compression caused by the continents northward drift and subsequent collision with the Indonesian Archipelago, a regime that commenced approximately 43 million years ago (Sandiford et al., 2009). In the general vicinity of the Arckaringa Basin, this compression is primarily orientated east-west and is generally larger than the principal vertical stress (Hillis et al., 1998; Hillis and Reynolds, 2000; Reynolds et al., 2005). Neotectonic expressions in the general region include reported seismic activity along the eastern margin of the Arckaringa Basin in the vicinity of the Adelaide Geosyncline (Geoscience Australia, 2014). Additionally, several authors including Aldam and Kuang (1988), Wacklawik et al. (2008), Karlstrom et al. (2012) and Keppel (2013) have summarised and presented evidence that GAB springs, which also coincide with the eastern margin of the Arckaringa Basin, may also be an expression of neotectonic activity.

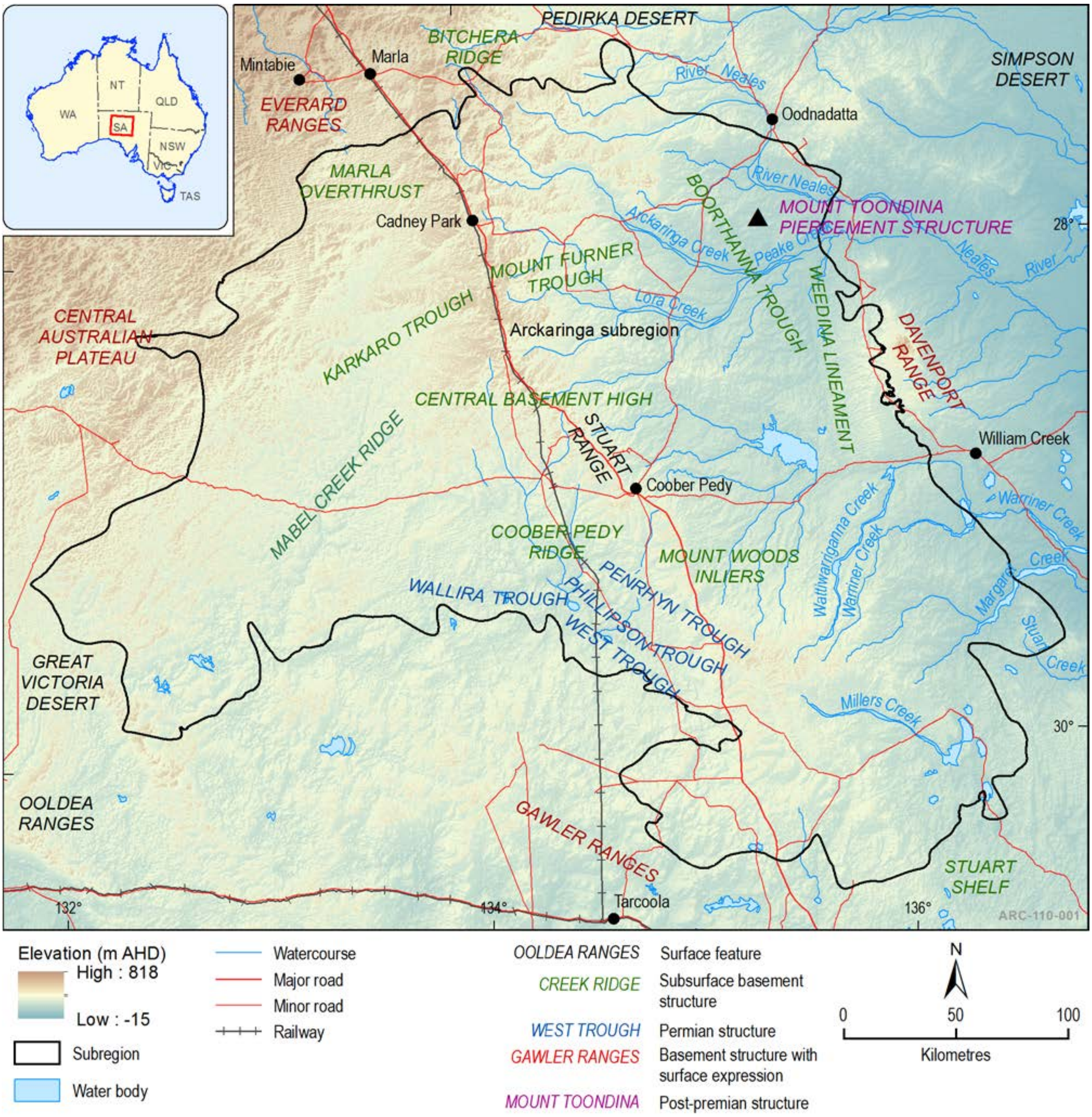

Figure 15 Structural framework of the Arckaringa subregion

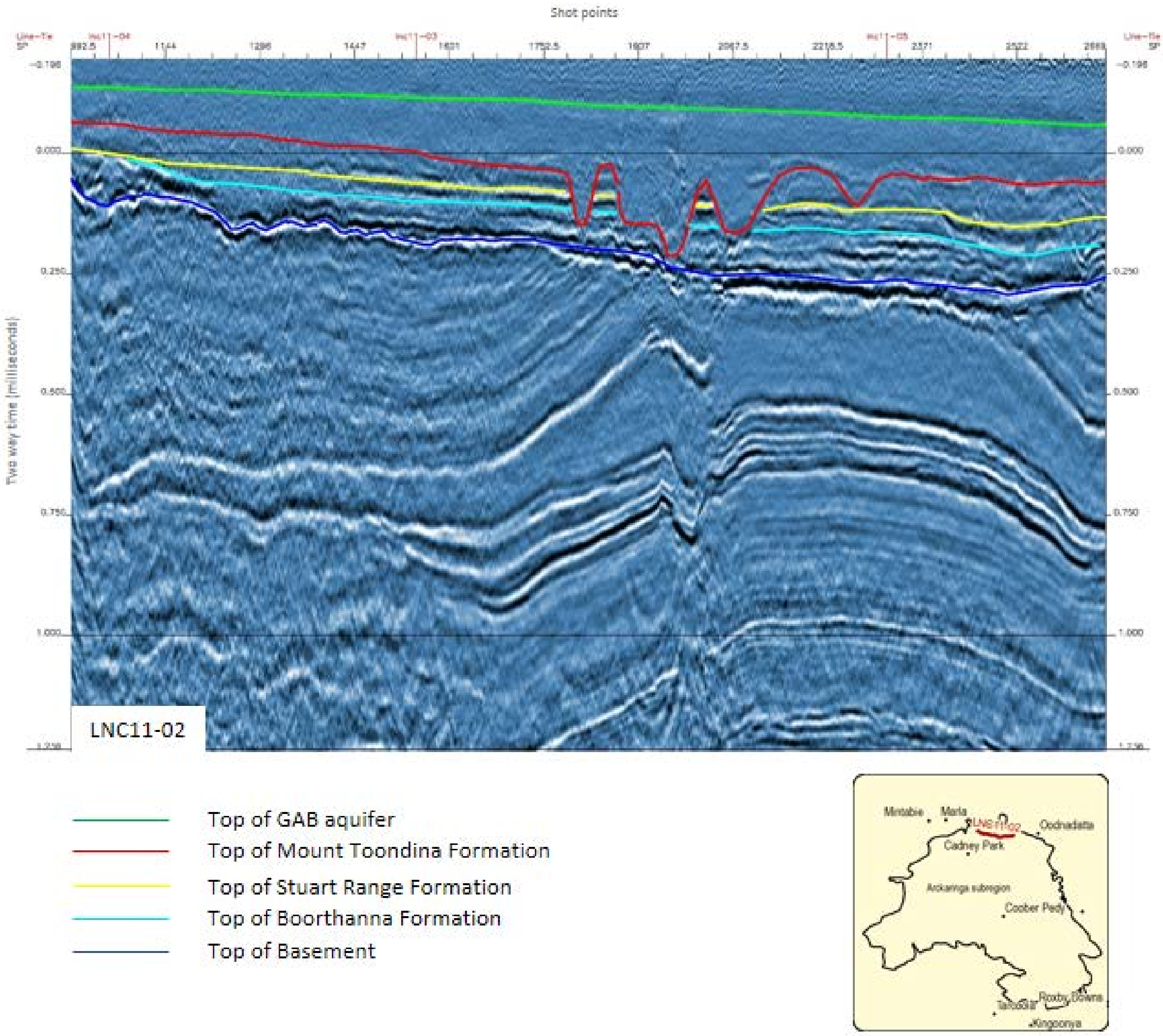

Figure 16 Interpreted seismic reflection section across the northern margin of the Boorthanna Trough

The Permian section is thin and largely comprises older Permian stratigraphy (Boorthanna Formation and Stuart Range Formation). Major incision and erosion is evident at the base of the Eromanga Basin regional unconformity. Large channels incised into the Permian succession are filled with chaotic, semi-transparent seismic facies identical to that of the Algebuckina Sandstone. These large channels are most likely sand-filled and therefore have important implications with respect to aquifer connectivity between the overlying Great Artesian Basin and the Mount Toondina Formation. The base of the Permian section is defined by an angular unconformity.

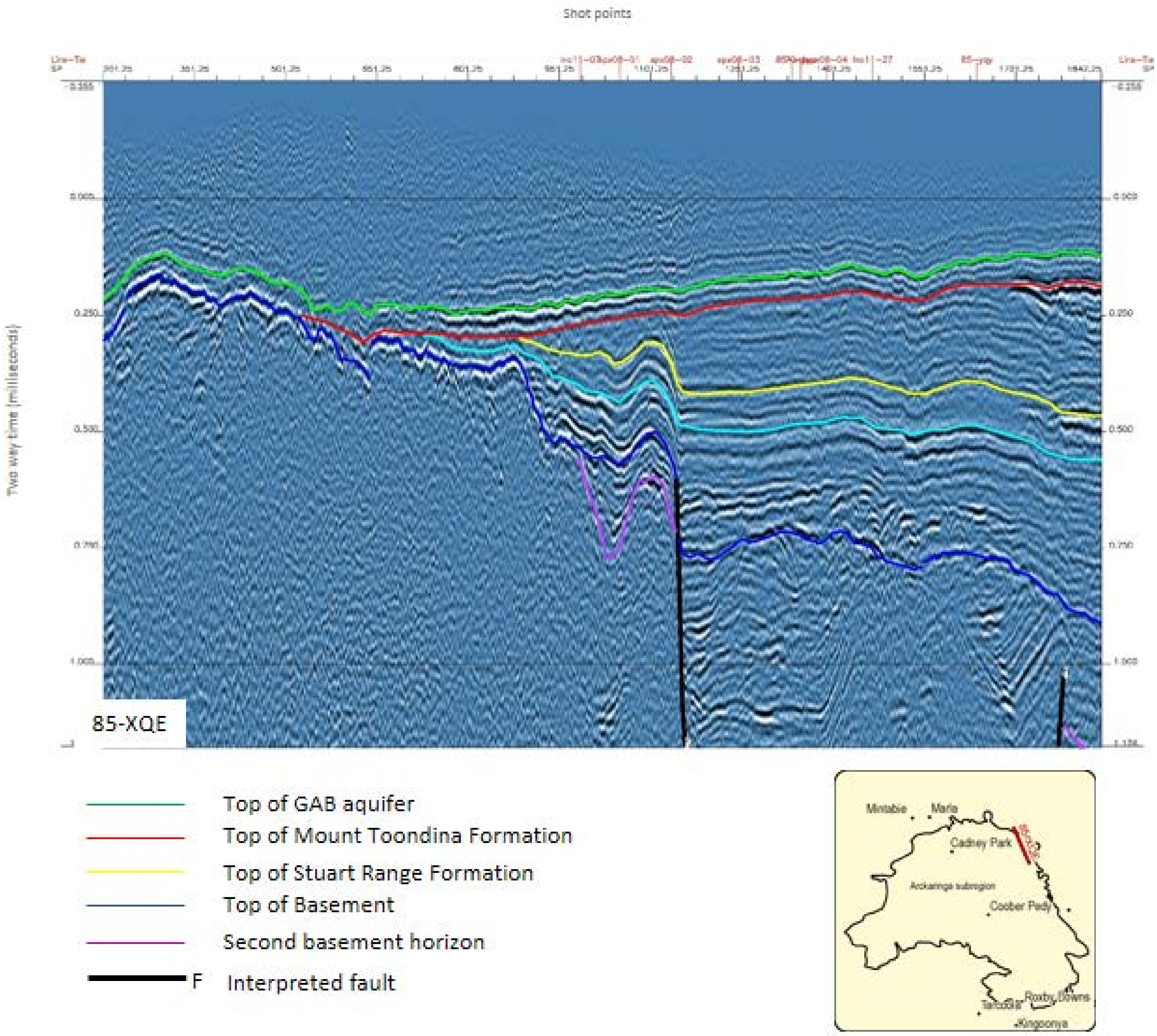

Figure 17 Interpreted seismic reflection section across the far northeast margin of the Boorthanna Trough

A steep major fault offsets the Permian stratigraphy. The preserved Permian section is considerably thicker to the south of the fault.

1.1.3.1.1 Structures

In addition to the previously discussed regional structures, there are a number of interpreted faults and fault zones within the Arckaringa Basin. The Billa Kalina and Boorthanna faults have been mapped in the south-east of the Arckaringa Basin (Figure 15). The Weedina Lineament occurs along a similar strike to the Billa Kalina Fault. Other named fault zones interpreted within the Arckaringa Basin include the Oogelima and Wallira faults, within the eastern and southern portions of the Arckaringa Basin respectively.

The Mount Toondina Piercement Structure occurs within the north-eastern Arckaringa Basin, approximately 45 km south of Oodnadatta. It is one of the few localities where Arckaringa Basin sediments are known to outcrop. This structure was first interpreted to be a diapir, but since Youles (1976) an alternative impact crater hypothesis has been the focus of study (Shoenmaker and Shoenmaker 1988; Plescia et al., 1994; University of New Brunswick, 2009) (Figure 15). More recently, Haines (2005) stated that existing seismic data over the piercement structure clearly shows no evidence for a diapir.

1.1.3.1.2 Regolith/surface geology

Abundant outcropping and sub-cropping Mesozoic sedimentary formations, most notable being outcrop of the Bulldog Shale, in the vicinity of the Arckaringa Basin has a significant role in determining the composition of the regolith in the subregion. In contrast, there is very little outcrop of Arckaringa Basin strata, being restricted to isolated occurrences on the western flank of the Peake and Denison Inlier, near Margaret Creek in the south-east corner of the basin and also in the south-west corner of the basin (Figure 18). Most of the subregion, notably the central and eastern parts of the Arckaringa Basin, have been interpreted to be dominated by erosional landforms composed of moderately to highly weathered bedrock or residual soil materials derived from the Mesozoic strata (Krapf et al., 2012). Other than aeolian sediments, depositional landforms and associated alluvial, colluvial and other transported sediments are primarily restricted to the immediate vicinity of drainage channels or within the headwaters and catchments of drainage systems. Consequently, these regolith landforms and associated sediment types are mainly in the larger drainage systems, associated with the Neales River/Peake Creek and Margaret River (Figure 18). Lacustrine and spring-related landforms are restricted in extent, but are primarily at Lake Cadibarrawirracanna, the Wilkinson Lakes region, downstream of Millers Creek, within Weedina Creek and with springs near the eastern margin of the Arckaringa subregion (Krapf et al., 2012) (Figure 18).

Aeolian landforms and sediments are primarily within the western and southern Arckaringa subregion, with smaller aeolian deposition west of the Peake and Denison Inlier and in the vicinity of the Millers Creek wetland area (Krapf et al., 2012).

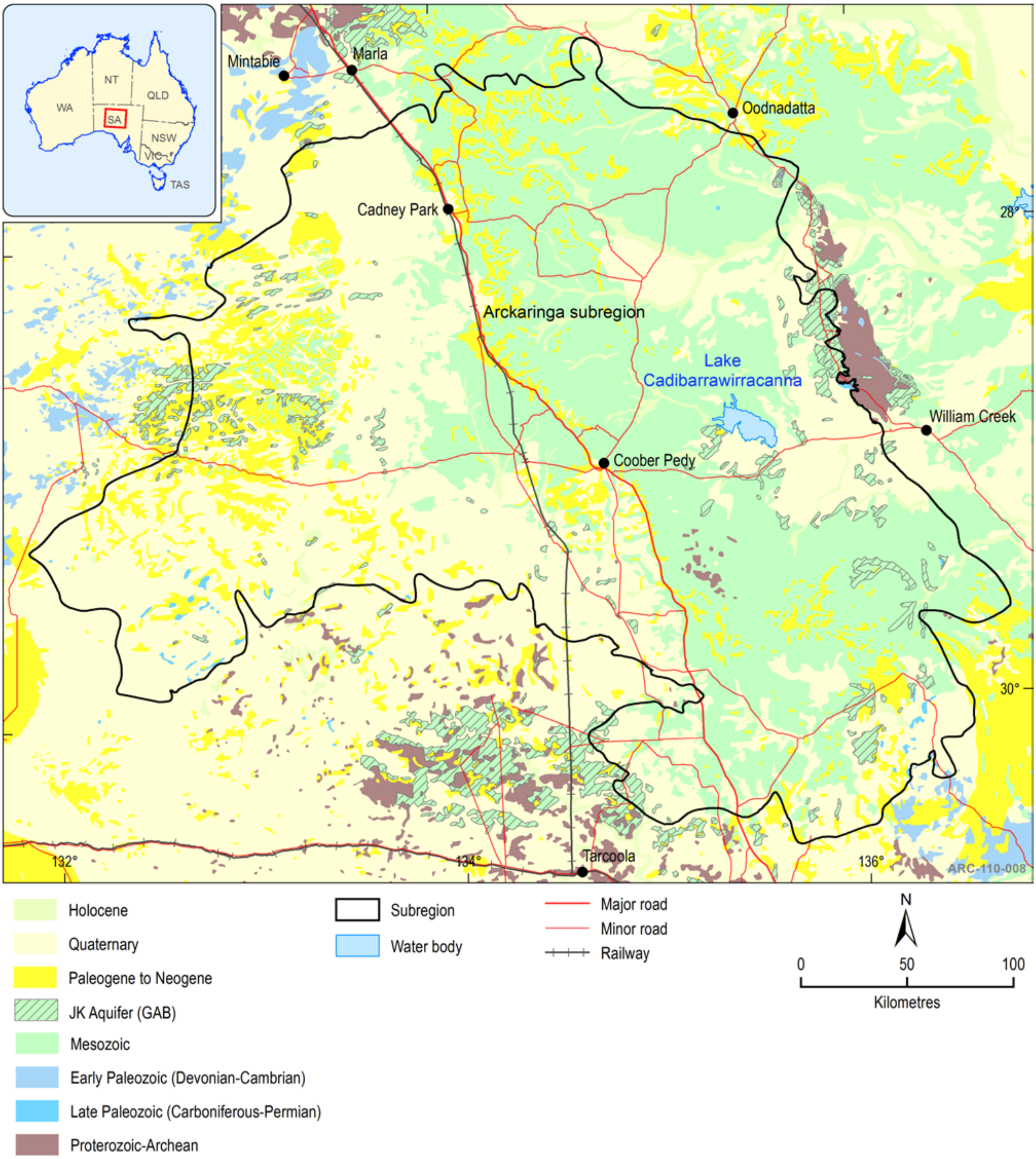

Figure 18 Surface geology of the Arckaringa subregion

The JK aquifer includes Cadna-owie Formation and the Algebuckina Sandstone. Together these two units represent the most important GAB aquifer within the Arckaringa subregion.

1.1.3.2 Stratigraphy and rock type

1.1.3.2.1 Underlying stratigraphy

Underlying the Arckaringa Basin are sedimentary rocks of the Warburton and Officer basins and crystalline basement sequences, including the Adelaide Geosyncline, Stuart Shelf, Gawler Craton and Musgrave Block.

Crystalline Basement

A number of other localised fractured rock and karstic aquifers occur within crystalline, largely Precambrian, but also some early Cambrian, basement rocks in the vicinity of the Arckaringa Basin and can be discussed as a number of geological provinces. These provinces include the Adelaide Geosyncline and the Stuart Shelf, which underlie the eastern and south-eastern portions of the Arckaringa Basin. These rocks are lateral equivalents and are referred to as Adelaidean (Preiss, 1987). They represent largely marine deposition within a pelagic and continental shelf environment respectively and include limestone, sandstone, shale, quartzite, dolomite, tillite, conglomerate and volcanics. These units outcrop within the Peake and Denison Inlier, in the vicinity of the Mount Woods Inlier and to the south and south-east of Cooper Pedy. The southern region of the Arckaringa Basin is underlain by rocks associated with the Gawler Craton. The Gawler Craton is a region of cratonised complex igneous, sedimentary and metamorphic rocks that displays a number sedimentation, intrusion and orogeny phases that cover a time period from the Archean to the Mesoproterozoic (Drexel et al. 1993). Finally, the north-western margin of the Arckaringa Basin is in the vicinity of the Musgrave Block, which is an east-west trending belt of Proterozoic granulite and gneiss (Drexel et al. 1993).

Warburton Basin

Sedimentary rocks of the Warburton Basin are primarily Cambrian to Ordovician, although Devonian strata (Mintabie beds) occur near the northern margin of the subregion (Gravestock et al., 1995). Gravestock et al. (1995) presented evidence for five separate depositional sequences in the Warburton Basin, although the depositional record has not been completely preserved. Simplistically, these sequences include a basal suite of shallow marine sedimentary rocks, followed by a marine prograding sequence through to deep marine organic-rich lime mud and shale. A marine regression sequence then follows into a shallow marine sequence. Additionally, there are also minor volcanolithic units (Gravestock, 1995; Radke, 2009). A paucity of exploration has meant that only a few formations have been named to date (Radke, 2009).

DMITRE (2013) state that the thickness of the Warburton Basin is in excess of 1800 m. Sedimentary rock of the Warburton basin are described by Stewart (2010) as unconformably overlying mafic volcanic rocks of the early Cambrian.

Officer Basin

Gravestock et al. (1995) suggested the Officer Basin primarily has five depositional sequences, three of which are Cambrian (collectively known as the Marla Group), a fourth is Ordovician-Silurian (known as the Munda Group) and a later stage Devonian sedimentary sequence are separated from the others by an unconformity. The first sequence is largely composed of the inter-fingering Relief Sandstone and Oulburra Formation, the latter unit representing transgressive marine sedimentation. The second sequence primarily comprises alluvial, fluvial, playa lake red-bed, alluvial fan and some marine sedimentary rocks of the Observatory Hill Formation, Arcoeillinna Formation, Apamurra Formation and lateral equivalents. The third stage of deposition is composed of fluviodeltaic and volcanolithic sequences of the Trainor Hill Sandstone, Table Hill Volcanics and lateral equivalents. Finally, Ordovician-Silurian sequences include the Mount

Chandler Sandstone, Indulkana Shale and Blue Hills Sandstone and are predominantly interpreted to represent deposition within a shoreline or shallow marine environment.

In addition to the stratigraphic description of the Officer Basin provided by Gravestock et al. (1995), Precambrian sequences of the Callanna, Lake Maurice and Ungoolya Groups that have age equivalents within the Adelaide Geosyncline are included in discussions concerning the Officer Basin. In a particular reference to groundwater, the Murnaroo Sandstone is discussed by AGT (2012) and Alexander and Dodds (1997).

Korsch et al. (2010) and Preiss et al. (2010) describes the contact between the Officer Basin and underlying crystalline basement as unconformable. Geoscience Australia (2012) state that the maximum thickness of the Officer Basin is 10,000 m. With respect to the Eastern Officer Basin, Haddad et al. (2001) use seismic and well data to calculate a maximum sediment thickness in the north-eastern Officer Basin in excess of 5,000 m.

1.1.3.2.2 Arckaringa Basin

There are three main geological formations that comprise the Arckaringa Basin: the Mount Toondina, Stuart Range and Boorthanna formations (Figure 19). The Arckaringa Basin unconformably overlies crystalline basement and older basinal sedimentary rocks of the Officer and Warburton Basins around its western and northern and eastern periphery (Carr et al., 2011; Preiss et al 2010).

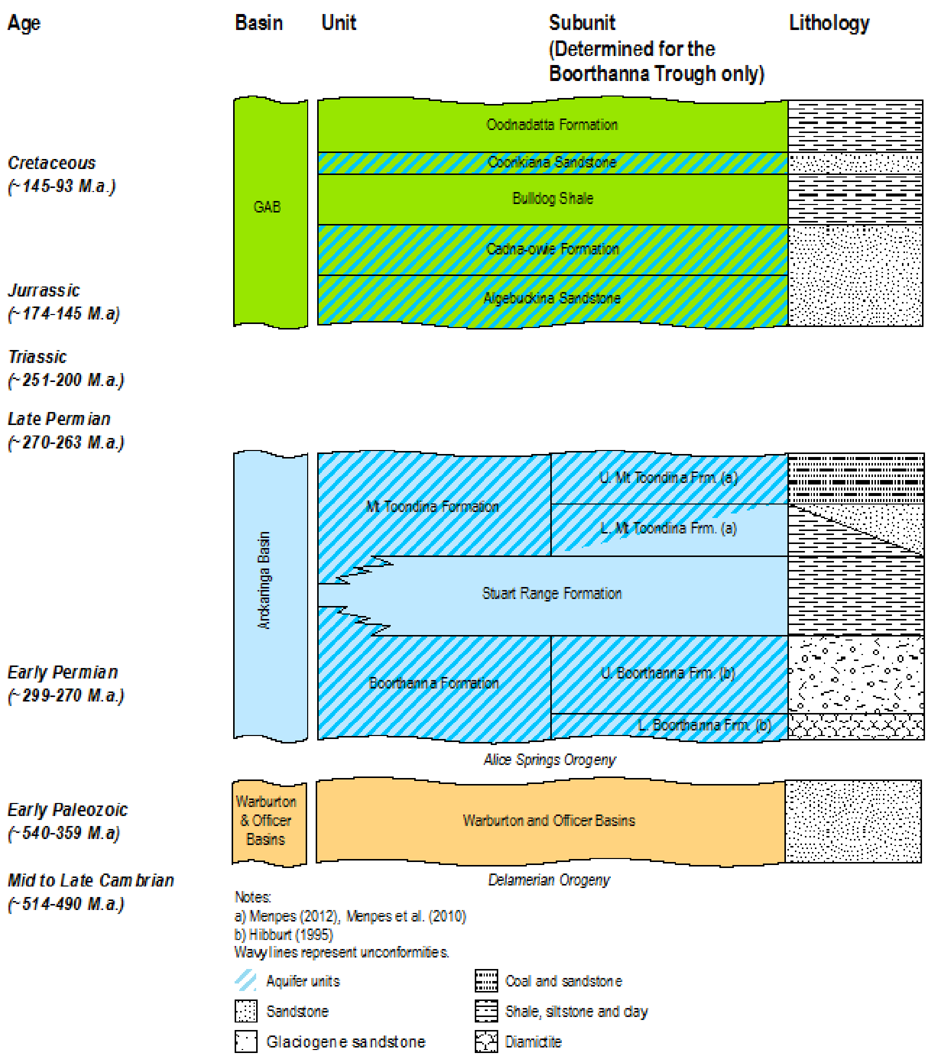

Figure 19 Simplified Cambrian to Cretaceous stratigraphy, hydrostratigraphy and general lithology, Arckaringa subregion

Boorthanna Formation

The Boorthanna Formation consists of two units: the upper unit consists of interbedded marine clastic rock, with grain sizes ranging from silt to boulders, whereas the lower unit consists of glaciogene sandy to bouldery claystone diamictite, intercalated with shale and carbonate layers. Occurrences of the lower unit are restricted to deeper parts of the basin, including the Wallira, West, Penrhyn and Phillipson troughs and the southern Boorthanna Trough. In contrast the upper unit is more widespread, particularly within the eastern half of the Arckaringa Basin. Boorthanna Formation rocks are described by Kellett et al. (1999) as weakly indurated, with localised calcareous, ferruginous and pyrite cementation. Alluvial and colluvial sediments consisting of coarse sand and gravel were interpreted as Permian paleovalleys cutting into Proterozoic basement in the vicinity of the Mount Woods Inlier (Belperio, 2005).

The Boorthanna Formation unconformably overlies Cambrian and Pre-Cambrian basement rocks. The maximum thickness of the Boorthanna Formation estimated from geophysics and logging data analysis presented in this report is approximately 1,200 m and is reported to occur within the Boorthanna Trough. The average thickness is calculated to be approximately 50 m.

Stuart Range Formation

Townsend and Ludbrook (1975) proposed the name Stuart Range Formation for the mudstone, siltstone and shale between the basal glacial unit (Boorthanna Formation) and Mount Toondina Formation. The organic-rich shale of the Stuart Range Formation was deposited during a marine transgressive phase, with the thickest successions in the deepest parts of the troughs. The definition of the Stuart Range Formation was further refined by Menpes (2012) and Menpes et al. (2010), who identified a surface representative of maximum sea inundation or 'maximum flooding surface' (mfs) that chronostratigraphically represents the top of the Stuart Range Formation at the base of the prograding lower Mount Toondina delta succession. The Stuart Range Formation is best developed within the depocentres along the eastern half of the Arckaringa Basin.

The contact between the Stuart Range Formation and the underlying Boorthanna Formation is described as typically conformable and occasionally disconformable. Variations to this are notable in the Boorthanna Trough where the contact between the two formations is unconformable, while near the south–western boundary of the basin, the two formations are inter-fingered (Hibburt, 1995). However, Menpes (2012) and Menpes et al. (2012) have identified a sequence boundary that cuts down into the Boorthanna Formation in the Boorthanna Trough, but appears to have been an exposure surface with marine sediments overlying marine sediments and minimal loss of section in the Phillipson Trough. The maximum thickness of the Stuart Range Formation estimated from geophysics and logging data analysis presented in this report is approximately 430 m and is reported to occur near the northern edge of the Arckaringa Basin. The average thickness is calculated to be approximately 13 m.

Mount Toondina Formation

The Mount Toondina Formation was defined by Townsend and Ludbrook (1975) as comprising an upper section of grey carbonaceous shale, coal and interbedded grey sandstone, siltstone and sandy shale. Menpes (2012) subdivided the Mount Toondina Formation into two sub-units. The upper Mount Toondina Formation is described as a fluvio-lacustrine succession with intermittent coal swamp development and is inclusive of all known potentially economic coal deposits within the Arckaringa Basin. The lower Mount Toondina Formation encompasses sedimentation indicative of a retreating ('retrograde') marine environment. The Mount Toondina Formation has been interpreted to occur over a large proportion of the basin, with notable exceptions being the south-east corner and far south-western corner of the Arckaringa Basin.

The Mount Toondina Formation generally overlies the Stuart Range Formation conformably but occasionally disconformably. Where the Stuart Range Formation is absent, the Mount Toondina Formation unconformably overlies the Boorthanna Formation (Hibburt, 1995). The maximum thickness of the Mount Toondina Formation estimated from geophysics and logging data analysis presented in this report is approximately 830 m and is reported to occur within the Boorthanna Trough. The average thickness is calculated to be approximately 37 m.

1.1.3.2.3 Overlying stratigraphy

Overlying the Arckaringa Basin are strata from the Great Artesian Basin and younger Cenozoic sediments and sedimentary rocks. With respect to hydrostratigraphy, of particular interest are the Cadna-owie Formation and Algebuckina Sandstone, which together form the main GAB aquifer, referred to as the JK aquifer in this report, overlying the Arckaringa Basin. Based on seismic and well data re-interpretation work presented in Keppel et al. (2013) the maximum thickness of the JK aquifer over the Arckaringa Basin is approximately 220 m, whereas the average thickness is 50 m. Likewise, the maximum thickness of strata overlying the JK aquifer in the vicinity of the Arckaringa Basin is 470 m, whereas the average thickness is 50 m. The maximum thicknesses in both cases occur near the northern margin of the Arckaringa Basin.

Great Artesian Basin

Directly overlying most of the Arckaringa Basin is the Eromanga Basin, which is synonymous with the sedimentological extent of the Great Artesian Basin (GAB) hydrogeological basin throughout the Arckaringa subregion. The GAB has been referred to as both a geological basin and hydrogeological basin; geologically, the GAB describes a terrestrial to marine Cretaceous–Jurassic super basin that covers much of eastern and central Australia (Keppel et al., 2013). Variations in either basin subsidence or up-warp and global sea level changes during the Mesozoic led to the development of a series of transgressional alluvial, fluvial and marine sequences (Krieg et al., 1995; Ollier, 1995; Toupin et al., 1997). Consequently, a number of stratigraphic units relating to various aquifers and confining layers exist within the Arckaringa subregion; a summary of the major units are provided in Table 4.

Table 4 Summary of hydrostratigraphy of the Eromanga Basin (GAB within the Arckaringa subregion)

Period	Formation name	Lithology description	Depositional environment	Hydrogeological characteristics
Cretaceous	Oodnadatta Formation (Rolling Downs Group)	Laminated, claystone and siltstone, with interbeds of fine-grained sandstone and limestone	Low energy, shallow marine	Tight aquitard with minor aquifers
	Coorikiana Sandstone (Rolling Downs Group)	Predominately carbonaceous, clayey, fine-grained sandstone and siltstone	High energy, marine, shore face and gravel bars	Minor aquifer
	Bulldog Shale (Rolling Downs Group)	Grey marine shaly mudstone, micaceous silt and pyrite are also present, with very minor silty sands. Occasional lodestones	Low energy, marine, cool climate	Tight aquitard
	Cadna-owie Formation	Heterogeneous, mainly fine-grained sandstone and pale grey siltstone. Coarser sandstone lenses occur in the upper part of the formation	Transitional from terrestrial freshwater to marine	Upper part in the vicinity of the Arckaringa is generally considered a good aquifer, high yields and good water quality. Known to be a leaky aquitard, in places, particularly east of the Arckaringa Basin (Berry and Armstrong, 1995; Ransley et al., 2012)
Jurassic	Algebuckina Sandstone	Fine to coarse-grained sandstone, with granule and pebble conglomerates	Low gradient fluvial including rivers, floodplain. Both arid and wet climates	Major GAB aquifer, high yielding bores

Source: DMITRE (2012), Jami and Ray (2007), Huleatt (1991) and SA Coal (2010)

Cenozoic Sediments

The most recent phases of sedimentation are predominantly composed of braided fluvial and lacustrine sediments. Cenozoic sedimentation may be divided into two depositional episodes; sedimentation that occurred during the Paleogene and Neogene prior to upwarping at 15 to 5 Ma and those associated with the current hydrological system; both phases may provide discrete aquifers. Two sedimentary basins of Paleogene and Neogene age occur in the vicinity of the Arckaringa subregion, namely the Billa Kalina Basin (Drexel and Preiss, 1995) and the Lake Eyre (geological) Basin.

The Billa Kalina Basin is a small terrestrial basin composed of fluvial and lacustrine-derived sandstone, clay and dolomite that partly overlies the south-eastern Arckaringa Basin (Callen and Cowley, 1995).

Sediments associated with the Lake Eyre (geological) Basin largely occur to the east of the Arckaringa subregion. These were primarily deposited in three phases of braided fluvial and lacustrine sedimentation.

1.1.3.3 Basin history

The development of conceptual models describing the hydrodynamics and flow characteristics of groundwater systems in sedimentary basins such as the Arckaringa Basin as well as determining the economic potential of any coal resources, require an understanding of their structural and tectonic history. Such an understanding provides important insights into the origins of basin architecture, deformation responsible for the development of sub-basins or preferential flow paths and the origins of sedimentary successions. The following provides a brief summary of pertinent information concerning the structural and tectonic history of the Arckaringa subregion.

After the amalgamation of a number of Archean cratons to form the Australian continent (Powell and Pisarevsky, 2002; Powell et al., 1993), a series of tectonic events commencing in the Late Proterozoic occurred. These events predominantly affected zones of lithospheric weakness associated with the margins of cratonic elements and were responsible for the development of the basic structural architecture and basinal development linked with the Arckaringa Basin.

During the Late Proterozoic to Early Phanerozoic, plate divergences formed complex continental margins. The inception of a number of basins have been interpreted as failed rift arms of deeply penetrating triple rift junctures that formed along these plate margins. Such basins include (but are not restricted to) the Officer and Warburton basins (Questa, 1990).

The Delamerian Orogeny that occurred during the Late Cambrian was associated with a number of west-north-west compressive tectonic events that produced north trending thrusts, north-west trending transgressive shears, recumbent folds, igneous intrusions and metamorphism (Cotton et al., 2006) as well as inverting parts of the Adelaide Geosyncline. Preiss (2000) interpreted five major successive rift cycles, each with its own locus and orientation, in relation to deformation events. Cotton et al. (2006) also suggested that the deep crustal scale, length and planar form of these structures were favourable for reactivation during later phases of tectonism.

Cotton et al. (2006) suggested that the structural grain of the Permo-Carboniferous basins of central Australian (Cooper, Pedirka and Arckaringa) were influenced by north-west orientated compression and uplift associated with the Alice Springs Orogeny that occurred during the Devonian and Carboniferous. This event re-activated a number of east-trending Proterozoic structures (ca. 1.0 Ga) associated with the Musgrave Block in north-west SA and the Albany Fraser belt in neighbouring WA (Karlstrom et al., 2013). Gravestock and Sansome (1994), described crustal shortening of up to 20 km and uplift of 3 km as a consequence of this event. Over-thrusting during this period resulted in the formation of many of the domal trends that controlled the position of depocentres for Permo-Carboniferous sedimentation (Karlstrom et al., 2013).

Menpes et al. (2010) and Menpes (2012) argued that trough-formation within the Arckaringa Basin was dominated by glacial processes. The location and orientation of these glacial valleys appears to have been controlled by pre-existing structural grain and rock types in the underlying basement. Minor contraction coincident with deposition culminated in gentle folding of the Early

Permian succession, uplift and erosion. Cotton et al. (2006) suggested that syn-depositional faulting occurred during the Early Permian. Shearer (1994) stated that the north-east faults have not been re-activated post-Permian, whereas the north-west fault system has been re-activated.

Deposition in the Arckaringa Basin appears to have ceased during the Sakmarian (Early Permian) on the basis of palynological data (Alley, 1995; Menpes, 2012). Menpes et al. (2010) and Menpes (2012) have suggested that this break in deposition may correlate with breaks in deposition within the Patchawarra Formation, or alternatively may be related to the Daralingie Unconformity between the Early and Late Permian identified in the Cooper Basin.

PIRSA (2010) estimated that between 500 m and 1000 m of the Mount Toondina section was removed prior to the deposition of Mesozoic sediments. Compression and uplift events during the Early Cenozoic (approximately 50 Ma) and in the last 15 to 5 Ma have caused deformation of Permo-Carboniferous sedimentary rocks, as well as terminating periods of sedimentation associated with the Mesozoic and Cenozoic respectively (Senior and Habermehl, 1980; Toupin et al., 1997, Karlstrom et al., 2013; Questa, 1990).

With respect to thermal history, analyses of organic-rich Permian shale samples from exploration holes Arkeeta 1, drilled within the Phillipson Trough in the southern Arckaringa Basin and Arck 1, drilled within the Boorthanna Trough, display Type II (oil and gas prone) and Type I/II (oil prone/ oil and gas prone) kerogen source rocks respectively at or near the onset of oil generation (DMITRE, 2012) (Figure 20). Kerogen is complex, fossilised organic material present in sedimentary rocks that may be converted to petroleum under the correct pressure and temperature conditions.

1.1.3.4 Coal and hydrocarbons

The Arckaringa Basin contains thick, extensive Permian coal measures comprising a number of discrete deposits within the upper Mount Toondina Formation. In total, seven major deposits of largely lignite A/subbituminous C rank coal have been measured, indicated or inferred within the Arckaringa Basin (DMITRE, 2012; Figure 20 and Table 5). These deposits are composed of multiple seam, with individual seams up to 10 m thick and cumulative thickness of up to 35 m. Recently, Geoscience Australia and Bureau of Resources and Energy Economics (2014) calculated that total recoverable black coal resources in the Arckaringa Basin amounted to 13 730 Mt. Inclusive in this figure was 623 Mt of economic demonstrated resources (EDR), 3635 Mt of sub-economic demonstrated resources (SDR) and 9472 Mt of inferred resources. Based on palynological studies, the age of the coal units within the upper Mount Toondina Formation is Late Sakmarian (Early Permian) deposited around 290 Ma (Alley, 1995; Menpes, 2012). With respect to coal seam gas, DMITRE (2012) suggested the grade of coal seams as currently understood is not sufficiently mature to have generated significant thermogenic gas volumes. However, potential connectivity with the overlying Algebuckina Sandstone may allow for biogenic coal seam gas generation. In contrast SAPEX (2007) provided an initial estimate of between 0.207 to 1.1 trillion cubic feet (cf) of coal seam gas contained within the Wintinna East coal deposit.

The occurrence of coals is interpreted to have been controlled by syn-depositional faulting described in Section 1.1.3.1, which influenced the amount of accommodation space available in depocentres for coal deposition. Post-depositional erosion may have removed coal-bearing sequences from the far northern and north-western parts of the basin and shallower parts of the southern basin (DMITRE, 2012).

Table 5 Summary of known major coal occurrences in the Arckaringa subregion

Deposit	No. of persistent seams	Cumulative coal thickness (m)	Depth to top of mineable coal (m)	Estimate of coal resource tonnage (million tonnes)
Ingomar	Up to six major seams	Up to 15	60 to 80	Total (Inferred, indicated and measured): 227
Murloocoppie	8	Averages 20	140 to 230	Measured: 250 Indicated: 300 Inferred: 2,600 Total: 3,150
Phillipson	6 major seams	Up to 25	50 to 143	Inferred and Indicated: 287 Total: 5,400
Weedina	6 major seams (several minor seams)	35	130 to 150	Measured and indicated: 1,200 Inferred: 6,000
Westfield	2	1 to 9	145 to 215	Measured: 100 Indicated: 200 Inferred: 500 Total: 800
Wintinna	8 to 10	15 to 25	104 to 250	Measured: 1,150 Indicated: 750 Inferred: 2,000 Total: 3,900
East Wintinna	6 to 7	Up to 20	220 to 300	Inferred: 690

Source: DMITRE (2012), Jami and Ray (2007), Huleatt (1991) and SA Coal (2010)

With respect to other hydrocarbon plays, the Arckaringa subregion is also subject to conventional hydrocarbon and shale oil exploration. Trace hydrocarbons have been found within sandstone units of the Mount Toondina and Boorthanna formations with analysis of oil samples suggesting a pre-Permian source. Additionally, organic-rich marine shale within the Stuart Range Formation, particularly within the Boorthanna and southern Arckaringa troughs, have been identified as potential unconventional shale oil plays (DMITRE, 2012). Work is ongoing to identify sedimentary packages within a sequence stratigraphic framework, with a particular focus on understanding the distribution of organic-rich shale within the Stuart Range Formation (DMITRE, 2012).

Additionally, the Officer and Warburton basin has also been the subject of exploration for conventional petroleum hydrocarbons. DMITRE (2012) suggest that both the Warburton and Officer basins are prospective for tight gas resources and that the Warburton Basin is also prospective for shale gas. With respect to the Warburton Basin, prospectivity is mostly found in the vicinity of the Cooper Basin.

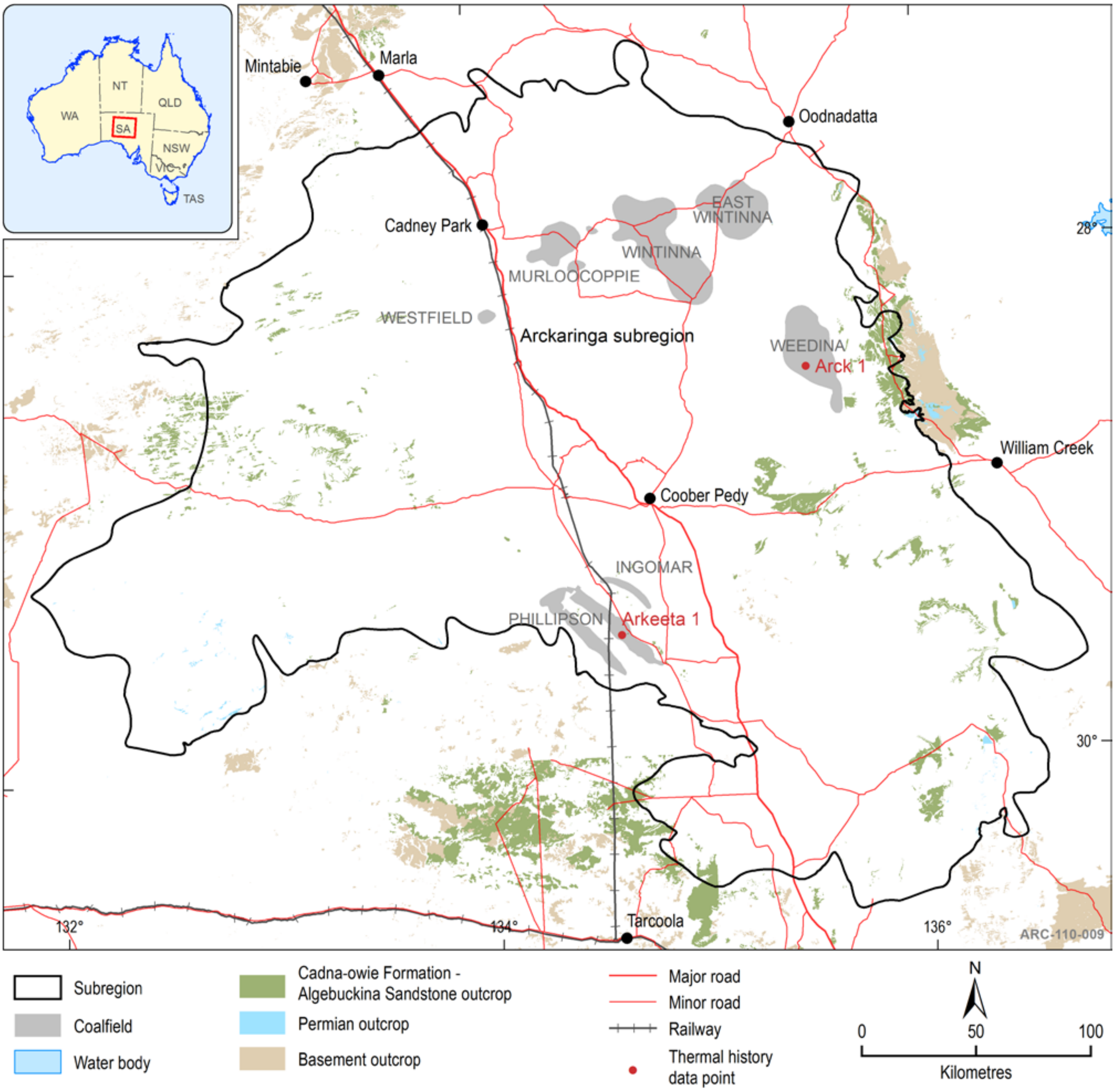

Figure 20 Defined coal resources of the Arckaringa subregion

1.1.3.5 Potential inter-basin connectivity

The potential for inter-basin connectivity is thought to be largely determined by the extent and characteristics of the Stuart Range Formation and paleochannels within the Mount Toondina Formation that have been filled with Mesozoic sediments. Much of the evidence for this stems from seismic data.

With respect to hydrogeological evidence, interconnectivity between the Arckaringa Basin and the overlying GAB at a regional scale is poorly understood. The limited scope and spatial extent of studies pertaining to the hydrogeology of the Arckaringa Basin has resulted in some contradictory results or interpretations, such as the hydrogeological properties of the Stuart Range Formation. For example, in the south-east of the Arckaringa Basin, Kellett et al. (1999) and Belperio (2005) described the Stuart Range Formation as a leaky aquitard that separates the GAB and Boorthanna

Formation aquifers. Additionally, SKM (2009) and Aquaterra (2009) suggested that the Stuart Range Formation potentially provides sufficient leakage to enable drawdown stability in groundwater production wells in the underlying Boorthanna Formation. Conversely, SKM (2009) and Lyons et al. (2010) concluded that the Stuart Range Formation provided an effective barrier to aquifer leakage between Boorthanna Formation and unconfined GAB aquifers near the Prominent Hill Mining operation, based on hydraulic head differences and short-term aquifer-testing. Although currently not planned, longer-term aquifer stress tests or information regarding hydraulic head within the confining units between aquifers is required to improve the understanding of interconnectivity between aquifers of the GAB and Arckaringa Basin.

1.1.3.5.1 Connectivity between Mount Toondina Formation and Great Artesian Basin

For the most part, the Mount Toondina Formation is interpreted to be in contact with the GAB (Figure 21). Where this is of most significance is where the GAB is in contact with sandier units within the Mount Toondina Formation and is likely to be reasonably common in marginal areas of the basin where sandier units are more abundant. This appears to be the case in the west and north-west of the Arckaringa subregion, where discriminating between sandstone from either the Mesozoic or Paleozoic eras has proven difficult when logging drill cuttings. In addition, the presence of paleochannels within the unconformity between the Eromanga Basin and Arckaringa Basin, particularly the north and north-west of the basin, are zones where potential exists for both cross-formational flow and recharge to the Permian aquifers section (Figure 16 and Figure 21). The extent of such paleochannels is currently unknown, however understanding their extent would clarify their importance with respect to inter-aquifer connectivity between the GAB and the Mount Toondina Formation.

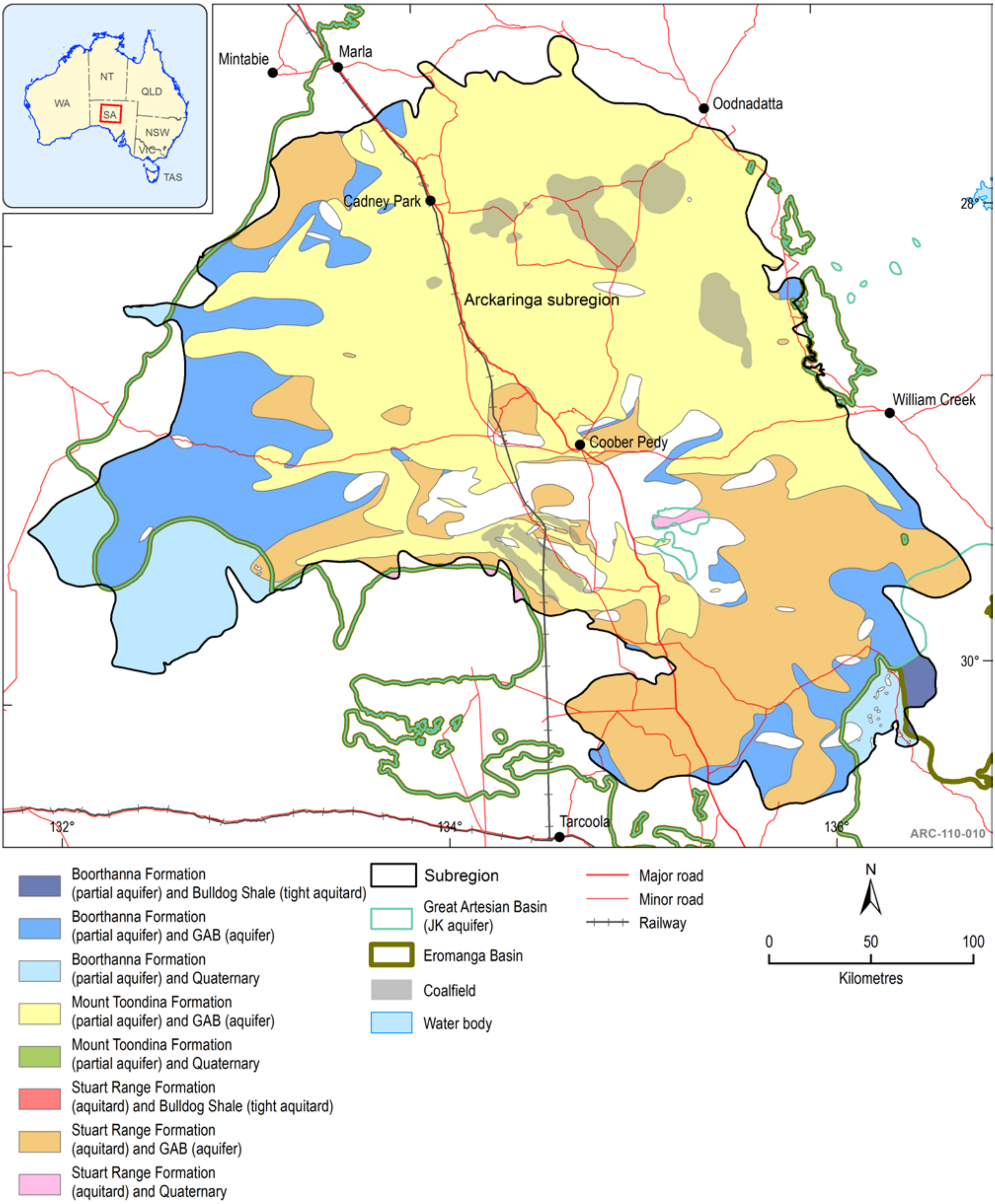

Figure 21 Possible hydraulic-connectivity relationships between the Arckaringa and overlying basins stratigraphic sequences

The presented interpretations in this figure are based upon the architecture and composition of the Arckaringa Basin as currently understood at the time of this report.

1.1.3.5.2 Connectivity between Boorthanna Formation and Great Artesian Basin

For deeper aquifers, such as those within the Boorthanna Formation, the removal of younger sedimentary horizons by erosion, in particular the Stuart Range Formation, prior to the deposition of the GAB or younger sedimentary units provides potential for interconnectivity between the Boorthanna Formation and overlying aquifer units. This is largely evident in the eastern and south-western margins of the basin (Figure 21).

1.1.3.5.3 Connectivity via faulting

Fault activity is also interpreted to have resulted in a variable thickness of Permo-Carboniferous formations, particularly relative to the overlying Mesozoic and Quaternary strata as well as potentially segmenting the wider Arckaringa Basin into sub-basinal areas. Evidence of seismic activity and active springs near fault zones of the eastern Arckaringa subregion suggests that faulting not only provides passive structural complexity, but may be actively contributing to changes in hydrodynamics and hydrogeological properties at both local and regional scales (Figure 17).

1.1.3.5.4 Connectivity between Arckaringa Basin, Stuart Shelf and Officer Basin

Existing hydraulic head data from Arckaringa Basin and Officer Basin aquifers to the west and the Stuart Shelf to the south and east, suggest that lateral connectivity is possible. Such basins may be important to recharge and discharge processes within Arckaringa subregion, although further information is required (Figure 22).

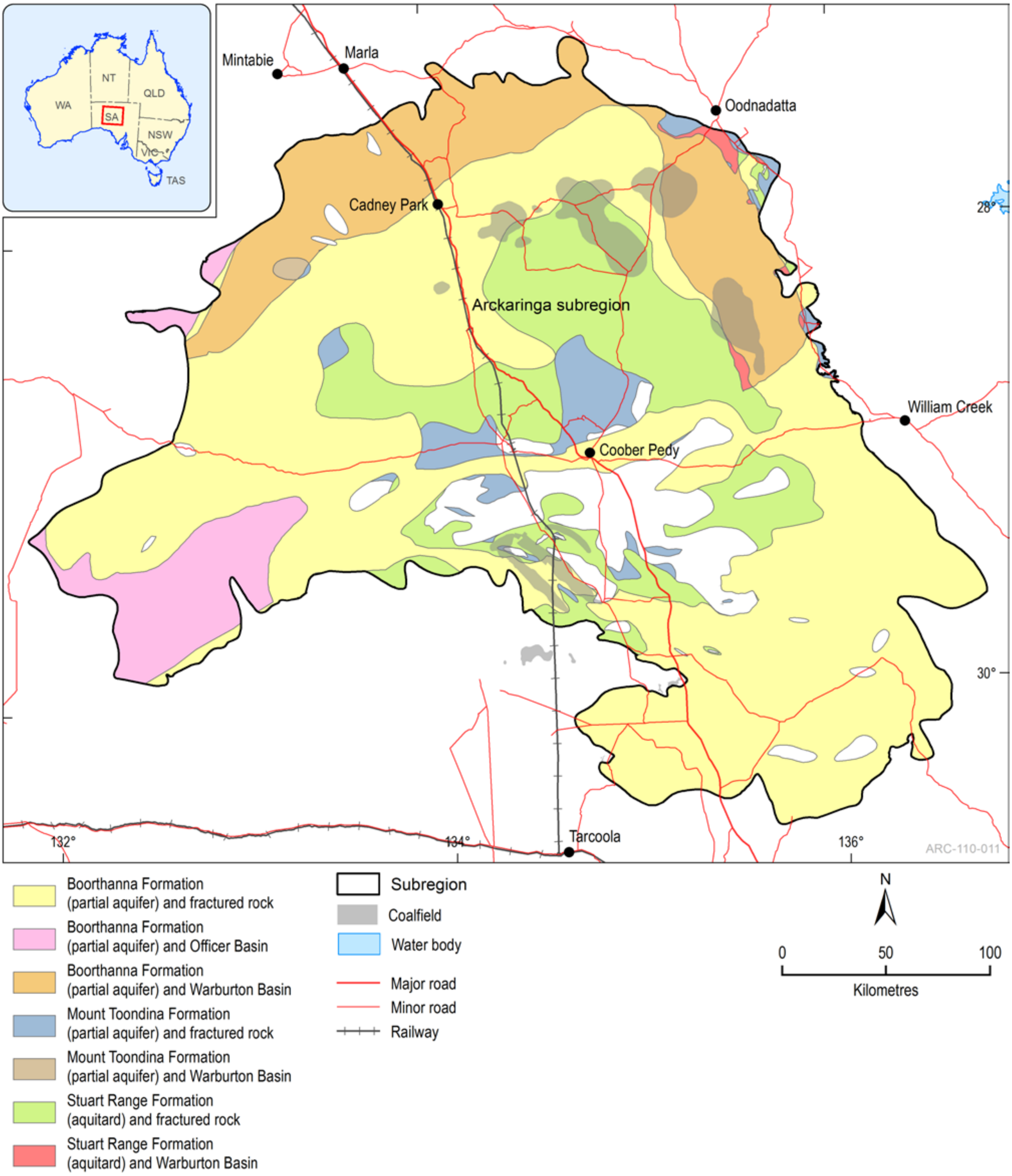

Figure 22 Possible hydraulic-connectivity relationships between Arckaringa and underlying basin stratigraphic sequences

The presented interpretations in this figure are based upon the architecture and composition of the Arckaringa Basin as currently understood at the time of this report.

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1.1.4 Hydrogeology and groundwater quality

Summary

A lack of data throughout the Arckaringa Basin limits our understanding concerning groundwater characteristics, with most information about groundwater within the Arckaringa Basin relating to the south-east corner.

Within the Arckaringa Basin, the Stuart Range Formation is characterised as confining layers and the Mount Toondina and Boorthanna formations as aquifers. That being said, interbeds of finer grained sediments within aquifer units and the formation of secondary porosity are important considerations. The separation of the Mount Toondina and Boorthanna formations by the Stuart Range Formation may lead to the existence of two regionally extensive aquifers that have determinably different hydrodynamics and flow characteristics. Groundwater from Arckaringa Basin aquifers is generally described as brackish to ultra-saline, although fresh supplies are known to occur. The recharge and discharge characteristics of the Arckaringa Basin are generally poorly understood. Recharge via diffuse discharge from the main GAB aquifer (JK aquifer), direct recharge near the southern basin margin and from freshwater stream and wetland environments have all been proposed. The most commonly proposed discharge mechanisms are direct discharge into the neighbouring Stuart Shelf along the south-eastern margin of the basin or into salt pan (salina) environments near the western margin of the basin. Currently, an important use of groundwater resources within the Arckaringa Basin is mining-related abstraction from the south-east corner near Prominent Hill; although no adverse impacts to the overlying GAB aquifer have been reported to date.

Groundwater within the Cenozoic, Officer Basin and fractured rock aquifers is typically very saline; consequently, these groundwaters have limited use. In contrast, good quality groundwater within the GAB is the most widely known and utilised groundwater resource in the vicinity of the Arckaringa subregion. Although there are a number of aquifer units within the GAB, the most important with respect to utilisation are the Cadna-owie Formation and Algebuckina Sandstone (and lateral equivalents). Current research suggests that diffuse recharge to the GAB along the western margin is currently minimal and major recharge events are linked to wetter climate periods. Periodic river flow events may have localised and regional importance. Discharge from the GAB occurs via direct discharge at springs or via diffuse discharge through confining layers, although such discharge is likely to only be meaningful where the confining layers have been deformed by faulting. Cenozoic aquifers are likely to be recharged via diffuse or focused recharge following large rainfall events and upward leakage through confining layers. Discharge occurs into localised wetlands or is driven by evapotranspiration. Recharge to Officer Basin aquifers occurs via old river channels or associated with Officer Basin outcrop near the Everard Ranges, while salt lakes along of the Officer Basin’s southern margin provide the only evidence for discharge. Recharge to fractured rock aquifers is inferred to occur either by direct infiltration or via river channels that incise basement rock.

1.1.4.1 Groundwater systems

1.1.4.1.1 Arckaringa Basin

A paucity of data through the majority of the Arckaringa Basin renders the determination of the Arckaringa Basin groundwater system difficult beyond a very general and basic understanding. The one exception is the south-east corner of the Arckaringa Basin, where adequate data allows for a more detailed assessment (Figure 23). At this localised level, SKM (2009) suggest that productive aquifer units may be present as relatively isolated semi-discontinuous ‘pods’ related to sporadic turbidite flows within an otherwise quiescent glacio-marine environment with further discontinuity arising from syn- and post-depositional faulting. Large observed draw-downs (>50 m) and complementary results from a shutdown test conducted at a production bore associated with the Prominent Hill Mine wellfield suggest that only weak hydraulic connectivity between multiple aquifers exists within the Boorthanna Formation. Additionally, secondary porosity development, either by mineral dissolution or structural deformation, is seen as an important variable with respect to aquifer quality.

SKM (2009) suggest the existence of deep groundwater flow associated with the Boorthanna Trough (north to south), although there is limited supporting data. Additionally, based on limited hydraulic head data, a groundwater flow system potentially exists between the western Arckaringa subregion, where the basin abuts or overlies the Officer Basin and the Stuart Shelf. Given the sedimentological similarity between Mesozoic, Mount Toondina and Boorthanna formations in this region, such a groundwater system may be inclusive of GAB formations. With respect to a more regional scale, the separation of the Mount Toondina and Boorthanna formations by the Stuart Range Formation may lead to the existence of two regionally extensive aquifers with restricted or spatially heterogeneous connectivity that have determinably different hydrodynamics and flow characteristics.

1.1.4.1.2 Cenozoic

Typically unconfined groundwater may be found in a number of geological formations that occupy the near surface environment over the Arckaringa subregion. Wopfner (1961) suggested that domal structures developed within underlying strata had an important influence on the occurrence and distribution of shallow groundwater. In the immediate vicinity of the Arckaringa Basin, little is known concerning this groundwater; however more is known to occur from similar aquifers in the wider vicinity of far north SA.

Cenozoic aquifers including aeolian deposits are scattered throughout the landscape. While it is possible that local flow systems occur, it is not assumed that these aquifers are continuous across the subregion. That being said, the phreatic surface presented in Figure 24 which in many cases is representative of groundwater within Cenozoic aquifers reflects the regional topography, with areas of high groundwater elevation found near the Musgrave Ranges and the Central Australian Plateau to the north-west and west respectively. Areas of low phreatic elevation occur in the vicinity of Kati Thanda – Lake Eyre and Lake Torrens, located to the east and south-east respectively. Areas of apparent localised mounding occur in the vicinity of the Stuart Shelf and Gawler Ranges, near the centre of the Arckaringa Basin, and near of the north-western and southern margins of the basin.

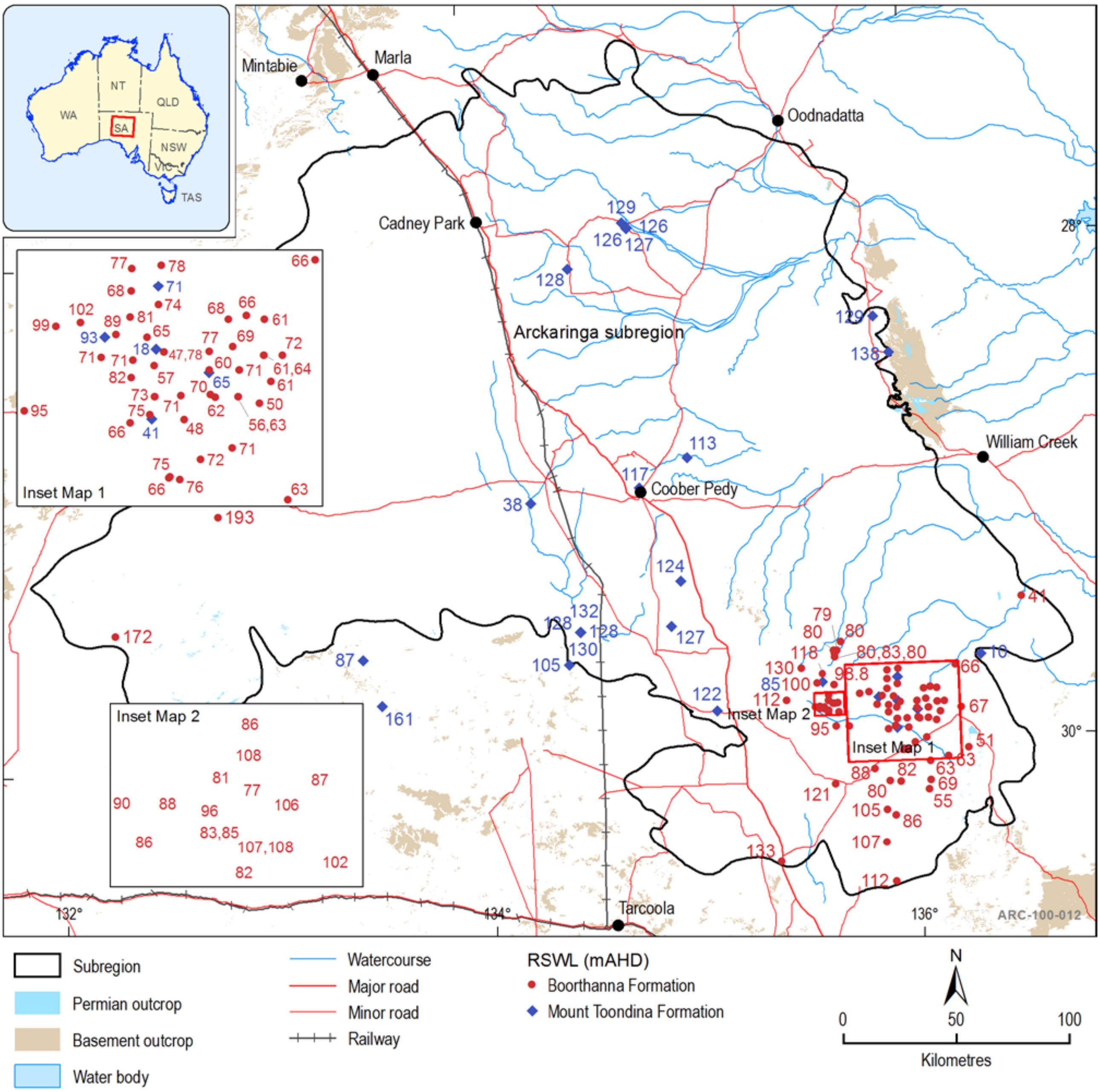

Figure 23 Water level data for the Permian aquifers within the Arckaringa subregion

Although limited information is available on Cenozoic aquifers across the Arckaringa subregion, groundwater extraction from these aquifers via pumping is considered minimal. Evaporation and transpiration are thought to be the main mechanisms controlling groundwater loss from the system.

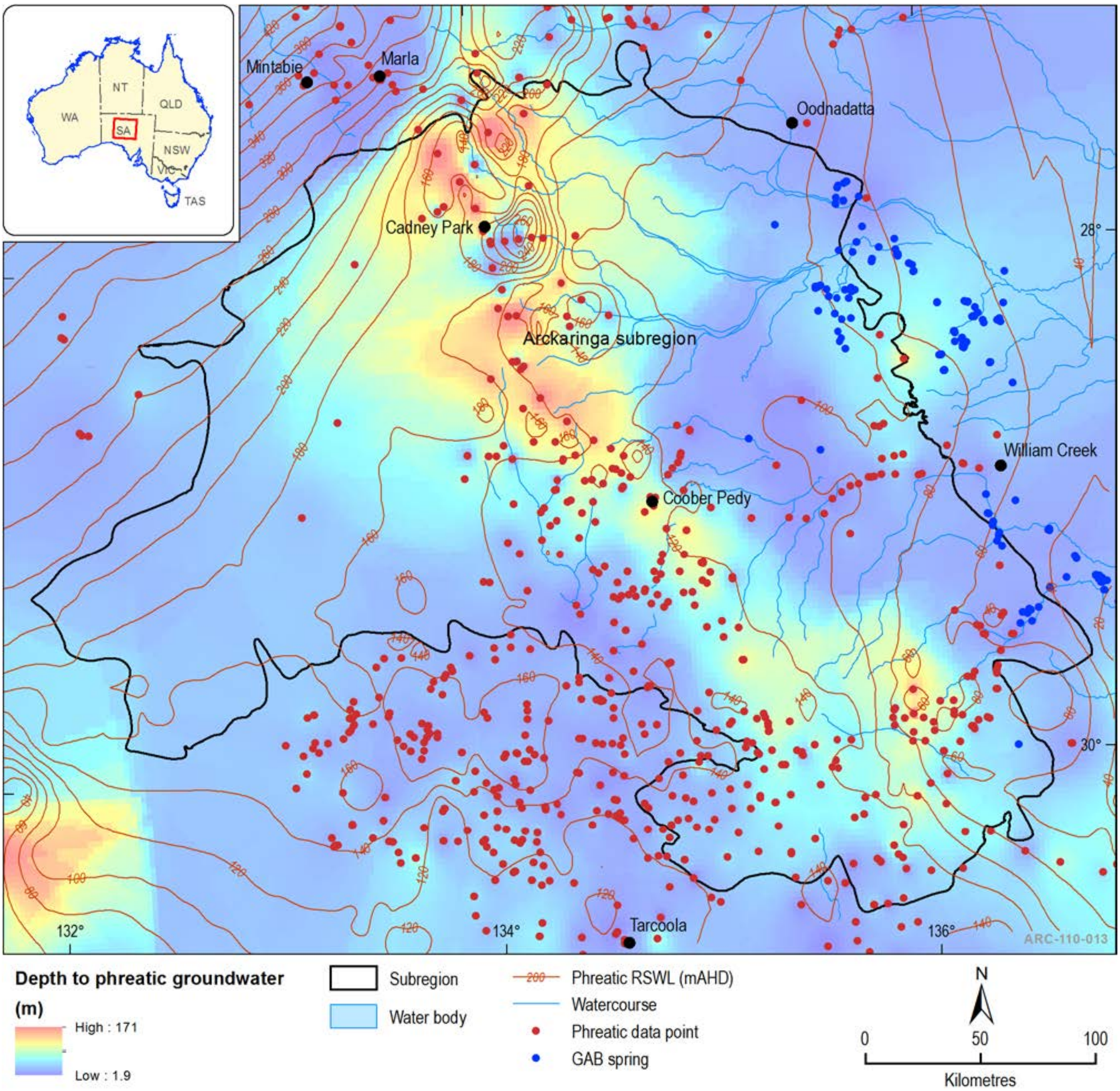

Figure 24 Interpreted phreatic groundwater contours for the Arckaringa subregion

Note: Although phreatic groundwater is ubiquitous across the landscape and is commonly represented by groundwater in Cenozoic formations, this surface does not necessarily imply continuous groundwater movement between formations, nor is it completely restricted to Cenozoic formations. The watertable measurements displayed have not been corrected for density because density corrections were determined to have only a negligible effect on head.

1.1.4.1.3 Great Artesian Basin

The Great Artesian Basin (GAB) is one of the largest groundwater basins in the world, underlying approximately 1.7 million km^2, or 22% of the Australian continent (Habermehl, 1980). The GAB is the most widely known and utilised groundwater resource and overlies most of the Arckaringa subregion. There have been several texts written about the GAB; recent summaries and the latest research about the GAB in the vicinity of the Arckaringa Basin may be found in Love et al. (2013a), Love et al. (2013b), Keppel et al. (2013) and Smerdon et al. (2013). Geologically, the GAB describes a terrestrial to marine, Cretaceous–Jurassic hydrogeological super basin that covers much of eastern and central Australia. Although the name GAB may cover a number of smaller sedimentary basins, in SA the GAB is synonymous with the Eromanga Basin (Wohling et al., 2013).

Although there are a number of aquifer units within the GAB, the most important with respect to utilisation in the Arckaringa subregion are the Cadna-owie Formation and Algebuckina Sandstone (and lateral equivalents), which can be collectively referred to as the main GAB aquifer (JK aquifer) (Keppel et al., 2013). Typical yields of the GAB within the Arckaringa subregion generally range between 0.1 L and 6.0 L/second, although larger yields of up to 130 L/second have been reported for the GAB aquifer outside the subregion (e.g. Olympic Dam Wellfield B, located approximately 30km east of the south-eastern margin of the Arckaringa Basin).

1.1.4.1.4 Warburton Basin

Due to the depth of the Warburton Basin and accessibility of groundwater in overlying sequences, groundwater utilisation is considered very minimal. Consequently, the hydrogeological characteristics of formations within the Warburton Basin are poorly understood.

1.1.4.1.5 Officer Basin

The regional groundwater flow system within the Officer Basin has been simplistically described as a single unconfined system with Precambrian sequences acting as hydrogeological basement

(Lau et al., 1995a; Lau et al., 1995b). Semi-confined to confined aquifers may be present in the Murnaroo Formation in the south-eastern part of the Officer Basin (Alexander and Dodds, 1997) while shallow groundwater supplies may be found in the Trainor Hill Sandstone (AGT, 2012).

Read (1990) provides yields from Officer Basin sandstone units between <0.1 to 3 L/second, while AGT (2012) reports yields between 1 and 5 L/second for wells within the Officer Basin at depths between 50 m and 400 m. Additionally, AGT (2012) also summarise yields of up to 40 L/second from very deep petroleum bores.

1.1.4.1.6 Cambrian and Precambrian basement (fractured rock and karstic aquifers)

A number of localised fractured rock and karstic aquifers occur within crystalline Cambrian and Precambrian basement rocks in the vicinity of the Arckaringa subregion. Of particular importance to the subregion are those found within the Stuart Shelf, located near the south-east corner of the Arckaringa Basin. As is the nature of most fractured rock aquifers, the hydrogeological properties are highly dependent of post-depositional deformation and therefore can be highly heterogeneous.

Groundwater yields within fractured rock aquifers are highly variable, with greater yields correlated to faults and with fracture density, while good yields are also obtained from limestone aquifers within the Proterozoic sequences. SAAL NRMB (2006), suggest that the vast majority of groundwater resources within fractured rock aquifers are either brackish or saline. With respect to yields from fractured rock aquifers, Belperio (2005) obtained yields of between 0.5 and 5 L/second In the vicinity of the Mount Woods Inlier.

1.1.4.2 Groundwater quality

1.1.4.2.1 Arckaringa Basin

In general, fresher groundwater occurs near the south-eastern and eastern margins of the basin, near the Gawler Ranges, southern Stuart Range and Peake and Denison Inlier, whereas higher salinities are found east of the Mount Woods Inlier and Stuart Range and south of the Mount Woods Inlier near the Phillipson Trough (Figure 25). Salinities generally range between 6000 and 25,000 mg/L although higher salinities (>100,000 mg/L) do occur near the southern margin of the subregion. pH ranges between 6.3 and 9.7. From very limited data, groundwater temperature varies between 25 °C (non-artesian wells located within the far south-west corner of the Arckaringa Basin) and 26.5 °C (artesian well located in the vicinity of the Wintinna Coalfield) (Wohling et al., 2013), although this is not thought to be representative of the true range. With respect to gross hydrochemistry, major ion hydrochemistry from Arckaringa Basin aquifers in the south and south-east of the basin is similar to that found within the overlying GAB, being predominantly Cl and Na + K dominant, with relatively high Mg and SO_4 (e.g. AGC, 1975; Howe et al., 2008).

With respect to the use of hydrochemistry to understand groundwater flow systems, all available studies to date have concentrated on the south-east corner of the Arckaringa Basin. Aquaterra REM (2005a), Howe et al. (2008), SKM (2009) and Lyons et al. (2010) all used hydrochemistry to differentiate between groundwater sources and groundwater systems pertaining to Boorthanna Formation aquifers and others located within the south-east corner of the basin. Aquaterra REM (2005a) state that GAB-related groundwater largely east of the Arckaringa Basin can be differentiated from Boorthanna Formation groundwater and GAB aquifer groundwater in the vicinity of the Arckaringa Basin via major ion concentration signatures. However, Aquaterra REM (2005a) and SKM (2009) conclude that Arckaringa Basin groundwater and GAB groundwater from the same vicinity cannot be differentiated based on either major ion hydrochemistry or salinity. Howe et al. (2008), SKM (2009) and Lyons et al. (2010) used stable isotope and ^{36}Cl data to differentiate between Arckaringa Basin sourced groundwater from the south-east corner of the Arckaringa Basin and groundwater from the western GAB. Finally, SKM (2009) used variations in salinity to suggest the influence of either multiple groundwater recharge zones or palaeoclimate variation.

1.1.4.2.2 Cenozoic Aquifers

With respect to groundwater quality from the Cenozoic aquifers, little information from the immediate vicinity of the Arckaringa subregion is known. From a wider area inclusive of the Arckaringa subregion, salinities ranging between 100 mg/L to 150,000 mg/L have been reported (C. Bleys and Associates, 1977; Shepherd, 1978; Howles, 2000; AGT, 2012).

1.1.4.2.3 Great Artesian Basin

There are in excess of 1,100 records for salinity data for wells completed in GAB sediments in the vicinity of the Arckaringa subregion stored within SA_Geodata database. The vast majority of these values reported for the JK aquifer. Water quality can vary greatly, with salinities ranging from approximately 150 to >72,000 mg/L. That being said, the majority of salinities reported are <5000 mg/L. Notable areas where salinity concentrations for GAB groundwater is in excess of

5000 mg/L include a broad area in the vicinity of the southern troughs in the Arckaringa subregion, west of the Mount Woods Inlier and near Lake Phillipson, within parts of the south-east Arckaringa Basin, near the eastern margin of the Arckaringa near the GAB springs, and in isolated parts of the upper reaches of the Neales River catchment area. With respect to general chemical composition, Jack (1923), Habermehl (1980) and Radke et al. (2000) describe groundwater originating from the western margin of the GAB to be characterised as Na-Cl-SO_4 type water, whereas that flowing from the east to be Na-HCO_3-Cl type water, with the two converging in the vicinity of the springs west of Kati Thanda – Lake Eyre. More recently, Crossey et al. (2013), through a more detailed analysis, was able to subdivide GAB groundwater into a number of groupings that describe different recharge sources and flow paths, including near the Birdsville Track Ridge, two areas east and west of the Peake and Denison Inlier respectively, between Marla and Kati Thanda – Lake Eyre South and the south-western GAB. Additionally, pH values for GAB groundwater typically range between 7.5 and 8.5.

1.1.4.2.4 Warburton Basin

Due to the depth of the Warburton Basin and accessibility of groundwater in overlying sequences, groundwater utilisation is considered very minimal. Consequently, the quality of groundwater from formations within the Warburton Basin is poorly understood.

1.1.4.2.5 Officer Basin

Little is known about the quality of groundwater from the Officer Basin, given the sparse usage of water and more readily available sources in shallower aquifers. That being said, AGT (2012) report that groundwater with salinities <30,000 mg/L from aquifers at >150 metres below ground level (mBGL) are typical of the Officer Basin, although groundwater from the southern part of the basin may contain salinities in excess of 35,000 mg/L. Additionally, Alexander and Dodds, (1997) describe groundwater from the Officer Basin as being highly saline, while Aldam (1994) report salinities from Officer Basin aquifers as ranging in salinity from 1100 to 150,000 mg/L, with the poorest quality water obtained from the vicinity of Lake Wyola, an area of known evaporitic discharge. Aldam (1994) also stated that the better quality water was obtained from areas thought to be subject to either enhanced recharge or a reduction of evaporitic discharge due to lithology or fracturing.

1.1.4.2.6 Cambrian and Precambrian basement (fractured rock and karstic aquifers)

Most information concerning the groundwater quality from Precambrian fractured rock aquifers in the vicinity of the Arckaringa subregion comes from the south-eastern portion where most groundwater studies have occurred. Near the Mt Woods Inlier, groundwater extracted for mining has salinities between 5000 and 10,000 mg/L (Belperio 2005). In contrast, Kellett et al. (1999) describe groundwater from crystalline basement fractured rock aquifers near salt lakes as being unusable for stock watering, with salinities exceeding 100,000 mg/L.

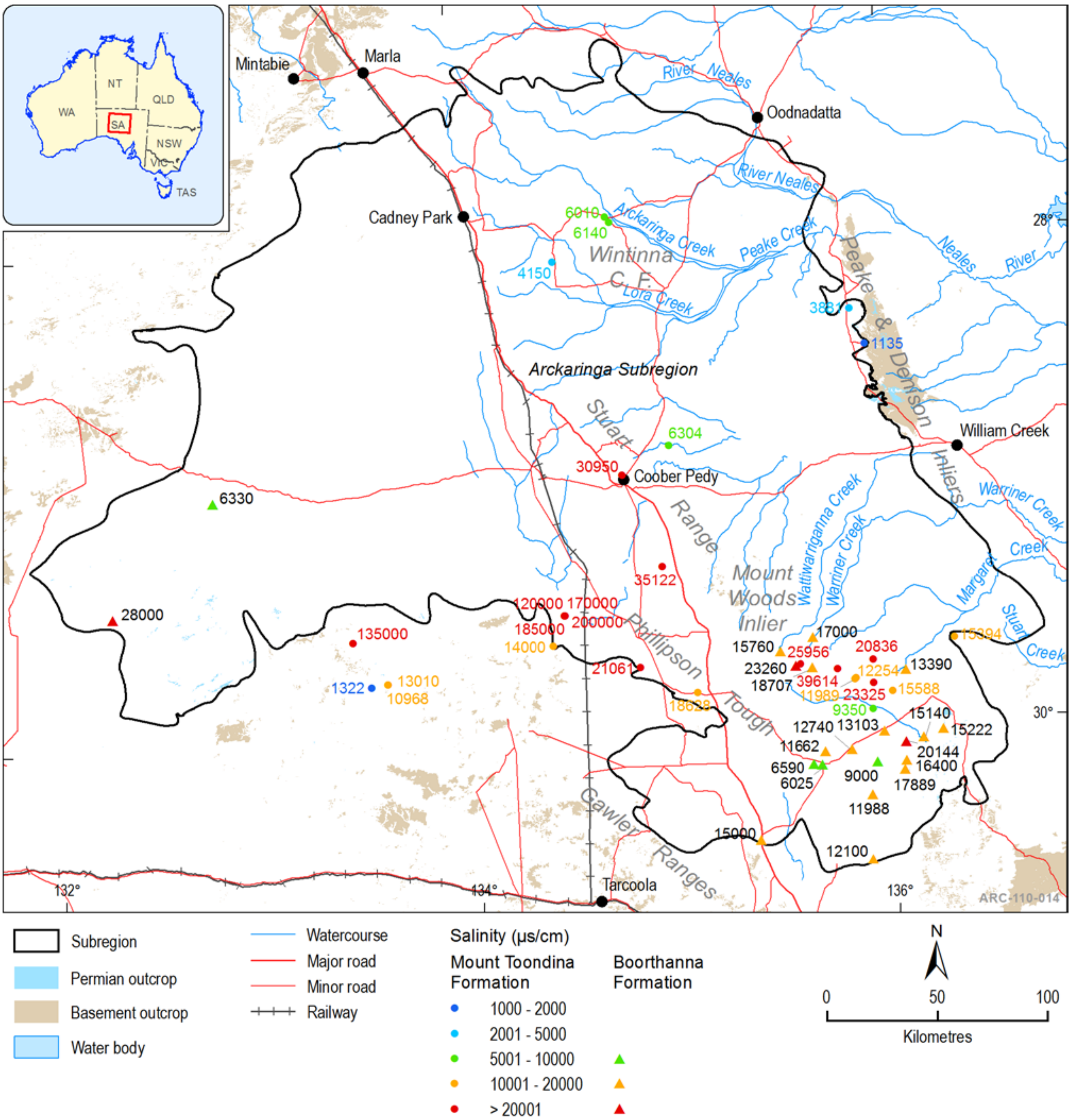

Figure 25 Groundwater quality from Permian groundwater, Arckaringa subregion

1.1.4.3 Groundwater flow

1.1.4.3.1 Hydrostratigraphic units and system boundaries

Within the Arckaringa Basin the Stuart Range Formation is characterised as a confining layers, and the Mount Toondina Formation and Boorthanna Formation as aquifers. A lack of confining layer between the Mount Toondina Formation and the overlying aquifers of the GAB suggests that there is potential for extensive connectivity between the GAB aquifer and aquifer units within the Mount Toondina Formation within the Arckaringa subregion (Ransley et al., 2012). That being said, the paucity of information concerning intra-formational variability with respect to lithology, spatial distribution and the impact of digenetic changes such as fracture development or mineral dissolution renders only a general interpretation possible.

There is insufficient information to define boundary conditions around the Arckaringa Basin, so the potential for lateral inter-basin connectivity along the western margin and south-eastern corner is considered possible. Discharge from the Arckaringa Basin into the Stuart Shelf has been conceptualised as an important hydrogeological flow feature (Figure 26).

The following is a summary of the main hydrostratigraphic units found within the Arckaringa subregion. Discussions concerning minor units such as the Cenozoic, Officer and Warburton Basins will be limited to what has previously been discussed for brevity and/or due to a lack of relevant data on the subject.

Rolling Downs Group

The Oodnadatta Formation, Bulldog Shale and lateral equivalents are the main units that confine the GAB aquifer. While the Bulldog Shale outcrops extensively through the subregion, outcrop of the Oodnadatta Formation is restricted to the northern and north-eastern portions of SA. Little information concerning the water quality or aquifer properties of this aquitard is known. Measured vertical hydraulic conductivity values range from 3.46×10^{-9} to 1.04×10^{-8} m/day (Love et al., 2013b), suggesting that intergranular cross-formational flow through the aquitard is much less than previously recognised and inferring that the majority of cross-formational flow must therefore occur via preferential flow paths such as faults.

JK aquifer

As previously discussed, the GAB aquifer at a regional scale is used to describe the Cadna-owie Formation and Algebuckina Sandstone as a single aquifer unit, although local variations to this may occur (Berry and Armstrong, 1995). In the Arckaringa subregion, the JK aquifer reaches a maximum thickness of approximately 220 m. Examples of hydrogeological properties pertinent to the Arckaringa subregion are provided in Table 6. Detailed discussion may be found in Keppel et al. (2013), Love et al. (2013a), Love et al. (2013b) and Smerdon et al. (2013).

Upper and lower Mount Toondina Formation

Sandstone units in the Mount Toondina Formation encountered during petroleum exploration work have been described as having porosities from as low as 4% (Wopfner and Allchurch, 1967) to as high as 36.6% (Linc Energy, 2010b), while shale and siltstone units have been interpreted as potential seals for petroleum (Cotton et al., 2006; Tucker, 1997). Although no direct comparative work has been undertaken to examine why there is such variance in porosity, possible reasons include lithological heterogeneity, diagenetic processes that may either enhance of reduce porosity or differences in measurement techniques. Six packer permeability tests conducted on coal seam and coal seam interbeds in the Wintinna Coal Field by Coffey and Partners (1983) found coal seams to be of low to moderate hydraulic conductivity, while interbedded sediments were found to have a very low to low hydraulic conductivity; the greater permeability in the coal seams was attributed to observed fracturing (fissility), which can be well developed (Coffey and Partners, 1983; Dames and Moore, 1986). Tucker (1997) notes that feldspar found in sandstone units within the Mount Toondina Formation can appear to be partially dissolved, indicating the development of secondary porosity that may enhance primary porosity. Published hydrogeological properties for the Mount Toondina Formation are provided in Table 6 and Table 7.

The definition of the lower Mount Toondina Formation used for this study is relatively new (Menpes et al., 2012). Previously, Hibburt (1995) noted that the lower units of the Mount Toondina Formation were composed predominantly of marine shales. However, recent reviews of seismic data by Menpes (2012), Menpes and Sansome (2012), Menpes et al., (2012) and this study have identified a maximum flooding surface (mfs) as the base of the Mount Toondina Formation. Above this mfs are prograding deltaic sedimentary rocks, which may correlate with the middle Mount Toondina Formation unit of Hibburt (1995), which was described as consisting of prograding deltaic sandstone and siltstone. Similarly, Hibburt (1995) suggested that the lower Mount Toondina Formation units were recorded in two drill-holes, whereas the most recent interpretation presented here does not specify a distribution. Given these uncertainties regarding the distribution and lithological composition of the Lower Mount Toondina Formation, little can be implied regarding the hydrogeological characteristics.

Table 6 Basic hydrogeological parameters for the JK aquifer within the western margin of the GAB

Parameter	Value	Source
Hydraulic Conductivity	0.1 m/day to 20 m/day	Welsh (2007)
	0.5 m/day to 22 m/day Mean 7.0 m/day	Armstrong and Berry (1997)
	1.6 m/day to 18.5 m/day Mean 8.9 m/day	Berry and Armstrong (1995)
	1 m/day to 13 m/day Mean 6.3 m/day	Rust PPK (1994)
	0.02 m/day to 82 m/day	Audibert (1976)
Transmissivity (T)	5 m^2/day to 380 m^2/day	Berry and Armstrong (1995)
	1 m^2/day to 2000 m^2/day With a predominance of recorded values 10 m^2/day to 20 m^2/day	Habermehl (1980)
Porosity	Mean of 0.21 for whole basin	Audibert (1976)
Storage Co-efficient	Mean of 2.5 x 10^{-4} for whole basin	Audibert (1976)
	7 x 10^{-6} to 7 x 10^{-3} for whole basin	Welsh (2007)

Source: Keppel et al. (2013)

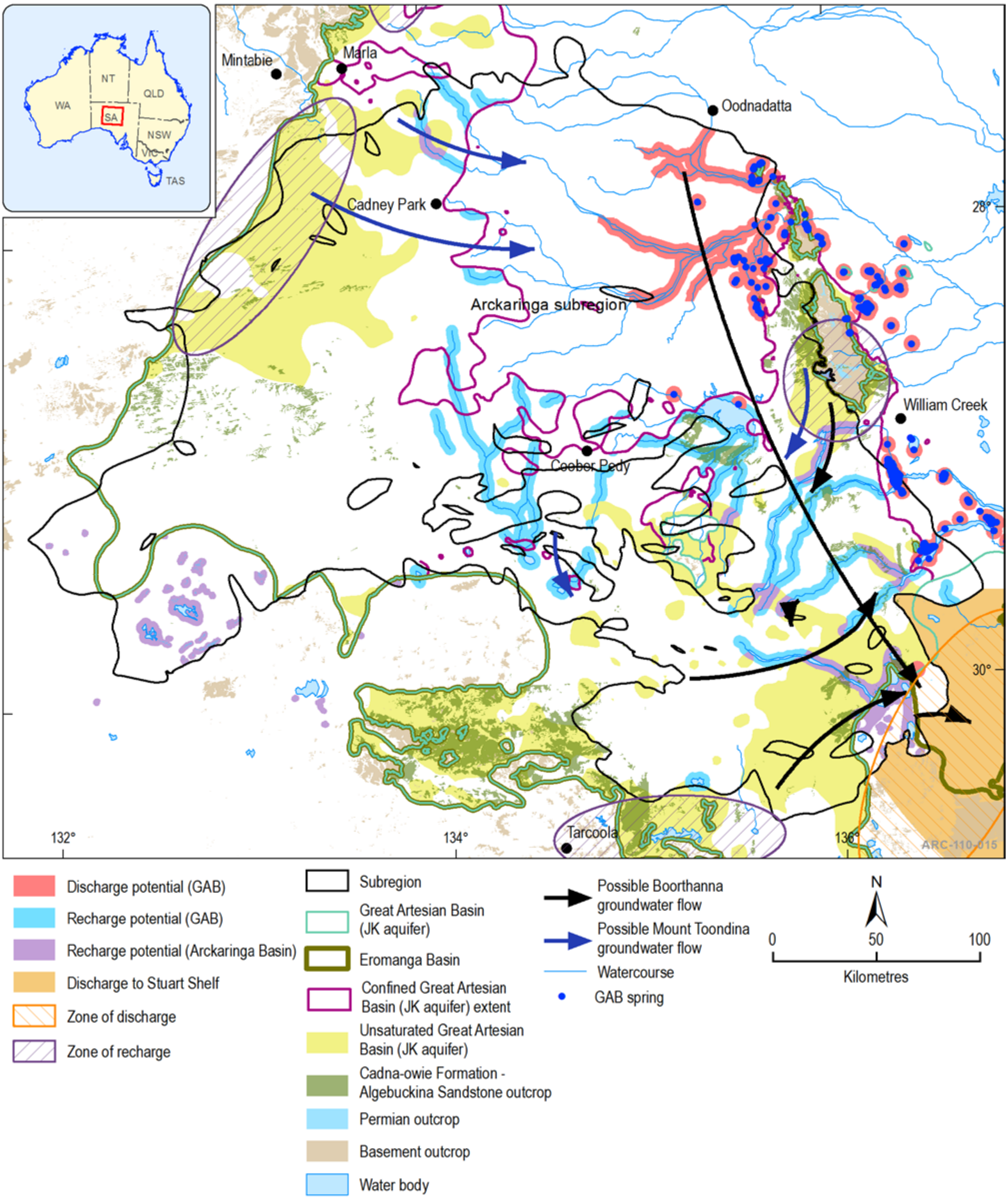

Figure 26 Conceptualised hydrogeological elements of the Arckaringa subregion

Note: Current figure has been developed by authors for this contextual statement.

Stuart Range Formation

No aquifers of any significance are known to occur in the Stuart Range Formation. Additionally, there is very little measured data with respect to the hydrogeological properties of the Stuart Range Formation, although a vertical conductivity of 1x10-4 m/day being one example (Table 7).

Ransley et al. (2012) suggested that minor sandstones within the south-western portion of the Stuart Range Formation may act as partial aquifers, However reviews of seismic, drill-hole and other geophysical datasets conducted for the purposes of this report have reclassified much of this rock as Boorthanna Formation. In most cases, descriptions of the hydrogeological properties of the Stuart Range Formation are qualitative. Kellett et al. (1999), Belperio (2005), SKM (2009) and Aquaterra (2009) suggest that the Stuart Range Formation is a leaky aquitard, while Aquaterra REM (2005a) and SKM (2009) used head differences between groundwater in the Boorthanna Formation and the overlying watertable to suggest that the Stuart Range Formation acts as an effective barrier to downward leakage. Published hydrogeological properties for the Stuart Range Formation are provided in Table 7.

Boorthanna Formation

Most information concerning the hydrogeological characteristics of the Boorthanna Formation is sourced from the south-eastern Arckaringa Basin, where several studies have been undertaken (Kellett et al., 1999; Rogers and Zang, 2006; Belperio, 2005; Howe et al., 2008; Lyons et al., 2010; Enesar, 2006; SKM, 2009). The aquifer characteristics of the Boorthanna Formation are interpreted to be heterogeneous at a regional scale and highly dependent on intra-formational characteristics and secondary porosity development. This heterogeneity is reflected by the range of lateral hydraulic conductivities, which vary from 0.02 to 5 m/day. In addition, a literature review by Wohling et al. (2013) found that sandstone units in the Boorthanna Formation can have relatively high porosity of up to 25%. Published hydrogeological properties for the Boorthanna Formation are provided in Table 7.

Table 7 Reported porosity and permeability for the Arckaringa Basin

Unit	Source	Porosity (%)	Effective Porosity (%)	Permeability (cm^2)
Permian	Papalia (1970)	5.5-16[a]		
Mount Toondina Formation	Wopfner and Allchurch (1967)	4-8		
	Allchurch and Wopfner (1967)	8 (sandstone unit)		
	DMITRE (2011)	6-9 (sandstone units)		
	Linc Energy (2010[a])	25.4-33.3[b]		3.06×10^{-12}–1.5×10^{-9} [c]
	Linc Energy (2010[b])	22-36.6[b]		1.48×10^{-12}–1.39×10^{-8} [c]
Boorthanna Formation	CRAE (1987)	3.6-23[a]	1.9-22.7	
	Tucker (1997)	20-25		2.96×10^{-9} – 1.97×10^{-8}
	DMITRE (2011a)	13.5	5	

Source: Wohling et al. (2013) a) Calculated from density; b) Determined in a laboratory using helium and a porosimeter; c) Determined in a laboratory using a permeameter.

Table 8 Reported hydrogeological properties for the Arckaringa Basin

Unit	Source	Method	Kh (m/day)	Kv (m/day)	Transmissivity (m^2/day)	Storativity	Specific Yield (%)
Mount Toondina Fm (P[a])	AGC (1975)a	Slug Test			38.14 (P)[b]		1
Mount Toondina Fm (T[a])					22.066 (T)		1
Mount Toondina Fm (S[a])					0.073–0.34 (S)		1
Mount Toondina Fm (S and T[a])					15.4–22.5 (S and T)		1
Mount Toondina Fm (P, S and T[a])		Aquifer Test			24.3 (P, S and T)	4.5×10^{-3}	1
Mount Toondina Fm (T[a])					22.1 (T)	2×10^{-7}	1
Mount Toondina Fm (S[a])					0.4 (S)	1.3×10^{-6}	1
Mount Toondina Fm (S and T[a])					21	2.6×10^{-5}	1
Mount Toondina Fm (coal seams)	Coffey and Partners (1983)	Packer test	0.9×10^{-3} - 9×10^{-3}				
Mount Toondina Fm (sedimentary interbeds)			9×10^{-4} - 9×10^{-5}				
Stuart Range Formation	Howe et al. (2008)	Aquifer tests		1×10^{-4}		1×10^{-5}	
Boorthanna Formation	Howe et al. (2008)	Aquifer tests	1-5		<5-180	1×10^{-4} - 1×10^{-5}	

Source: Wohling et al. (2013) a) Three discrete aquifers identified in Mount Toondina Formation: these were called the P (Permian sediments), S (S coal seam) and T (T coal seam) aquifers; b) Results are thought to be affected by slumping of P aquifer and partial blockage of underlying S and T aquifers

Cambrian and Precambrian basement (fractured rock and karstic aquifers)

Whereas the Andamooka Limestone has developed karstic features, the hydrogeological characteristics within the Arcoona Quartzite and Corraberra Sandstone are largely structurally controlled. Kinhill (1997) calculated that hydraulic conductivity values for a combined Arcoona Quartzite and Corraberra Sandstone hydrogeological unit may vary between 1×10^{-3} m/day in the upper part of the section to 1 m/day in the basal fractured section. Additionally, air-lift yields from monitoring bores at Olympic Dam range from less than 1 to greater than 10 L/second in the more highly fractured sections.

1.1.4.3.2 Groundwater Flow Paths

Arckaringa Basin

Based on hydrogeological studies completed within the south-east, the possibility that the Arckaringa Basin is partitioned into a series of semi-discrete sub-basinal areas exists. It is also assumed that a regional groundwater flow regime exists.

Groundwater flow in the south-east Arckaringa Basin is generally eastward toward the Stuart Shelf and a number of salt pan and saline environments near the basin margin (Kellett et al., 1999; Aquaterra REM, 2005a; Howe et al., 2008; SKM, 2009; Lyons et al., 2010). Additionally, a deep groundwater flow path from the Boorthanna Trough to the south has been inferred (Aquaterra REM, 2005a).

With respect to other sub-basinal groundwater flow systems based on limited head data, groundwater within the western Arckaringa Basin is speculated to flow in an easterly direction from the basin margin abutting the Officer Basin towards the Stuart Range. Also, headward erosion contributing to the development of the Stuart Range and the subsequent development of the Lake Eyre (hydrological) Basin may be associated with a zone of recharge for the eastern Arckaringa Basin. Subsequent flow associated with this conjectural zone of recharge is interpreted to be eastward toward the Boorthanna Trough.

Great Artesian Basin and other overlying aquifers

Outcropping aquifer units along the western GAB are important recharge zones that contribute to the groundwater resource and provide water to the many GAB spring environments located in SA. Consequently, groundwater within the GAB in the vicinity of the Arckaringa subregion is typically interpreted to flow from the western basin margin to the east and south-east, where discharge at least partially occurs at a series of springs located along the Torrens Hinge Zone (Figure 27).

As previously mentioned, Cenozoic aquifers are scattered throughout the landscape and are conceptualised as a number of discontinuous local groundwater systems. However, the phreatic surface presented in Figure 24 may be used to provide a general indication regarding groundwater flow. The phreatic surface reflects the regional topography, displaying elevevated groundwater near the Musgrave Ranges and the Central Australian Plateau to the north-west and west respectively and low groundwater elevation near Kati Thanda – Lake Eyre and Lake Torrens, located to the east and south-east respectively. Consequently a general groundwater flow of north-west to south-east may be implied.

Officer Basin

Little is known about the flow dynamics of groundwater within the Officer Basin, however using a regionally scaled, simplistic approach, Alexander and Dodds (1997) and Read (1990) suggested a general north to south groundwater migration from the southern Everard Ranges to discharge points associated with salt lakes along the southern margin of the basin, while recharge via paleochannels may form localised groundwater flow paths.

Cambrian and Precambrian basement (fractured rock and karstic aquifers)

The most well-known fractured rock and karstic aquifers in the Arckaringa subregion are in the south-east. Here, such aquifers may be found in a number of stratigraphic formations, inclusive of the Andamooka Limestone, the Arcoona Quartzite and the Corraberra Sandstone (Kellett et al., 1999). Kellett et al. (1999) interpreted flow lines within Precambrian fractured rock to be short (approximately 20 km), radial and essentially following surface drainage lines centred toward the numerous number of salt lakes in the region. Kellett et al. (1999) stated that such a flow pattern highlighted the importance of structural control on the hydrodynamics of the fractured rock aquifers in this region.

A similar interpretation was made with respect to fractured rock aquifer hydrodynamics within the Peake and Denison Inlier, located near the eastern margin of the Arckaringa Basin (Love et al., 2013a), with localised flow away from areas of Precambrian outcrop within the uplifted ranges toward basinal areas in the nearby surrounds.

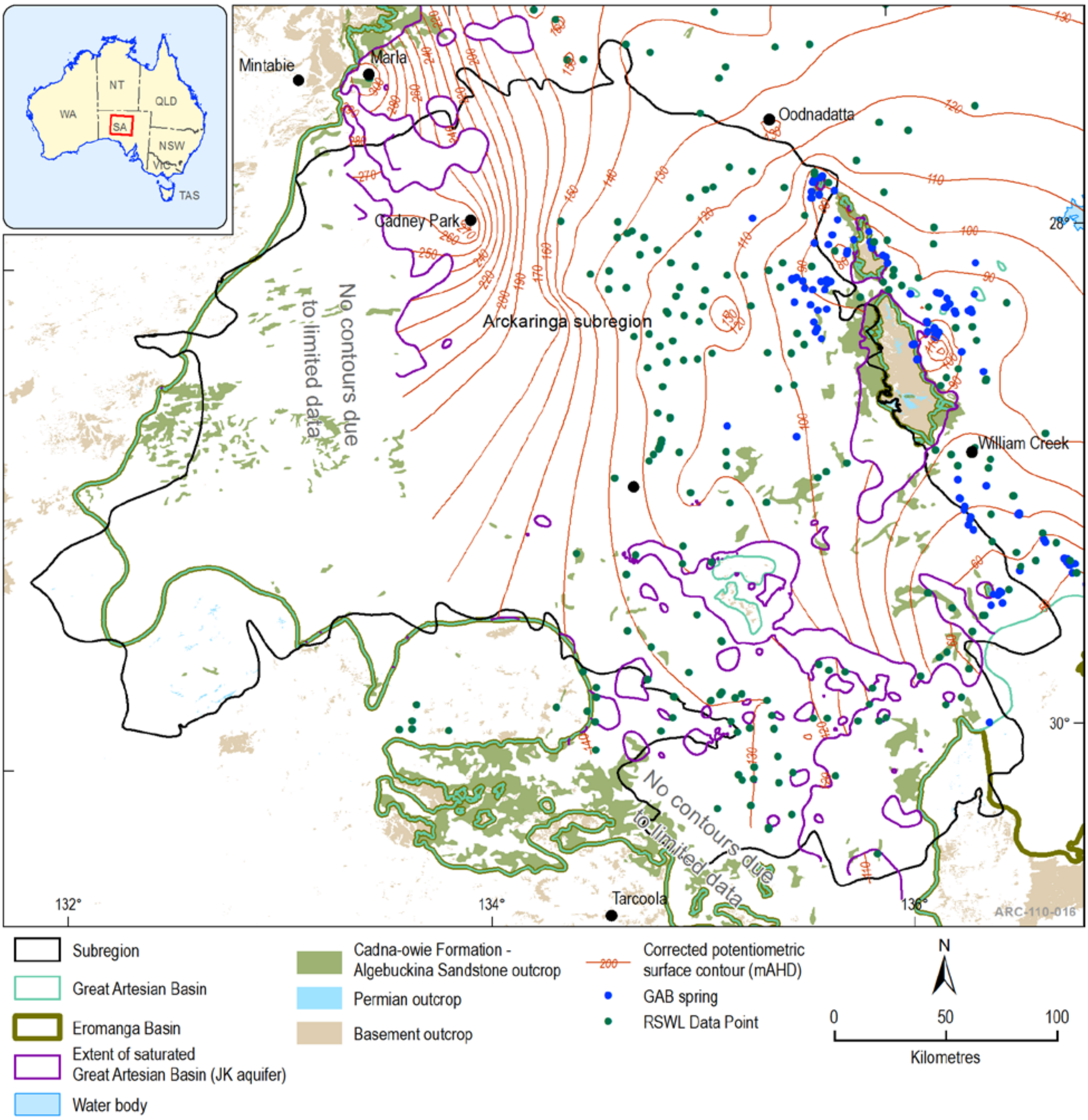

Figure 27 GAB aquifer potentiometric surface for the Arckaringa subregion. Contours based on head data corrected for temperature and salinity.

1.1.4.3.3 Groundwater recharge and discharge

Arckaringa Basin

Kellett et al. (1999) proposed that recharge in the south-east corner of the Arckaringa Basin occurs via diffuse discharge from the JK aquifer. Howe et al. (2008) suggested possible direct recharge to the Boorthanna Formation near the southern basin margin and north of the Boorthanna Fault. Other suggested recharge zones include freshwater stream and wetland environments located near the south-eastern margin of the basin. An average groundwater velocity of 1.4 m/year and a residence time up to 200,000 years was estimated by Kellett et al. (1999) for Boorthanna Formation groundwater. Beyond the south-east corner of the Arckaringa Basin, the use of very limited head data suggests that recharge occurs along the western margin of the Arckaringa Basin, near the Musgrave and Everard ranges and Central Australian Plateau (Figure 26).

An estimate for diffuse recharge to the Permian aquifers in the south-east corner of the Arckaringa Basin using a chloride mass balance approach ranged between 0.05 and 0.22 mm/year, with an average rate of 0.09 mm/year (Wohling et al., 2013). Kellett et al. (1999) used a similar chloride mass balance approach to obtain a recharge rate of 0.5 mm/year through a combined GAB/Boorthanna Formation for the south-eastern corner of the Arckaringa Basin. Both results indicated that diffuse recharge at the well locations assessed is small.

Discharge from the south-east corner of the Arckaringa Basin occurs into the Andamooka Limestone of the Stuart Shelf (Kellett et al., 1999; Howe et al., 2008; Lyons et al., 2010); while Aquaterra REM (2005a) and SKM (2009) also indicate that upward leakage from the Boorthanna Formation aquifer into the overlying GAB, salt pan and saline environments along the western margin of the Billa Kalina Fault is possible on the basis of hydraulic gradient data. Beyond this, discharge from the Arckaringa Basin is poorly understood, although conditions similar to those described for the south-east corner of the Arckaringa Basin occur to the west of the Peake and Denison Inlier (Figure 26).

Overlying aquifers (Cenozoic and Great Artesian Basin)

Current research suggests diffuse recharge to the GAB along the western margin is currently minimal with major recharge events linked to wetter periods of paleoclimatic history. Consequently the GAB groundwater system is now viewed as being in a state of transience (Love et al., 2013a).

Of potentially more importance to the current day system is ephemeral river recharge (ERR), which has been identified as an important contributor to recharge to the GAB in the vicinity of the Finke River, southern NT. ERR describes the process of focused recharge to aquifers resulting from episodic flow events in arid zone rivers (Love et al., 2013a). Recharge rates of between 380 and 850 mm/year were estimated using carbon-14 derived groundwater velocities; while recharge from a single flow event in 2010 was estimated at 1275 mm based on hydraulic head measurements. The volumetric contribution of this recharge event across the recharge zone was estimated at 17,000 ML (Love et al., 2013a). Although ERR has not been recognised in the Arckaringa subregion to date, this is due to a lack of research. As there are a number of river catchments located within the Arckaringa sub-basin, the possibility that ERR may be contributing to recharge requires consideration. Discharge from the GAB occurs via direct discharge from springs, creek beds or other groundwater-dependent environments or via diffuse discharge through confining layers such as the Bulldog Shale. That being said, diffuse discharge is likely to only be meaningful where the confining layers have been deformed by faulting, as the vertical hydraulic conductivity ranges of 3.46×10^{-9} to 1.04×10^{-8} m/day for the Bulldog Shale would necessarily preclude this as a major discharge mechanism (Love et al., 2013b).

With respect to younger aquifers, the source of groundwater to these systems is hypothesised to occur via diffuse or focused recharge following large rainfall events and upward leakage, typically from the underlying GAB aquifer through the Bulldog Shale and Oodnadatta Formation.

Officer Basin

Alexander and Dodds (1997) suggested that recharge was primarily being achieved via Paleogene and Neogene paleochannels that extend southward from the Musgrave Block over the extent of the Officer Basin, as well as via points of localised recharge. Additionally, Read (1990) suggested that recharge to the Officer Basin aquifers was likely to be occurring along the southern margin of the Everard Ranges and that salt lakes along the basin's southern margin provided the only evidence for discharge from the basin.

Cambrian and Precambrian basement (fractured rock and karstic aquifers)

Typically, groundwater recharged into fractured rock aquifer systems within the subregion is interpreted to be either by direct infiltration or via drainage channels to crystalline Precambrian basement rocks. The radial flow patterns mapped by Kellett et al. (1999) indicate that salt lakes located near basement outcrops are the likely points of discharge for such groundwater.

1.1.4.3.4 Aquifer connectivity

Areas of potential intra-basinal aquifer connectivity at a regional scale are influenced by the extent and characteristics of the Stuart Range Formation. In particular, in areas where the removal of the Stuart Range Formation prior to the deposition of younger sedimentary units occurred interconnectivity between the Boorthanna Formation and overlying aquifer units in the Mount Toondina Formation is possible. An issue concerning the extent and characteristics of the Stuart Range Formation is not only a lack of quantitative information regarding hydrogeological characteristics, but also identification. Much of the Stuart Range Formation located in the south-west portion of the Arckaringa discussed by Ransley et al. (2012) as potentially containing partial aquifers has been reclassified during the compilation of this report as Boorthanna Formation.

Additionally, pre-depositional erosion by glaciation and possibly syn- and post-depositional faulting are interpreted to have resulted in a highly variable thickness of the Permo-Carboniferous formations, as well as potentially demarcating the wider Arckaringa Basin into sub-basinal areas. Faulting may also be actively contributing to changes in regional hydrodynamics and hydrogeological properties, such as porosity and permeability and therefore providing a means of inter-aquifer connectivity.

Lateral interconnectivity between the Arckaringa Basin aquifers and those on the margins may occur. Aquaterra REM (2005a) proposed interconnectivity between the Boorthanna Formation aquifer and fractured rock aquifer on the south-east margin of the Arckaringa Basin. Additionally, based on an understanding of lithology and regional groundwater flows, there is a possibility that groundwater throughflow from the Officer Basin into the Arckaringa Basin along the north-western margin may occur, however there is no groundwater related data to support such a theory.

1.1.4.3.5 Current stresses

Currently, a large and important use of groundwater resources within the Arckaringa Basin is mining-related abstraction from the south-east corner of the Arckaringa Basin associated, with mining operations at Prominent Hill. To date, groundwater monitoring has not suggested any adverse impacts to either the overlying GAB aquifer or the Arckaringa aquifer system on a regional scale. However, due to the nature of development in the region, there is currently no long term data to determine impacts to either neighbouring aquifer systems or groundwater related ecosystems within the general vicinity, nor is there any monitoring of groundwater levels within the Stuart Range Formation, which provides the primary confining layer within the area.

1.1.4.4 Groundwater planning and use

The groundwater monitoring networks in the vicinity of the Arckaringa subregion (Figure 28) include:

- The Great Artesian Basin Network that is used to monitor pressure within the artesian and water levels within the non-artesian parts of the GAB. The network in SA is monitored by the South Australian Government Department of Environment, Water and Natural Resources (DEWNR).
- The Marla Monitoring Network, which is used to monitor yield, flow, accumulated flow and water level with data loggers are located in the vicinity of Marla.
- The OZ Minerals Prominent Hill Mining operation monitors water quality, groundwater chemistry and water levels in the vicinity of their wellfield, located approximately 140 southeast of Coober Pedy.
- The IMX Cairn Hill mining operation and the Arrium Mining Peculiar Knob tenement area, located approximately 50 and 60 kms southeast of Coober Pedy respectively, both have associated groundwater monitoring networks within areas that partially overlap. Water levels and water quality are monitored using these networks.

Additionally, a number of different spring groups in the vicinity of the Olympic Dam mining operations are monitored by BHP-Billiton (Sibenaler, 2010). Groundwater monitoring networks associated with the Olympic Dam mining operation are largely located to the east and southeast of the Arckaringa subregion.

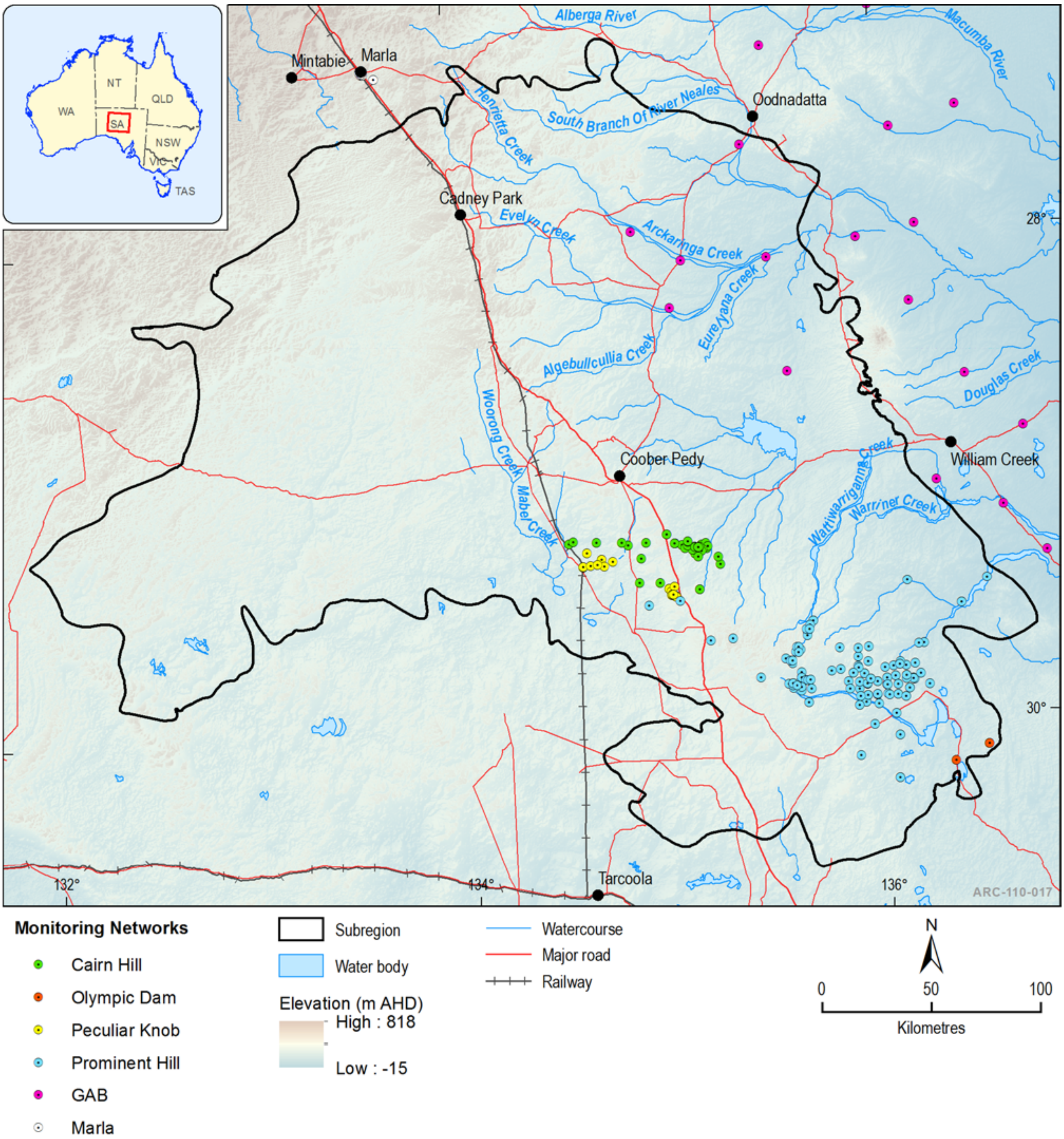

Figure 28 Groundwater monitoring networks within the Arckaringa subregion

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1.1.5 Surface water hydrology and surface water quality

Summary

The Arckaringa subregion of the Lake Eyre Basin bioregion is located in northern SA and contains the majority of the Neales-Peake catchment. It also intersects the southernmost watercourse in the Macumba catchment, Woolridge Creek. As only the most upstream 38 km of Woolridge Creek lies within the boundaries of the Arckaringa subregion and the creek is of low hydrologic significance to the Macumba catchment, rarely connecting to the main drainage lines, it is not considered further in this report. The Macumba catchment is further described in the Pedirka subregion report. The south-east of the Arckaringa subregion also contains much of the Warriner Creek and Margaret Creek subcatchments, though very little is known of these subcatchments and no hydrologic data have been collected. The Arckaringa subregion, Neales-Peake and Macumba catchments are shown in Figure 29.

In recent times, several dedicated data-gathering projects in the Neales-Peake catchment have delivered a 13 year inventory cataloguing data relevant to the persistence of waterholes in the catchment, including water quality, though there is still a pronounced knowledge gap in terms of volumetric data. In spite of the short time scale, missing and unreliable stage data, and lack of flow data, the data collected on the Neales-Peake catchment represent the most comprehensive dataset of all western Lake Eyre Basin river systems.

The waterholes of the Neales-Peake catchment can be divided into those that are saline and flushed only during flow events and those that are mostly fresh and may slowly increase in salinity as they lose water to evaporation and transpiration of local flora in periods of no flow. Found mostly in the upper reaches of the catchment, the mostly fresh waterholes have salinities similar to those of floodwaters (100 to 200 mg/L), which increases to 500 to 1,400 mg/L in periods of little to no flow whereas the predominantly saline waterholes have salinities ranging from 20,000 mg/L at Algebuckina Waterhole to over 250,000 mg/L at Peake Crossing Waterhole. The saline waterholes are found typically in the mid and lower reaches of both rivers.

Although there are no volumetric flow data collected in the Arckaringa subregion, stage data of varying quality and length have been collected for all waterholes over the period 2000 to 2013 for the Neales-Peake catchment. There is little consistency in the data collected across waterholes and no single waterhole has continuous data for that period, however the data collected are invaluable and are currently being used to inform hydrologic modelling that is being undertaken for the region.

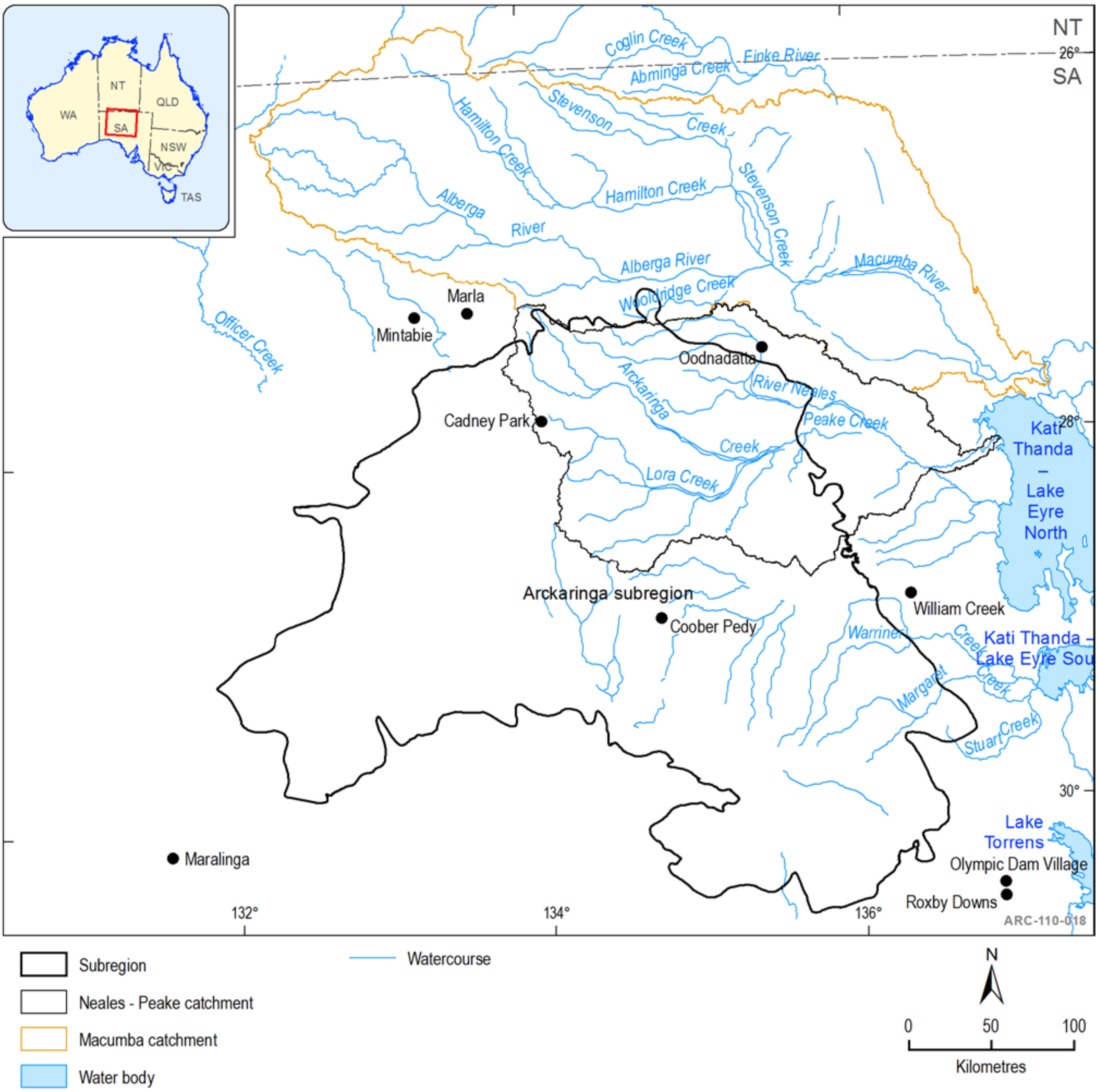

Figure 29 The Arckaringa Subregion with Neales-Peake and Macumba catchments shown

1.1.5.1 Surface water systems

1.1.5.1.1 The Neales-Peake catchment

With a total catchment area of 34,415 km^2, the Neales-Peake catchment is an ephemeral, unregulated river system, consisting of the Neales and Peake Rivers and associated tributaries. The headwaters of the catchment develop on the stony tablelands forming the western rim of the Lake Eyre Basin, at an elevation of 300 to 370 m, with the main drainage channel running 430 km before terminating at Kati Thanda – Lake Eyre North at approximately sea level (Costelloe et al., 2005a).

Rainfall and potential evapotranspiration in the Neales-Peake catchment are consistent with those observed in the wider Arckaringa subregion, with a mean annual precipitation depth of 150 mm and mean annual point potential evapotranspiration of 2,510 mm. Although the majority of rainfall occurs in the summer months, significant winter rains are not uncommon (Costelloe et al., 2005a). The variability of rainfall over the catchment is both spatially and temporally among the highest in Australia (Allan, 1985). Key rainfall events in the Neales–Peake range from convective thunderstorms with limited spatial extent, but often with high intensities, to large transient depressions of tropical origin (Allan, 1985; Croke et al., 1999) that result in catchment-wide flooding.

Characterised by complex, multiple anastomosing channels, shallow channel definition, wide floodplains and waterholes, the intermittent watercourses of the Neales-Peake system typically flow in response to the more localised thunderstorm-derived rainfall. Such events can be important in maintaining aquatic refugia, but result in limited connectivity between waterholes. The volume of the waterholes is often quite small, with most waterholes ranging between 5 and 90 ML, though they can be as large as 280 ML (Costelloe et al., 2008). The small size of most waterholes means that small runoff events in the main channel system are capable of filling waterholes to their maximum cease-to-flow level. The larger rainfall events result in runoff through much of the channel system, recharging the alluvial and floodplain groundwater stores and allowing widespread migration of aquatic fauna.

In-channel flow events in the Neales-Peake catchment are observed by pastoralists once or twice a year, with larger floodplain inundating events occurring more infrequently (Costelloe et al., 2005b). In-channel waterholes are developed on the Neales River and Peake Creek and range from shallow (<1 m), predominantly salty, ephemeral waterholes containing water for some months following a flow event, to rare deeper waterholes (2 to 4.5 m) that are near permanent and form important refugia for the biota in this ephemeral, unpredictable system. The observed salinity of these waterholes varies significantly, both spatially and temporally, within the reach (Costelloe et al., 2008).

Understanding the ecohydrology of ephemeral to intermittent arid zone river systems is greatly hindered by the paucity of hydrological data describing both individual flow events and the long term flow regime in the river (Costelloe et al., 2005a). The need for hydrological and biological data on dryland rivers is increasing as the demand for the water resources of these rivers increases (Walker et al., 1995; Sheldon et al., 2000). In responding to this need, several dedicated data-gathering projects have been undertaken in the Neales-Peake catchment in recent times (Costelloe et al., 2008; Costelloe, 2011a). This has resulted in a 10 year inventory cataloguing data relevant to the persistence of waterholes in the catchment, including water quality (Costelloe, 2011a), though there is still a pronounced knowledge gap in terms of volumetric data. In spite of the short time scale, missing and unreliable stage data and lack of flow data, the data collected on the Neales-Peake catchment represent the most comprehensive dataset of all western Lake Eyre Basin river systems.

Over the period 2000 to 2010, 30 flow events were recorded in the Neales-Peake catchment, of which approximately half (16) were local flows, resulting in limited or no longitudinal connectivity and little floodplain inundation. These flows were typically caused by localised thunderstorms that did not produce enough rainfall to overcome the high transmission losses owing to poorly channelised reaches between waterholes and have demonstrable significance for local biota

(Bunn and McMahon, 2004). On eight occasions, flow events were large enough to be classed as 'subcatchment flows', meaning that flows had considerable downstream extent and longitudinal connectivity, although they were unlikely to utilise all available floodplain or deliver inflow to Kati Thanda – Lake Eyre North (Costelloe, 2011a). The remaining six flows (February 2000, June 2001, February 2003, probably October 2005 and December 2008, and December 2009) were whole catchment floods, large enough to use most of the floodplain, connect all major rivers and tributaries, and likely flow into Kati Thanda – Lake Eyre North. Additionally, some flood data are available for the period 2010 to 2012 and indicate that a major flood, estimated as a 1:10 year event (Costelloe, 2011a), occurred in February 2011 in response to rainfall from a rain depression associated with Cyclone Yasi. At the time of writing, no subcatchment sized flows or greater have been observed in the Neales-Peake catchment since around February 2012, meaning that all but the largest waterholes are dry (JF Costelloe, pers. comm., 2013).

There are 20 waterholes in the Neales-Peake catchment that have been identified as significant ecological refugia, and have been surveyed in previous work (Costelloe et al., 2004; 2005a; 2011a). This collection provides possibly the most complete catchment scale inventory of riverine refugia in any arid zone catchment of Australia (Costelloe et al., 2011a). The waterholes are indicated in Figure 30 and physical characteristics summarised in Table 9.

The maximum depth of a waterhole when flow ceases (cease-to-flow depth; cease-to-flow depth (CTFD) has been found to be an important measure of how long water will persist in the waterhole (Costelloe et al., 2007), with persistence being of great significance to local biota. From Table 9, it can be seen that the CTFD of the key waterholes in the Neales-Peake catchment tends to vary over time. This is likely a normal part of the long term flood cycle, where high flows associated with large floods will scour some of the bed sediments of the waterholes, increasing CTFD, and smaller flow events will deposit suspended sediments leading to increasing sedimentation of the waterholes and a decrease in CTFD. The precise mechanics of these processes in this region are not fully understood at this time; however, ongoing monitoring and modelling projects will continue to deliver a greater insight into the long term flood cycle.

The persistence of a waterhole between flow events has been identified as the major differentiating feature of ecological refugia. Reliable measurements of CTFD in conjunction with vegetation surveys have enabled robust estimation of potential evapotranspiration (PET), crucial to calculating persistence. Work by Russell (2009) has demonstrated that losses from some waterholes in the catchment (South Stewart, Cramps Camp) are in excess of calculated evapotranspiration (ET). This suggests that some water is lost to the unconfined aquifer, reducing the persistence of the waterhole between flow events. The same research showed that Algebuckina Waterhole largely loses water at the ET rate, further enhancing its importance as the most significant refugia in the region (McNeil et al., 2011a). The high rates of ET, means that even non-leaky waterholes, like Algebuckina Waterhole, will lose more than 2 m of water per year. Given the CTFDs in Table 9, this means that all waterholes are likely to be dry after two years of no flow. The variability in loss rates across the region further emphasises the need for improved and ongoing monitoring and research in the area.

In the context of the greater Lake Eyre Basin, the waterholes of the Neales-Peake catchment are relatively shallow. For instance, the deepest known waterhole in the Lake Eyre Basin is

Cullyamurra Waterhole on Cooper Creek with a CTFD of between 20 to 30 m. Other waterholes on Cooper Creek and the Diamantina River have CTFDs of 4 to 9 m (McMahon et al., 2005).

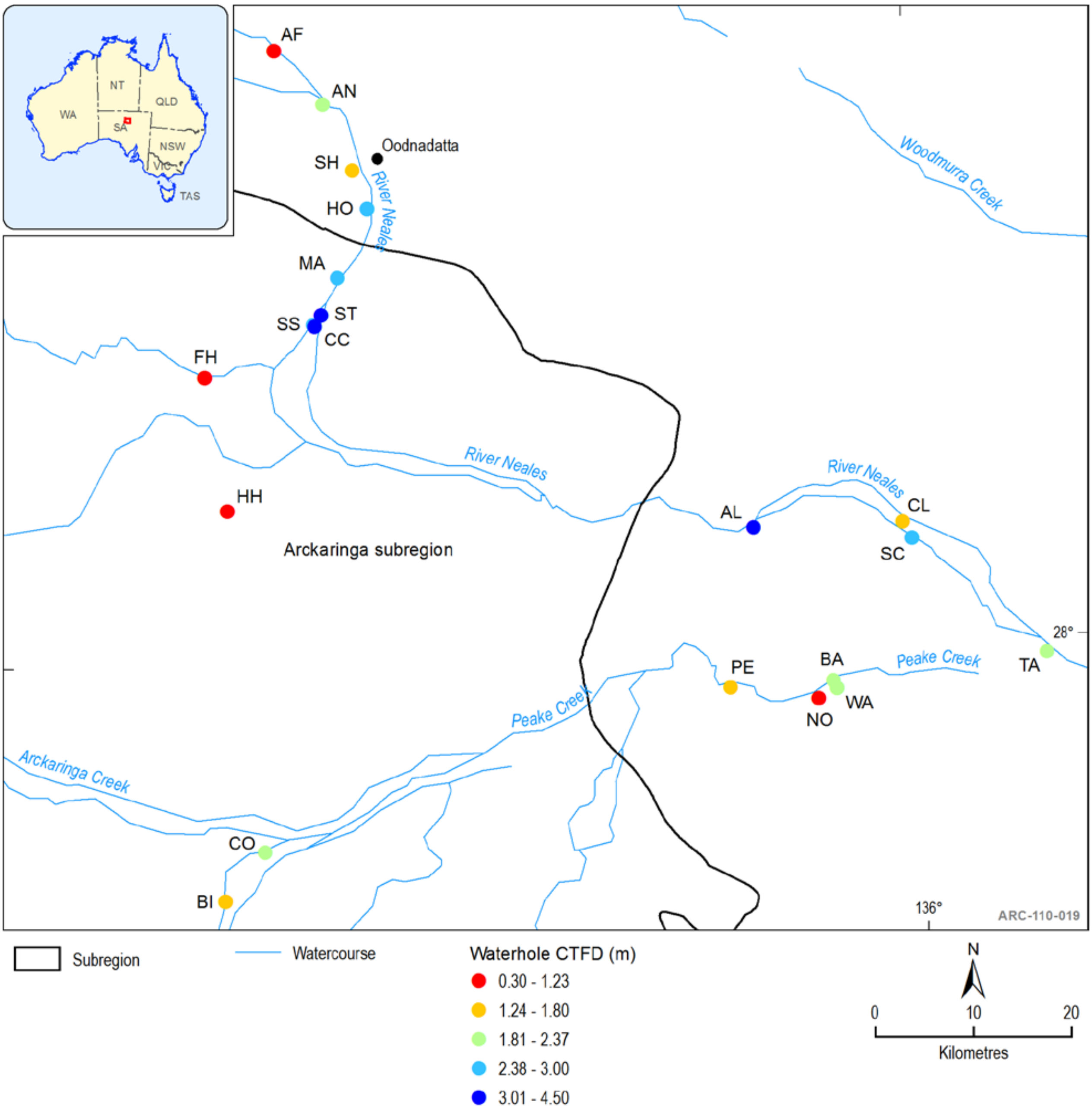

Figure 30 Locations and cease-to-flow depths of waterholes of the Neales-Peake catchment

Refer to Table 9 for Waterhole Names

Table 9 Physical characteristics of waterholes of the Neales-Peake catchment (nm = not measured)

Waterhole	2004 Survey cease-to-flow depth (m)	2009-2010 Survey refugia cease-to-flow depth (m)	Bankfull width (m)	Bankfull depth (m)
Afghan (AF)	nm	1.20	32	2.2
Angle Pole (AN)	nm	2.16	24	2.7
Shepherds (SH)	nm	1.70	22	2.3
Hookey (HO)	nm	2.56	34	3.9
Mathieson (MA)	2.50	2.73	59	3.3
Stewart (ST)	2.60	3.23	52	3.7
South Stewart (SS)	2.40	2.53	23	3.9
Cramps Camp (CC)	2.60	3.85	44	4.4
Fish Hole (FH)	1.16	nm	47	1.8
Hagans Hole (HH)	nm	1.20	nm	nm
Algebuckina (AL)	4.50	3.45	70	7.9
South Cliff (SC)	2.50	2.40	85	3.3
Cliff (CL)	0.86	1.28	24	2.2
Tardetakarinna (TA)	2.20	nm	40	3.6
Warrarawoona (WA)	nm	2.00	55	4.7
North Freeling (NO)	nm	0.30	nm	nm
Baltucoodna (BA)	nm	2.30	37	4.4
Peake Crossing (PE)	1.50	1.50	54	4.7
Cootanoorina (CO)	2.10	nm	50	2.5
Birribiana (BI)	1.80	nm	83	2.5

Note: Surveys following the floods of February 2011 have indicated that the CTFD of Algebuckina Waterhole may increase up to 4.8m (Costelloe, 2011b).

In addition to waterholes, the Neales-Peake catchment contains numerous Great Artesian Basin springs that are hydraulically connected to the river system (see Figure 31). The hydraulic connection can be due to springs occurring on the floodplain of the river (i.e. North Freeling group) or experiencing periodic connection from tributary flow (e.g. Hawker spring group). This connectivity is further discussed in Section 1.1.6.1.

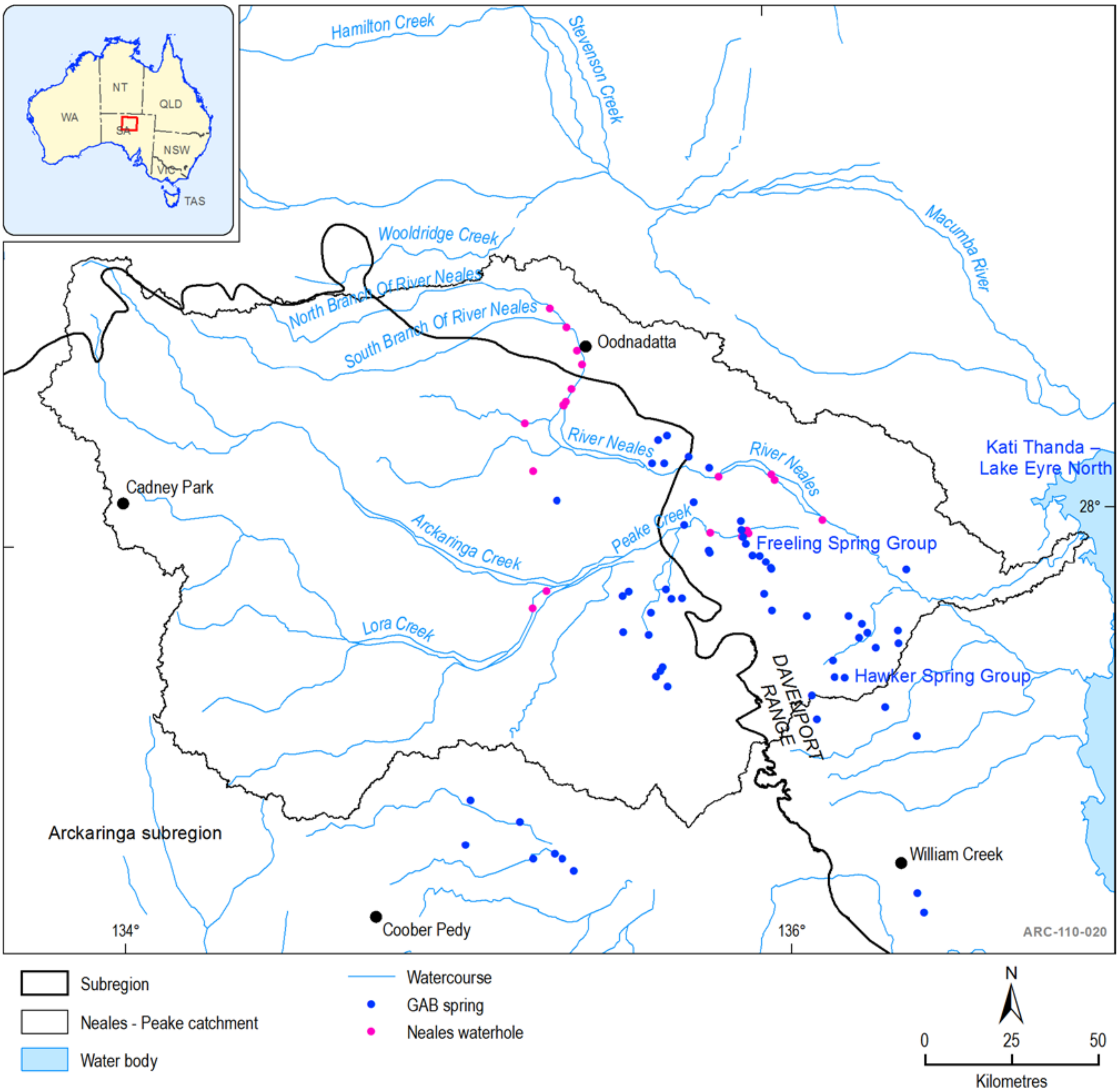

Figure 31 Springs and waterholes of the Neales-Peake catchment

1.1.5.1.2 Warriner-Margaret Creeks

As previously mentioned, very little is known of the hydrology of the Warriner Creek and Margaret Creek subcatchments. They experience similar rainfall and PET totals to the Arckaringa subregion and it is likely that they share similar flow regimes to the Neales-Peake catchment, particularly in terms of frequency of flow events (JF Costelloe, pers. comm., 2013). The highly variable nature of rainfall and flow events over the Arckaringa subregion and Lake Eyre bioregion generally is exemplified by the observations of Hunter (1984, as referenced in Kotwicki, 1986) who describes flood events of such magnitude in the Warriner-Margaret Creeks subcatchments that Kati Thanda – Lake Eyre South filled and spilled over to Kati Thanda – Lake Eyre North. This is the only time such an event has been recorded and is likely the result of a very specific weather pattern whereby a very large rain depression was situated over the south-western part of the Kati Thanda – Lake Eyre Basin, with no rainfall observed in the north-east. No surface water fed waterholes have been identified in these subcatchments. Examination of topographic maps of the area indicates that both creeks contain Great Artesian Basin springs within their floodplains, which, given the lack of waterholes, are likely very important refugia for biota in the area.

1.1.5.2 Surface water quality

1.1.5.2.1 The Neales-Peake catchment

The waterholes of the Neales-Peake catchment can generally be divided into those that are saline and flushed only during flow events and those that are mostly fresh and may slowly increase in salinity as they lose water to evaporation and transpiration of local flora in periods of no flow. Typically located in the upper reaches of the catchment, the mostly fresh waterholes have salinities similar to those of floodwaters (100 to 200 mg/L), which increases to 500 to 1400 mg/L in periods of little to no flow. The predominantly saline waterholes have maximum observed salinities ranging from 20,000 mg/L at Algebuckina Waterhole to over 250,000 mg/L at Peake Crossing Waterhole. The saline waterholes are found typically in the mid and lower reaches of both rivers. Maximum observed salinity at waterholes for the period 2000 to 2010 is summarised in Table 10.

A hypersaline reach separates the fresh from saline waterholes, coinciding with the occurrence of Great Artesian Basin springs, upstream of the Peake-Denison Ranges (which follow the easternmost edge of the Arckaringa subregion) and immediately downstream of poorly channelised reaches of the Neales and Peake that do not contain any waterholes (Costelloe, 2011a). In this reach, saline groundwater discharges into the main channel, which, in periods of no or low flow, is concentrated by evaporation. The presence of a shallow watertable in the hypersaline reach is likely assisted by the presence of relatively impermeable mudstone (Bulldog Shale) underlying the alluvial sediments and also the upward hydraulic gradient from vertical leakage of Great Artesian Basin groundwater. At specific sites, leakage from the Great Artesian Basin is probably also making a small but significant contribution to the alluvial groundwater (Costelloe, 2011a; Smerdon et al., 2012). However, this is probably confined to areas where secondary porosity development via faulting has occurred (Keppel et al., 2013).

Located in the hypersaline reach of the Peake, it can be seen from Table 10 that North Freeling Waterhole is less saline than neighbouring waterholes, Baltucoodna and Peake Crossing. Located some 150 m from the main channel of the Peake, North Freeling is the only artesian groundwater fed waterhole in the Neales-Peake catchment. It is quite shallow (approximately 0.2 m of water depth over a thick underlying bed of mud) and this water level is maintained by Great Artesian Basin inflow (Costelloe, 2011a). During the 2009-2010 floods, the conductivity of the pool was 5150 mg/L (Nov 2009) and this was slightly above the range of the conductivity of nearby springs. The frequency of surface inflow may be sufficient to keep this pool from becoming hypersaline or else there is a sufficient gradient for constant outflow that prevents excessive salinity build-up (Costelloe, 2011a).

Table 10 Maximum observed salinity of waterholes of the Neales-Peake catchment

Waterhole	Number of observations (2000-2014)	Max salinity (mg /L)
Afghan (AF)	2	149
Angle Pole (AN)	2	<200
Shepherds (SH)	8	<200
Hookey (HO)	10	<200
Mathieson (MA)	2	224
Stewart (ST)	12	3754
South Stewart (SS)	14	895
Cramps Camp (CC)	6	1006
Fish Hole (FH)	4	1390
Hagans Hole (HH)	2	426
Algebuckina (AL)	32	19,550
South Cliff (SC)	4	398
Cliff (CL)	2	2156
Tardetakarinna (TA)	4	169,200
Warrarawoona (WA)	3	4210
North Freeling (NO)	4	5150
Baltucoodna (BA)	3	48,600
Peake Crossing (PE)	8	265,400
Cootanoorina (CO)	4	264
Birribiana (BI)	2	327

The salinity of the waterholes downstream of the Peak-Denison Ranges varies significantly. Algebuckina Waterhole is typically fresh, but registers a sharp increase in salinity as a result of saline inflow from the hypersaline reaches during a flood event. Other nearby waterholes, like South Cliff, remain quite fresh even at low water levels.

1.1.5.2.2 Warriner-Margaret Creeks

No water quality data have been recorded in the Warriner-Margaret Creeks area. Anecdotal evidence indicates that water quality is highly variable, with very high salinity observed between flow events (L Sampson, pers. comm., 2013).

1.1.5.3 Surface water flow

As previously mentioned, there are no consistent discharge data available for the Arckaringa subregion. Opportunistic flow measurements at Algebuckina Waterhole, situated 2km downstream of the subregion boundary (Figure 31), during field trips have been collected during periods of flow recession and, in November 2000, a moderate flow event was observed. This flood was sub-bankfull but utilised several channels in the anastomosing channel reach upstream of the waterhole. This enabled the development of a partial rating curve that was used in converting daily water level data into daily discharge estimates for the period April 2000 – February 2002 (Costelloe et al., 2005a). However, in that case the rating curve was deemed unreliable above the maximum gauged level (9000 ML/day) as larger flows also enter another channel that bypasses Algebuckina Waterhole. As water level data are a function of channel morphology, this rating curve cannot be applied to other waterholes for the same time period, or indeed to stage data for Algebuckina Waterhole itself at a different time, owing to the inherent variability of CTFD in this subregion.

Although there are no volumetric flow data collected in the Arckaringa subregion, stage data of varying quality and length have been collected for all waterholes over the period 2000 to 2013 for the Neales-Peake catchment. Owing to malfunctioning loggers, disturbance from local fauna, theft and varying installation and removal dates, there is little consistency in the data collected across waterholes and no single waterhole has continuous data for that period (JF Costelloe, pers. comm., 2013). However, the data collected is invaluable (due to a paucity of other available data) and is currently being used to inform hydrologic modelling that is being undertaken for the region.

The stage data for Algebuckina Waterhole represent the most complete set of water level data in or near the region, and are shown in Figure 32. The data shown represent a merging of data collected through multiple loggers installed through the ARIDFLOW project (Costelloe et al., 2004), the Critical Refugia Project (Costelloe, 2011a) and a telemetered gauge installed by the South Australian Department of Environment, Water and Natural Resources in 2011, with post-processing necessary to ensure consistency throughout the period of record (JF Costelloe, pers. comm., 2013).

The stage record shown in Figure 32 indicates not only the major floods described in Section 1.1.5.1.1, but also local flows. The period 2010 to 2011 is particularly interesting as it demonstrates multiple small flow events of that notably wet year.

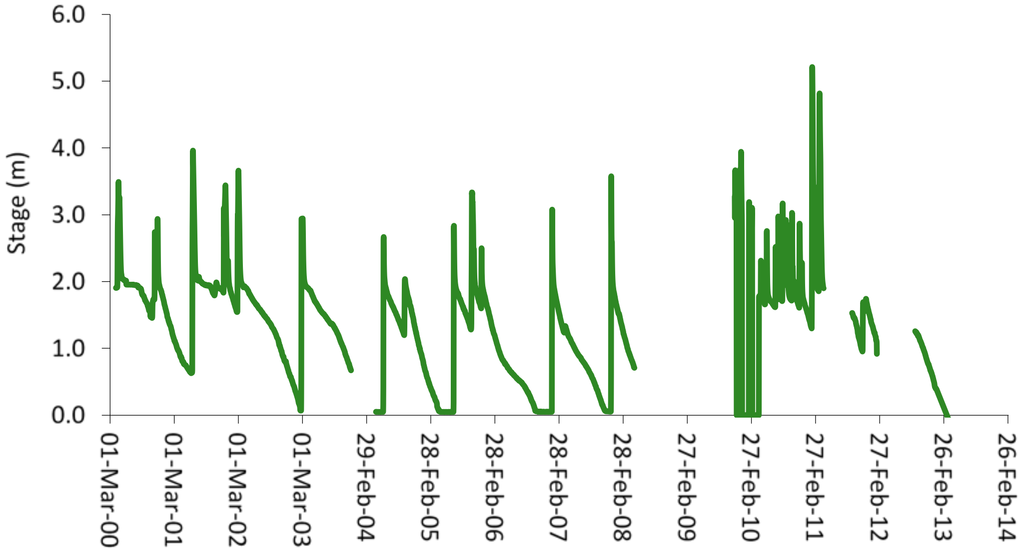

Figure 32 Stage at Algebuckina Waterhole from March 2000 – March 2013

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1.1.6 Surface water – groundwater interactions

Summary

There is very little information available regarding surface water – groundwater interactions in the Arckaringa subregion. Recent research indicates that there is negligible recharge to the Great Artesian Basin (GAB) aquifers in the north of the subregion, with minor scattered zones of recharge potential predominately in the south-west of the basin. Interactions between surface water systems and groundwater resources in the area occurs either via hydraulic connectivity between GAB springs and the river system or local interactions between surface water drainage networks and shallow alluvial aquifers. The Neales-Peake catchment contains numerous GAB springs that are hydraulically connected to the surface water network, either due to springs being located on the floodplain of a river (e.g. North Freeling) or experiencing periodic connection from tributary flow (e.g. Hawker spring group). It is probable that this connectivity between springs and surface water drainage networks also exists in the south-east of the subregion in the Margaret Creek and Warriner Creek subcatchments, although very little is known of these areas. In addition to the waterholes of the area, the springs provide an important aquatic refuge environment for fish communities and, in an area prone to extended dry spells, will provide the only available refuge following 18 months of no rain.

1.1.6.1 The Neales-Peake catchment

GAB springs in the Neales-Peake catchment are located coincidentally with hypersaline reaches of both the Neales River and Peake Creek. Directly upstream of these saline reaches are poorly channelised sections of river, with no permanent waterholes. This section separates the generally fresh upstream reaches from the more saline downstream reaches. The hypersaline reach is characterised by a single primary channel, hypersaline unconfined groundwater in the floodplain and no deep, permanent waterholes (Costelloe, 2011). During periods of no flow, shallow residual pools in this reach eventually become hypersaline owing to discharge from the hypersaline unconfined groundwater into the primary channel. This process is facilitated by recharge to the unconfined groundwater during flow events, resulting in the local watertable level rising to above, or near, the base of the channel (Costelloe, 2011). Two factors contribute to the presence of the shallow watertable in this reach, namely the presence of relatively impermeable mudstone underlying the alluvial sediments and the upward hydraulic gradient from vertical leakage from the GAB (Costelloe, 2011). It is likely that the leakage from the GAB is also making a small but significant contribution to the alluvial groundwater (JF Costelloe, pers. comm., 2013). However, this is probably confined to areas where secondary porosity development via faulting has occurred (Keppel et al., 2013). Zones of recharge potential have been identified throughout the centre and south-west of the basin (Figure 12 in Section 1.1.4), however these have not been verified.

The most illustrative example of interaction between surface water networks and GAB springs occurs at North Freeling Waterhole. Labelled in Figure 33, North Freeling Waterhole is a shallow (0.2 m) artesian groundwater fed waterhole located approximately 500 m south of the well-defined main channel of Peake Creek. Large subcatchment or whole of catchment floods would cause the inundation of the waterhole and these events may be expected once per five to ten years (JF Costelloe, pers. comm., 2013). The 2010 floods did not connect the waterhole with Peake Creek. Salinity measurements taken during the course of the Critical Refugia Project (Costelloe, 2011) demonstrated that the waterhole was slightly more saline than nearby springs. The frequency of surface water inflow may be sufficient to keep this pool from becoming hypersaline or, alternatively, there is a sufficient gradient for constant outflow that prevents excessive salinity build-up (Costelloe, 2011).

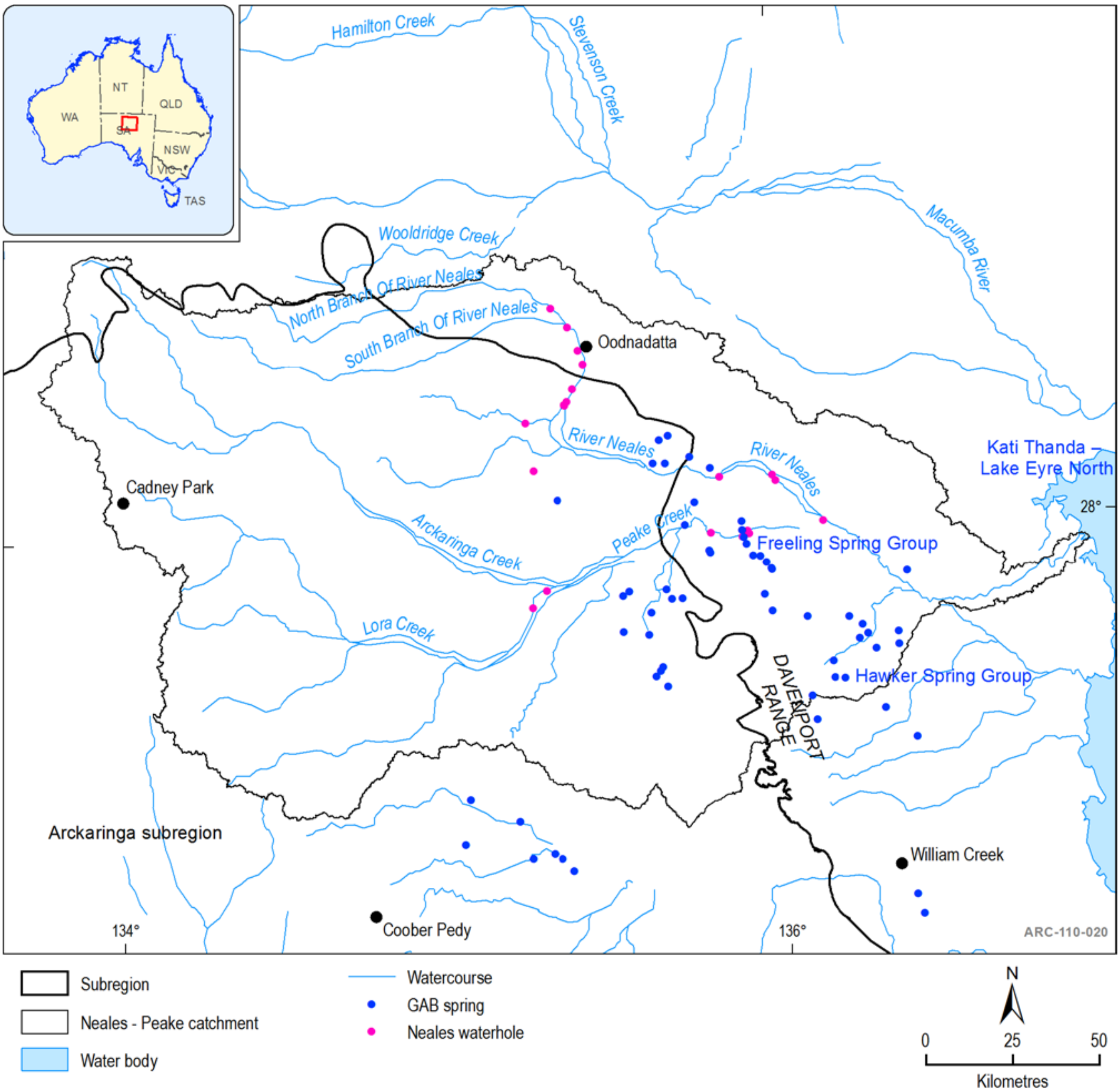

Figure 33 Springs and waterholes of the Neales-Peake catchment

In addition to interconnections between GAB springs and surface water drainage networks, several waterholes in the Neales-Peake catchment have been identified as potentially losing some water to shallow, unconfined aquifers (Russell, 2009), the significance of which is discussed in Section 1.1.5.1.1).

1.1.6.2 Warriner-Margaret Creeks catchments

The poorly studied south of the Arckaringa subregion contains numerous GAB springs that appear to be located on the floodplain, some of which may lie in the main channels (D Wohling pers. comm., 2013). Similarly to North Freeling Waterhole, these springs are most likely important refugia for local biota and would probably be inundated during high flow events. No quantitative information is available regarding the springs or watercourses and limited observational data indicates that during periods of no flow the spring-fed waterholes become hypersaline owing to evapoconcentration (L Sampson, pers. comm., 2013). This area has also been suggested as a potential groundwater recharge zone (see Section 1.1.4.3.3), although no data exist to confirm this.

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1.1.7 Ecology

Summary

The Arckaringa subregion is situated in Australia's arid zone where highly variable rainfall, low soil fertility and localised soil differentiation are the dominant physical environmental drivers of ecosystem composition. The subregion contains a diverse range of native flora and fauna.

The subregion has become increasingly arid over past millennia, leading to the isolation of aquatic ecosystems. Great Artesian Basin (GAB) springs of the Lake Eyre supergroup are found along the eastern boundary of the Arckaringa subregion and to the south and east. These springs have flowed continuously for at least 465,000 years, providing the only refugia for obligate aquatic species with poor dispersal capabilities. The springs contain a high proportion of endemic species and populations of species that were once widespread. Based on current data, 64 out of the 116 spring complexes in the Lake Eyre supergroup contain endemic or threatened species, and one complex supports a species not found at any other location. However, recent research on invertebrates in springs indicates that it is likely that levels of endemism have been substantially underestimated to date and the true levels of endemism may be higher than is currently understood.

The Neales catchment is the major surface water drainage system within the Arckaringa subregion, draining east into Kati Thanda – Lake Eyre. Ten native fish species occur in the catchment and the hydrology of the catchment is considered largely unaltered. The catchment is highly ephemeral with only one known potentially permanent freshwater waterhole, Algebuckina. Large floods occur infrequently, but drive spectacular booms in biotic production. Clusters of smaller floods prolong waterbody persistence and connectivity between waterbodies and produce a cumulative response from aquatic biota. During extended dry periods, Algebuckina Waterhole has supported the entire diversity of obligate aquatic species in the catchment, although some saline waterholes and low-lying GAB springs provide refuge for a subset of the smaller and hardier species.

To the south of the Neales catchment are the catchments of Stuart, Margaret and Warriner Creeks that flow into Kati Thanda – Lake Eyre South. Very little is known about the ecology or biological composition of these catchments, although two species of fish have been observed in Margaret Creek.

To the west of the Lake Eyre Basin there are dune lakes and depressions in the Great Victoria Desert and minor drainages, gilgais and cracking clay plains in the Stony Plains. These systems are filled very occasionally from local rainfall events and support unique desert biota and nomadic waterbirds. These systems are very poorly studied.

1.1.7.1 Ecological systems

The Arckaringa subregion is situated in Australia's arid zone where highly variable rainfall, characterised by long periods of no rain and occasional heavy rainfall events (Allan, 1985;

Croke et al., 1999; see 1.1.2.3), coupled with low soil fertility and localised soil differentiation, are the dominant physical environmental drivers of ecosystem composition (Morton et al., 2011).

The Interim Biogeographic Regionalisation for Australia (IBRA) identifies biogeographic regions and subregions based on common climate, geology, landform, native vegetation and species information. The Arckaringa subregion contains four IBRA bioregions: Stony Plains, Simpson Strzelecki Dunefields, Gawler Ranges and Great Victoria Desert (Figure 34).

The Stony Plains are the predominant IBRA bioregion in the Arckaringa subregion, dominated by vast, gently undulating gibber and gypsum plains dotted with occasional lakes, claypans, low hills, overlain in some areas by dune systems and intersected by watercourses draining east towards Kati Thanda – Lake Eyre. An assessment of regional species status for each IBRA subregion was recently undertaken for the Outback region (including most of the Arckaringa subregion) (Gillam and Urban, 2013). While most of the IBRA bioregions have been the subject of biological surveys, the Great Victoria Desert IBRA bioregion is relatively unknown. The Great Victoria Desert IBRA bioregion comprises a significant portion of the Arckaringa subregion, however it mainly consists of dune fields and contains only a few, highly ephemeral playa lakes, mostly within the Tallaringa Conservation Park and Woomera Protected Area (Table 11, Figure 35).

The Arckaringa subregion has not been cleared of native vegetation, however, the natural biodiversity and condition has been altered through changes in burning regimes, the introduction of pastoral grazing, pest plants and animals, additional watering points and free-flowing bores, changes in water pressure to Great Artesian Basin (GAB) springs, and changes to surface water flow through construction of infrastructure (DEH & SAAL NRMB, 2009). The majority of the subregion is currently used for pastoral grazing; other significant land uses comprise military testing and conservation (section 1.1.2). Most of the vegetation of the subregion has been mapped, and is dominated by low chenopod shrublands with wattle (*Acacia* spp.), hop-bush (*Dodonaea* spp.) and emu-bush (*Eremophila* spp.) shrublands found in dunefields and ranges and coolabah (*Eucalyptus coolabah* ssp. *arida*) woodlands along watercourses (Table 11; Figure 35).

The subregion has undergone gradual desertification over past millennia (Cohen et al., 2011; Magee et al., 2004), leading to the isolation of aquatic ecosystems (Gotch 2013b). The aquatic ecosystems, including floodplains, floodouts, springs and ephemeral watercourses provide critical refuge and vital habitats and resources for many species, including aquatic and terrestrial species (McNeil et al., 2011a). Ecological processes are influenced by high levels of disturbance and variability driven by the variable and arid climate. Large floods occur infrequently, but drive spectacular booms in biotic production in the Lake Eyre Basin (Kingsford, 1999; Bunn et al., 2006). Clusters of smaller floods prolong waterbody persistence and provide an increased opportunity for dispersal between habitats compared with isolated flood events (Puckridge et al., 2000). Flood clusters increase the extent of the second and follow-on floods and produce a cumulative response from aquatic biota (Puckridge et al., 2000; Reid et al., 2010). During extended dry periods, aquatic ecosystem-dependent species exist either in highly fragmented sub-populations in isolated refugia, or as desiccant resistant propagules (e.g. eggs or seeds), or by reducing their productivity. When sufficient rainfall events occur, the surviving sub-populations emerge, disperse to other habitats, mix with other sub-populations and rebuild their populations. Algebuckina Waterhole, located 2 km downstream of the Arckaringa subregion in the Neales catchment, is the only surface water-driven aquatic ecosystem of the Neales catchment not to have dried out in living memory (Costelloe, 2011), and is the most critical refugial habitat for riverine fauna (McNeil et al., 2008). The cease-to-flow depth of Algebuckina Waterhole has been shown to vary in response to sedimentation and flow events and, at its shallowest has been recorded at 3.45 m and its deepest at 4.8 m (Costelloe 2011b). Based on modelling it is vulnerable to drying out through a combination of extended drought and sedimentation (see Section 1.1.5.1; Costelloe, 2011a, 2011b). Therefore, all obligate aquatic species in the catchment dependent on this habitat are also vulnerable, with potential 'follow-on' effects through the trophic structures operating in the catchment. Therefore, the only truly permanent waterbodies are the GAB springs that occur along the eastern boundary of the Arckaringa subregion. Recent research has shown that discharge has occurred at the same general locations for up to 465,000 years (Priestley et al., 2013). These evolutionary refugia support many short-range endemic species (Fensham et al., 2011) and relict species that would have been more widespread under past climatic conditions (McNeil et al., 2011b; Davis et al., 2013; Gotch, 2013). The community of species dependent on discharge from the GAB is listed as an endangered ecological community under the Environment Protection and Biodiversity Conservation Act 1999 (Cth) (EPBC Act) with reductions in spring flow from groundwater development being one of the main threats (Fensham et al., 2010).

The national approach to identifying High Ecological Value Aquatic Ecosystems (HEVAE) is based on multiple criteria: diversity, distinctiveness, vital habitat, naturalness and representativeness (AETG 2012b). In a trial application of the HEVAE process in the LEB, Kati Thanda – Lake Eyre, into which the larger surface catchments of the Arckaringa subregion drain, was one of only two aquatic ecosystems in the entire LEB to score very high in three HEVAE criteria (Hale et al., 2010). The Lake Eyre supergroup of springs were split into three geographical areas, each of which scored very high in at least one HEVAE criteria (Hale et al., 2010). Both Kati Thanda – Lake Eyre and the Lake Eyre supergroup of springs are also listed in the Directory of Important Wetlands in Australia.

Table 11 IBRA bioregions and subregions with a significant portion occurring in the Arckaringa subregion

IBRA bioregion	IBRA subregion code	IBRA subregion	Description
Stony Plains	STP01	Breakaways	A dissected silcrete tableland and mesas, and extensive gibber-covered footslopes on deeply weathered shales. There is a cover of chenopod shrubs and forbs (*Atriplex vesicaria*, *Sclerolaena* spp. *Halosarcia* spp.) on crusty red duplex soils and reddish firm siliceous loams with small areas of low woodland (*Acacia cambagei, Eucalyptus camaldulensis, E. coolabah* ssp. *arida*) on brown self-mulching cracking clays.
	STP02	Oodnadatta	Undulating plains with some gypsum crusting, low hills with silcrete gibbers and low gypcrete escarpments. On escarpments and the reddish powdery calcareous loams of the tableland, *Maireana astrotricha* chenopod shrubland occurs along with a tall open shrubland of *Acacia aneura, A. cibaria* and *Hakea leucoptera*. The plains support the same vegetation communities, while on the floodplains a low woodland of *Eucalyptus coolabah* ssp. *arida, Acacia salicina, A. cambagei* and *A. aneura*, and *Eucalyptus camaldulensis* woodland occur.
	STP04	Peake-Dennison Inlier	Hills and low ridges on metasediments, and small areas of undulating plain. Hills and ridges support a tall open shrubland of *Acacia aneura, A. cibaria* and *Eremophila freelingii* on reddish firm siliceous loams, while plains support a chenopod shrubland of *Atriplex rhagodioides, A. vesicaria, Sclerolaena* spp. and *Maireana astrotricha* on crusty red duplex soils, and small areas of *Eucalyptus coolabah* ssp. *arida, E. camaldulensis* and *Acacia cambagei* low woodland on brown self-mulching cracking clays. A tall shrubland of *Acacia ligulata, Senna* spp., *Eremophila* spp. and *Dodonaea viscosa* ssp. *angustissima* is found on the red siliceous sands of the dunes.
	STP07	Baltana	Silcrete gibber flats, undulating plains and extensive areas of self-mulching clay loams with exposed gypsum.
Simpson Strzelecki Desert	SSD04	Warriner	A gently sloping plain with extensive dunefields, isolated gypcrete remnants, broad floodplains and large pans. There is a cover of low open woodland with a chenopod understorey (*Acacia aneura, A. cibaria, Enneapogon* spp. *Aristida contorta*), tall shrubland with a grass understorey (*Acacia ligulata, Senna* spp. *Eremophila* spp*, Dodonaea viscosa* ssp. *angustissima*) chenopod shrubland (*Eragrostis australasica, Nitraria billardierei, Halosarcia* spp, *Atriplex nummularia*) and low fringing woodland (*Eucalyptus coolabah* ssp. *arida, Acacia cambagei*).

IBRA bioregion	IBRA subregion code	IBRA subregion	Description
Gawler Ranges	GAW07	Roxby	The ancient alluvial plain between the Arcoona Tablelands and Stuart Range complex, is substantially covered with more recent sands. In the west are well-spaced low dunes of *Acacia aneura* woodland over *Acacia* spp., *Dodonaea* sp. and grasses and sandsheets of *A. aneura* woodland over *Maireana sedifolia* and grasses. *Acacia* shrublands also typify the dunes. Calcareous plains have *Acacia papyrocarpa* woodlands with *M. sedifolia* and *Atriplex vesicaria*. *Casuarina pauper* over *Hakea leucoptera*, perennial chenopods and *Ptilotus obovatus* occupy rises above the plain. The linear dunefield in the east has dunes of *A. aneura*, *Acacia ramulosa* and *Callitris* sp. over *Dodoneae*, *Eragrostis eriopoda* and *Aristida contorta*. Between the dunes are *A. papyrocarpa* and *M. sedifolia* on calcareous soils, saline swales of *Atriplex* spp., *Gunniopsis quadrifida* and *Frankenia* spp. or claypans of *Eragrostis* sp., *Duma florulenta* or *Melaleuca glomerata* fringes. Broad saline flats in the west of the region, possibly marking older palaeochannels, support variable *Atriplex* sp- *Maireana* sp. low shrublands and possess salt-lake/lunette chain complexes of mixed character.
	GAW08	Commonwealth Hill	A sandplain in a regional depression to the north of the Gawler Craton, with chains of salt-lake complexes and characterised by *Acacia aneura* woodlands over grasses, chenopod low shrublands and sandy topsoils. The extensive sand sheets overlie ancient alluvial plains and dune systems, both of which are extensively calcreted. Thick sand sheets support *A. aneura* low woodland over *Eragrostis eriopoda* and *Aristida contorta* building into small dunefields of *Acacia ramulosa* and *A. aneura* over grasses. Thin sand sheets over calcrete have *A. aneura* low woodland over *Maireana sedifolia* and grasses and diverse shrubs including *Acacia* spp., *Senna* ssp. and *Eremophila* ssp. *M. sedifolia* low shrublands grow where the soils are almost calcareous throughout and alternate with hard soil flats of *Eremophila scoparia* tall open shrublands. Low-lying parts of the sandplain are mildly to highly saline, with mixes of *Atriplex vesicaria*, *Maireana astrotriche*, *Frankenia* sp., especially where red clayey subsoils persist. Salt-lake complexes have dunes and lunettes of *A. aneura*, *Dodoneae* sp., *Acacia* spp. over grasses and flats with any of *Maireana aphylla*, samphire, *Duma florulenta*, *Eragrostis sp*. or *Chenopodium nitrarium*; some have *Eucalyptus coolabah* ssp. *arida*. isolated silcrete rises with low *A. aneura, Eremophila* spp. and *Maireana* spp.
Great Victoria Desert	GVD05	Tallaringa	An undulating plain with dunes, low gibber-covered rises and shallow sandy depressions associated with a relict drainage system. The plains support a tall shrubland of *Acacia aneura, A. cibaria, Enneapogon* spp. and *Aristida contorta* on red massive clays; and a chenopod shrubland of *Atriplex vesicaria* and *Sclerolaena* spp. on red earthy sands. The dunes support a low shrubland of *Acacia aneura, Aristida contorta, Senna* spp. and *Eremophila* spp. on red siliceous sands. Depressions support a chenopod shrubland of *Maireana* spp. *Halosarcia* spp. and *Frankenia* spp. on crusty red duplex soils.

Source: Gillam and Urban (2013, p.25–27)

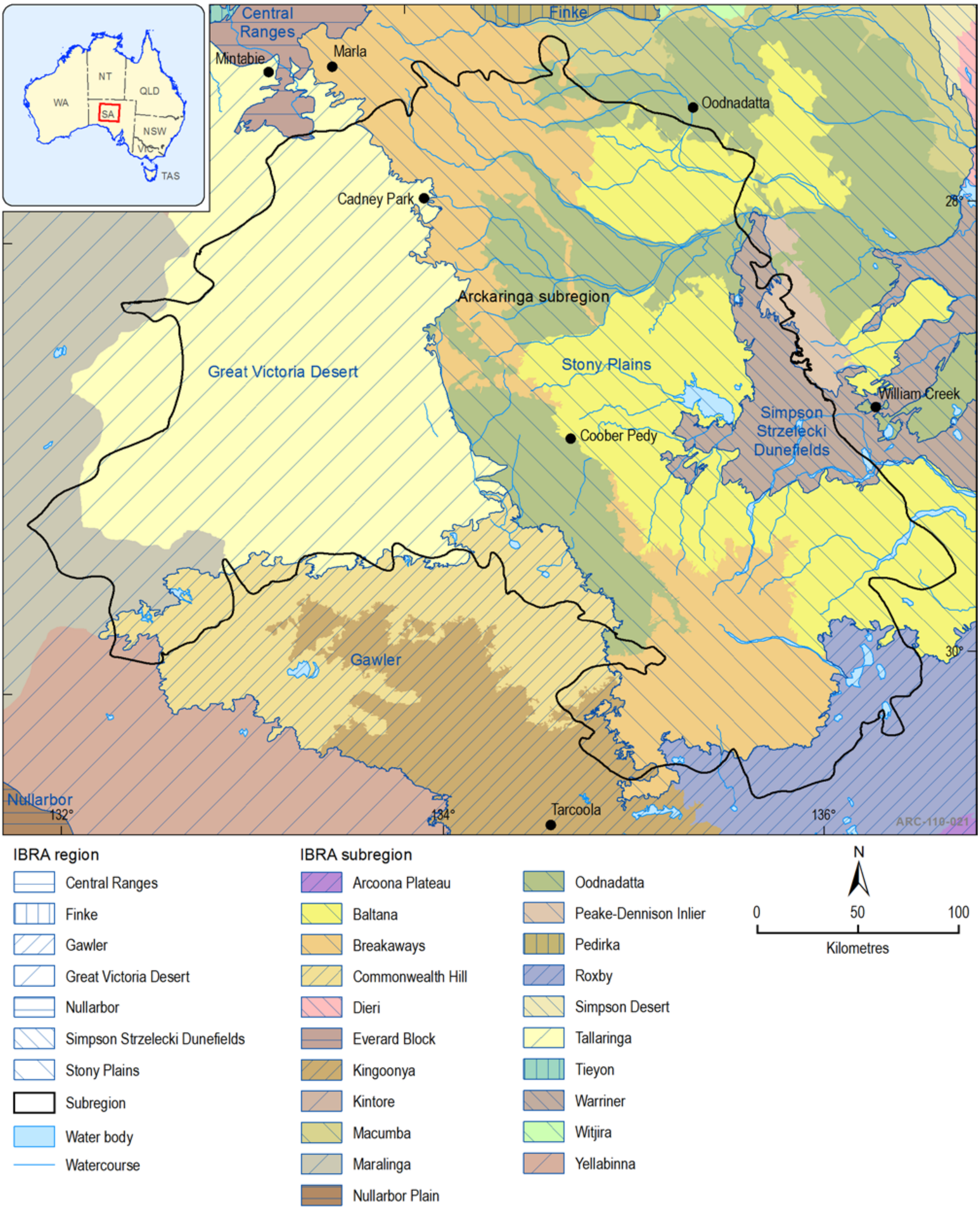

Figure 34 Interim Biogeographic Regionalisation of Australia (IBRA) regions and subregions

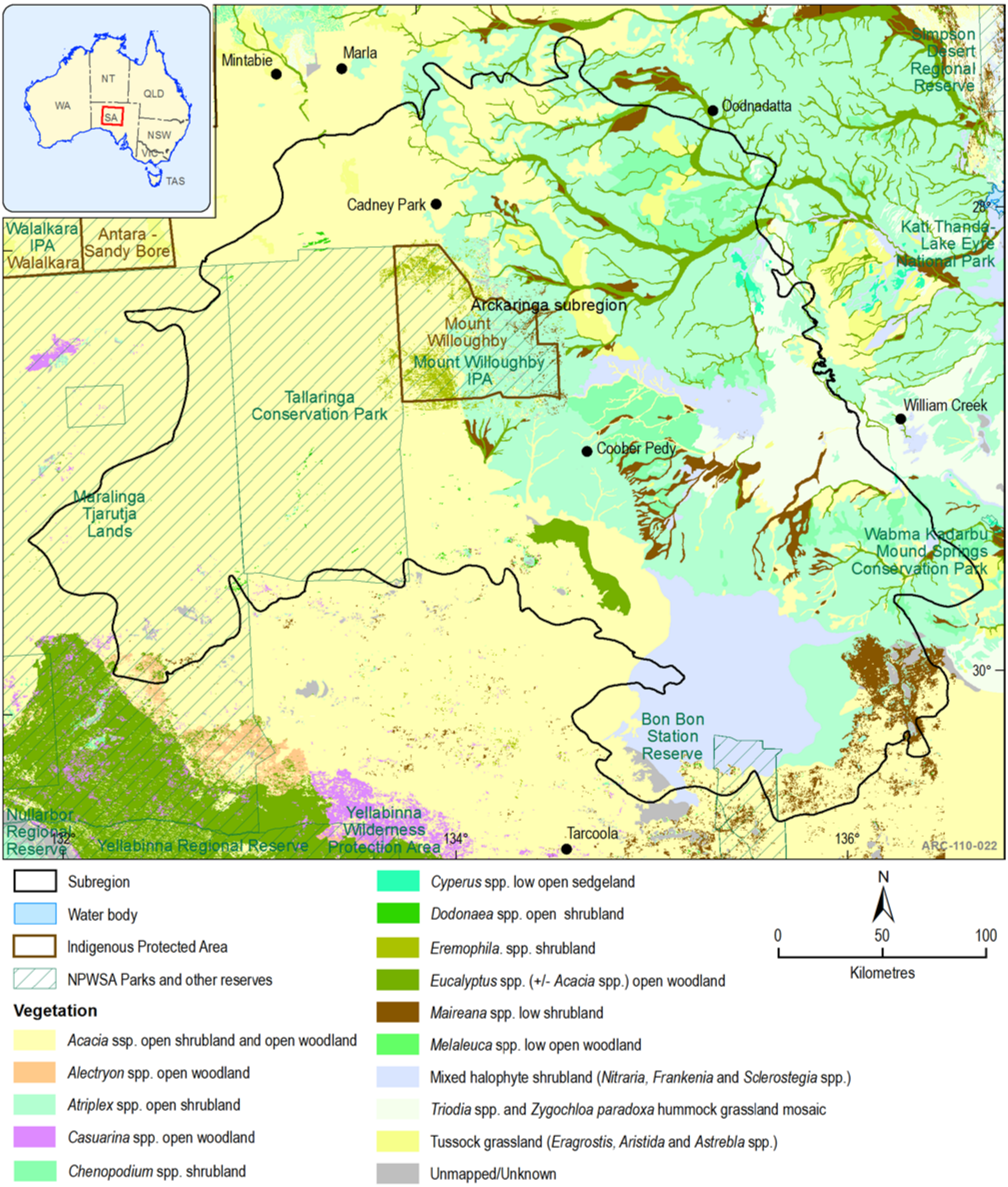

Figure 35 Mapped vegetation associations for the Arckaringa subregion

1.1.7.2 *Terrestrial species and communities*

Northern SA, and in particular the Lake Eyre Basin, is made up of three dominant landscape or environment types:

- Sandy deserts (consisting mostly of parallel sand dunes and swales)
- Stony or gibber deserts (usually associated with clay soils) and
- Wetlands (including creeks, floodplains, waterholes, lakes and springs).

The area is recognised for being part of the driest area in Australia, however its diverse flora and fauna are not generally appreciated (Brandle, 1998).

The stony or gibber deserts of the Lake Eyre Basin were first described to the European settlers by Captain Charles Sturt following his search for the great inland sea during the mid 1840s (Sturt, 1849). The stony deserts north-west of Kati Thanda – Lake Eyre were traversed 50 years later (1894) by the Horn Natural History Expedition (Spencer, 1896).

Systematic descriptions of parts of the Assessment area began with botanists. Jessup (1951) described the habitats of substantial areas to the west of Kati Thanda – Lake Eyre, and produced some structural vegetation community maps. This work and the efforts of Murray (1931) and Crocker (1946) with the aid of Northcote's (Northcote et al., 1968) soil maps, provided the groundwork for much of Specht's synthesis of the vegetation communities of SA (Specht, 1972).

There have been numerous specific biological surveys in the areas comprising the Pedirka and Arckaringa subregions. The earliest was an undergraduate student project in the Breakaways Reserve area to the south (Hobbs, 1987). The South Australian Department for Environment and Planning undertook a survey of the Tallaringa Conservation Park prior to its dedication (Robinson et al., 1988) in the sandy areas to the west. The Australian & New Zealand Scientific Exploration Society undertook two surveys in the hills of Arckaringa Station to the north-east (ANZSES 1994, 1995). The Stony Plains and breakaways to the east and north-east were sampled in 1995 as part of the Biological Survey of the Stony Deserts (Brandle, 1998). This survey sought to systematically sample the central Australian gibber country, the bulk of which occurs in the South Australian portion of the Lake Eyre Basin, and to draw together information gathered about similar land types in adjacent areas of other states. A number of quadrats were also sampled in 1992 on Evelyn Downs Station adjacent to the north-east of Mount Willoughby as part of a threatened species project, the results of which were included in Biological Survey of the Stony Deserts (Brandle, 1998). The Biological Survey of the Anangu-Pitjantjatjara Lands sampled the hard mulga and sand country to the north and north-west in 1996 and 1998 (Robinson et al., 2003).

More recently a biological survey and vegetation mapping of the Mount Willoughby Indigenous Protected Area (IPA) was undertaken to assist the management of the area for biodiversity and management planning. The Sandy Deserts Survey (including Simpson, Pedirka and eastern portions of the Great Victoria Desert) contributed a vast amount of data and vegetation mapping (J. Foulkes, in prep.). Similarly, the Arid Rivers Survey (creeks and floodplains in western Lake Eyre Basin catchments) undertook vegetation and fauna sampling (including fish) (DEWNR, unpublished).

Other work in the region has come in the form of a conservation management appraisal of the former Mount Dare Station, which resulted in its purchase for the Witjira National Park (Davey et al., 1985) and other more specific studies. For example, there have been ongoing investigations into the springs since a major overview of the vegetation, fish and invertebrates was produced in 1985 (McLaren et al., 1985). A number of species-specific studies that have been published are listed in the introductions to the various chapters. Davies (1995) published a report dealing with the management of several threatened plant species populations in the area.

Two books summarising much of the known natural history of the Lake Eyre Basin in SA, including stony desert habitats, have also been published. The Natural History of the North-east Deserts (Tyler et al., 1990) provides scientific summaries, while A Natural History of the Kati Thanda – Lake Eyre Region (Badman et al., 1991) is written as a visitor's guide to the region. The Royal Geographical Society also published a three volume set for Kati Thanda – Lake Eyre South.

1.1.7.2.1 Threatened species

Data sourced from the Biological Database of SA and *Atlas of living Australia*, identifies the distribution of threatened flora and fauna for the Arckaringa subregion, shown in Figures 3 to 6. It should be noted that these databases do not include all data collected in the region, particularly aquatic species monitoring records (e.g. Costelloe et al., 2004; Cockayne et al., 2012, 2013; McNeil et al., 2011). All records from sites within a 5km buffer of the subregion are displayed. Species are displayed as having a conservation ranking if they have a threatened status of critically endangered, endangered, vulnerable or rare under the following:

- National: EPBC Act;
- State: South Australian National Parks and Wildlife Act 1972 or Territory Parks and Wildlife Conservation Act 2000; and
- Regional: Outback region status (Gillam and Urban 2013), note: there is no equivalent regional rating for the NT and the Outback region is not equivalent to the South Australian Arid Lands Natural Resources Management region.

The location of other species records for the relevant biotic group ('non-rated species') are displayed (black dots) to indicate the distribution of survey sites across the subregion and level of survey effort. As can be seen from the maps, surveys generally follow roads and tracks and less data are available for sites away from roads and tracks. Survey methods, including site selection, are provided in survey reports.

The density of significant species is displayed using a grid of cells to indicate whether a point indicates a single record or multiple records for that location. The total number of significant species surveys within each grid cell can include records of the same or different species, at the same or a nearby location, on one or more occasion.

Conservation rankings for significant species are provided in Table 12.

Table 12 Conservation ratings and abbreviations under the National (EPBC Act 1999), South Australian (SA NPW Act 1972), NT (TPWC Act 2000) or regional (Gillam and Urban, 2013)

Abbreviation	Rating	Relevant Rating system
CR	Critically endangered	EPBC Act, Regional
DD	Data deficient	Regional
E	Endangered	SA NPW Act
EN	Endangered	EPBC Act, Regional
EX	Extinct	EPBC Act
LC	Least concern	Regional
NT	Near threatened	Regional
R	Rare	SA NPW Act
RA	Rare	Regional
RE	Regionally Extinct	Regional
V	Vulnerable	SA NPW Act
VU	Vulnerable	EPBC Act, Regional
ssp		Where status is listed as 'ssp', the status applies to a sub-specific level, but the resolution of the record in BDBSA is at a species level. Expert interpretation is required to resolve sub-specific taxonomy (Gillam and Urban, 2013)

Reptiles

There have been a total of 99 taxa from 9 reptile families recorded from within the Arckaringa subregion (Table 13 and Figure 36). There is a single EPBC rated reptile species, the Bronzeback Legless Lizard (*Ophidiocephalus taeniatus*), which is also rated Rare at the state level and Vulnerable at the regional level. It is endemic to the western Lake Eyre Basin and is confined to dense leaf litter in drainage lines in mulga woodlands (Table 13).

There are four reptile species that are rated Rare regionally and one rated Vulnerable. Slaters Skink (*Liopholis slateri*) is rated as Endangered in SA, however it was not considered in regional ratings. Two subspecies have been described; *L. s. slateri* from the southern NT (NT) and *L. s. virgata* from northern SA. The SA subspecies is known from only four specimens; three collected in 1896 from the Oodnadatta area, the other collected in 1914 between Oodnadatta and Everard Range. No other specimens of this subspecies have been located and little is known about their ecology or whether they are still present. At most sites, Slater's skink occurs in shrubland and open shrubland on alluvial soils close to drainage lines, although all historical sites have been in open floodplain type situations (McDonald 2012). Figure 4 shows the distribution of rated species records within each rating category and the density of rated species records within 1 km^2 grid cells. Densities of up to 8 records per 1 km^2 grid cell have been recorded from numerous locations within the subregion, with a higher concentration of locations NW and SE of Coober Pedy.

Table 13 List of reptiles by family with conservation status ratings at the National (EPBC Act), South Australian (SA NPWS Act) or regional level (Outback NRM Region) recorded within the Arckaringa subregion

Species	Common Name	EPBC Act	SA NPWS Act	Regional Status
Furina ornata	Moon Snake			RA
Lerista elongata[a]	Woomera Slider			RA
Liopholis slateri[a]	Black-lined Desert Skink		E	
Morethia butleri	Butler's Snake-eye			RA
Ophidiocephalus taeniatus[a]	Bronzeback Legless Lizard	VU	R	VU
Ramphotyphlops bicolor	Southern Blind Snake			RA

[a]Wetland, drainage-line or floodplain dependant taxa are indicated

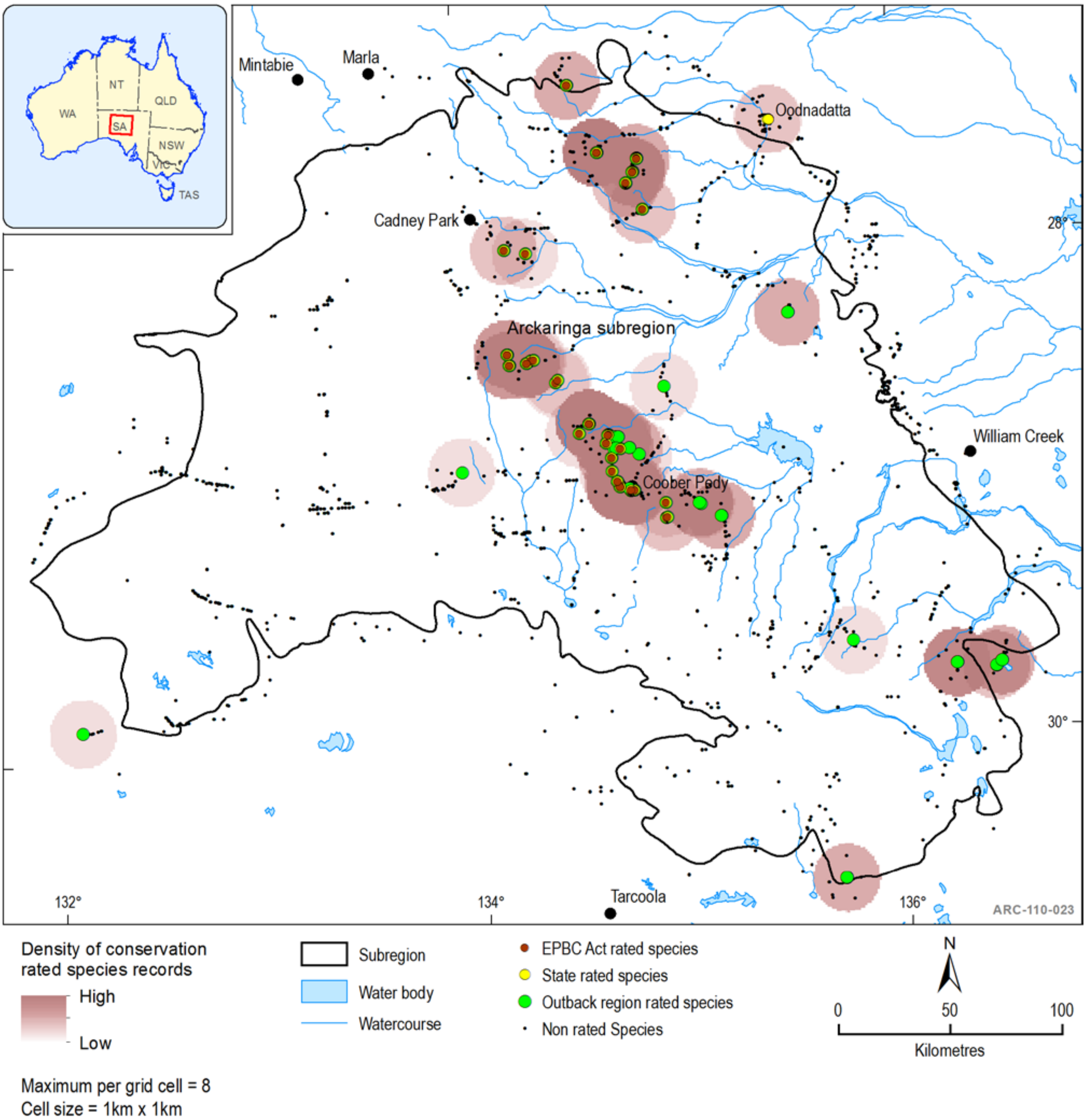

Figure 36 Distribution of significant reptiles in and near the Arckaringa subregion

Birds

Within the Arckaringa subregion, approximately 220 native taxa from 59 bird families have been recorded. Of these, 75 taxa from 37 families have a National (EPBC - 4 taxa), State (SANPWS - 37 taxa) or Regional (Outback NRM Region - 68 taxa) conservation status rating (Table 14). Figure 37 shows the distribution of rated species records within each rating category and the density of rated species records within 1 km^2 grid cells. Densities of up to 14 records per 1 km^2 grid cell have been recorded from numerous locations within the subregion. More than 40 species are waterbirds (including migratory birds) or birds dependent on wetlands or riparian systems for breeding or roosting (Table 14 and Figure 37).

Table 14 List of birds by family with conservation status ratings at the National (EPBC Act), South Australian (SA NPWS Act) or regional level (Outback NRM Region) recorded within the Arckaringa subregion

Species	Common Name	EPBC Act	SA NPWS Act	Regional Status
Acanthiza iredalei	Slender-billed Thornbill	VU	R	CR
Acanthiza robustirostris	Slaty-backed Thornbill			RA
Acrocephalus australis[a]	Australian Reed Warbler			RA
Actitis hypoleucos[a]	Common Sandpiper			RA
Amytornis modestus	Thick-billed Grasswren	ssp		
Anas castanea[a]	Chestnut Teal			RA
Anas rhynchotis[a]	Australasian Shoveler		R	RA
Anhinga novaehollandiae[a]	Australasian Darter		R	RA
Aphelocephala pectoralis	Chestnut-breasted Whiteface		R	RA
Ardea alba[a]	Great Egret			RA
Ardea intermedia[a]	Intermediate Egret		R	RA
Ardea pacifica[a]	White-necked Heron			RA
Ardeotis australis	Australian Bustard		V	RA
Arenaria interpres[a]	Ruddy Turnstone		R	
Artamus minor	Little Woodswallow			RA
Biziura lobata[a]	Musk Duck		R	RA
Burhinus grallarius	Bush Stonecurlew		R	EN
Cacatua leadbeateri	Major Mitchell's Cockatoo		R	EN
Calidris acuminata[a]	Sharp-tailed Sandpiper			RA
Calidris melanotos[a]	Pectoral Sandpiper		R	
Chalcites osculans	Black-eared Cuckoo			RA
Charadrius ruficapillus[a]	Red-capped Plover			RA
Charadrius veredus[a]	Oriental Plover			RA
Chlidonias hybrida[a]	Whiskered Tern			RA
Cinclosoma castanotum	Chestnut Quailthrush		ssp	RA
Circus approximans[a]	Swamp Harrier			RA
Climacteris affinis	White-browed Treecreeper		R	EN
Corvus mellori	Little Raven			RA
Cygnus atratus[a]	Black Swan			RA
Daphoenositta chrysoptera	Varied Sittella			RA
Elanus scriptus	Letter-winged Kite		R	RA
Emblema pictum	Painted Finch		R	RA

Species	Common Name	EPBC Act	SA NPWS Act	Regional Status
Falco hypoleucos	Grey Falcon		R	EN
Falco peregrinus	Peregrine Falcon		R	RA
Falco subniger	Black Falcon			RA
Gallinula tenebrosa[a]	Dusky Moorhen			RA
Gelochelidon nilotica[a]	Gull-billed Tern			RA
Gerygone fusca	Western Gerygone		R	RA
Grus rubicunda[a]	Brolga		V	RA
Hamirostra melanosternon	Black-breasted Buzzard		R	RA
Himantopus leucocephalus[a]	Black-winged Stilt			RA
Hydroprogne caspia[a]	Caspian Tern			RA
Leipoa ocellata	Malleefowl	VU	V	CR
Lichmera indistincta	Brown Honeyeater		R	RA
Melanodryas cucullata	Hooded Robin		ssp	
Microcarbo melanoleucos[a]	Little Pied Cormorant			RA
Microeca fascinans	Jacky Winter		ssp	RA
Myiagra cyanoleuca	Satin Flycatcher		E	
Myiagra inquieta	Restless Flycatcher		R	RA
Neophema chrysostoma	Blue-winged Parrot		V	RA
Neophema elegans	Elegant Parrot		R	RA
Neophema splendida	Scarlet-chested Parrot		R	RA
Northiella haematogaster	Bluebonnet		ssp	
Nycticorax caledonicus[a]	Nankeen Night-heron			RA
Pachycephala inornata	Gilbert's Whistler		R	RA
Pedionomus torquatus	Plains-wanderer	VU	E	CR
Pelecanus conspicillatus[a]	Australian Pelican			RA
Phalacrocorax carbo[a]	Great Cormorant			RA
Phalacrocorax sulcirostris[a]	Little Black Cormorant			RA
Phalacrocorax varius[a]	Pied Cormorant			RA
Phaps histrionica[a]	Flock Bronzewing		R	RA
Platalea flavipes[a]	Yellow-billed Spoonbill			RA
Platalea regia[a]	Royal Spoonbill			RA
Plegadis falcinellus[a]	Glossy Ibis		R	RA
Pluvialis fulva[a]	Pacific Golden Plover		R	

Species	Common Name	EPBC Act	SA NPWS Act	Regional Status
Porzana fluminea[a]	Australian Spotted Crake			RA
Recurvirostra novaehollandiae[a]	Red-necked Avocet			RA
Rhipidura albiscapa	Grey Fantail			RA
Stictonetta naevosa[a]	Freckled Duck		V	RA
Tadorna tadornoides[a]	Australian Shelduck			RA
Threskiornis spinicollis[a]	Straw-necked Ibis			RA
Todiramphus sanctus[a]	Sacred Kingfisher			RA
Tringa glareola[a]	Wood Sandpiper		R	RA
Tringa nebularia[a]	Common Greenshank			RA
Tringa stagnatilis[a]	Marsh Sandpiper			RA

[a]Wetland, drainage-line or floodplain dependent taxa are indicated

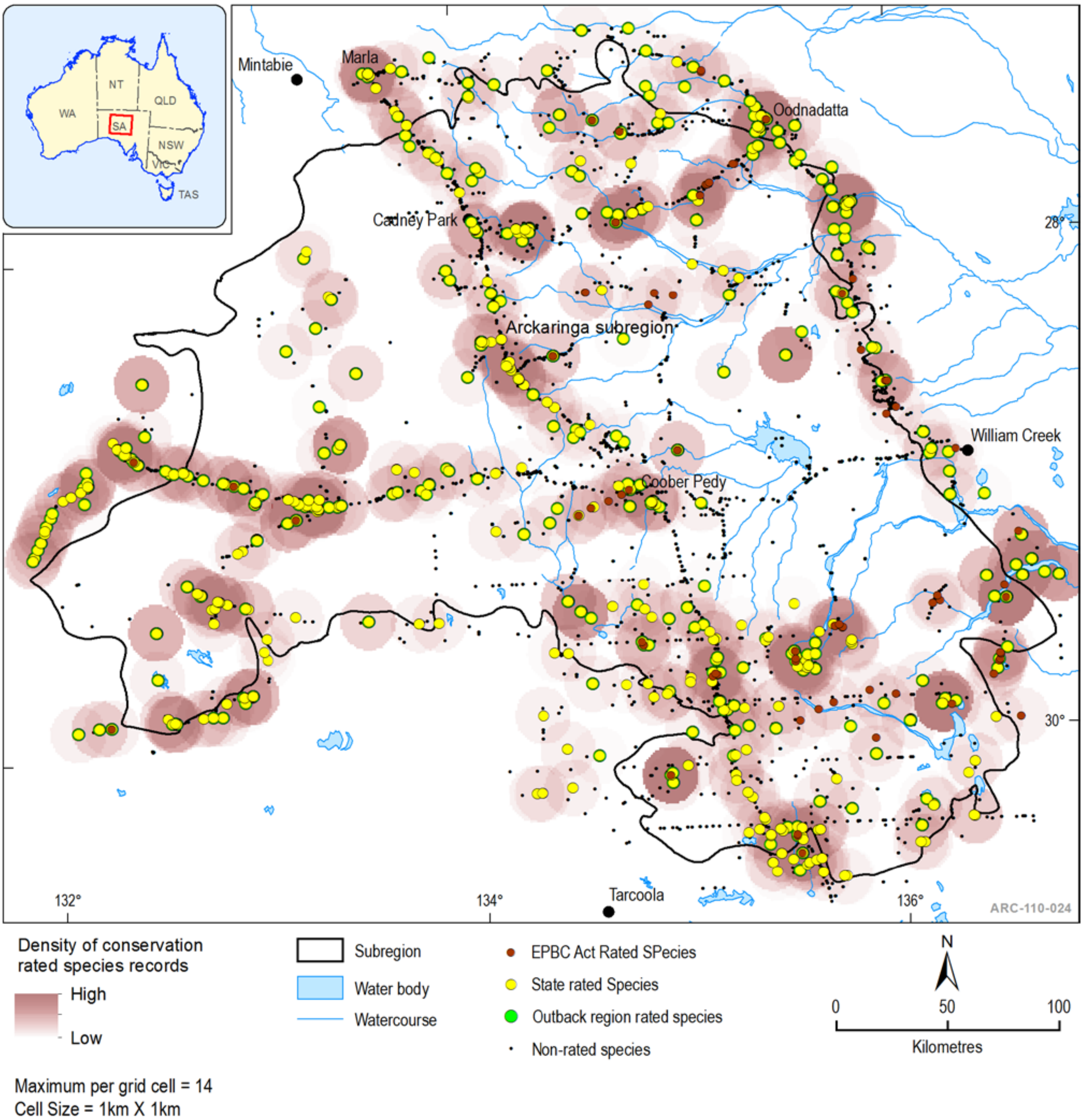

Figure 37 Distribution of significant birds in and near the Arckaringa subregion

Mammals

Within the Arckaringa subregion, 46 native taxa have been recorded from 13 mammal families. Of these, 18 taxa from 11 families have a National (EPBC - 12 taxa- 6 extinct), State (SANPWS – 15 taxa (including 5 extinct in SA) or Regional (Outback NRM Region - 15 taxa (including 5 regionally extinct)) conservation status rating (Table 15 and Figure 38). Figure 38 shows the distribution of rated species records within each rating category and the density of rated species records within 1 km^2 grid cells. The highest density of records is in several locations south of Coober Pedy, south-west of Oodnadatta and east of Cadney Park.

Five taxa (Greater Long-eared Bat, Yellow-bellied Sheath-tailed Bat, Plains mouse, Long-haired Rat (Plague Rat) and Common Brushtail Possum) are reliant on riparian or floodplain systems as a major part of their habitat or for breeding and roosting (Table 15).

Table 15 List of mammals by family with conservation status ratings at the National (EPBC Act), South Australian (SA NPWS Act) or regional level (Outback NRM Region) recorded within the Arckaringa subregion

Species	Common Name	EPBC Act	SA NPWS Act	Regional Status
Bettongia lesueur	Burrowing Bettong	EX	E	VU
Canis lupus dingo	Dingo			RA
Chaeropus ecaudatus	Pig-footed Bandicoot	EX	E	RE
Dasycercus byrnei	Kowari	VU	V	VU
Lagorchestes hirsutus hirsutus	Mala (Rufous Hare-wallaby)	EX	E	RE
Lasiorhinus latifrons	Southern Hairy-nosed Wombat			RA
Leporillus conditor	Greater Stick-nest Rat	VU	V	VU
Leporillus sp.	Stick-nest Rat	EX	E	RE
Notomys cervinus	Fawn Hopping-mouse		V	VU
Notomys longicaudatus	Long-tailed Hopping Mouse	EX	E	RE
Notoryctes typhlops	Southern Marsupial Mole (Itjaritjara)	EN	V	DD
Nyctophilus major[a]	Greater Long-eared Bat	ssp	ssp	DD
Petrogale lateralis lateralis (McDonnell Ranges race)	Black-footed Rock-wallaby	VU	E	CR
Pseudomys australis[a]	Plains mouse	VU	V	RA
Pseudomys gouldii	Goulds Mouse	EX	E	RE
Rattus villosissimus[a]	Long-haired Rat (Plague Rat)			RA
Saccolaimus flaviventris[a]	Yellow-bellied Sheath-tailed Bat		R	DD
Trichosurus vulpecula[a]	Common Brushtail Possum		R	RE

[a]Wetland, drainage-line or floodplain dependent taxa are indicated

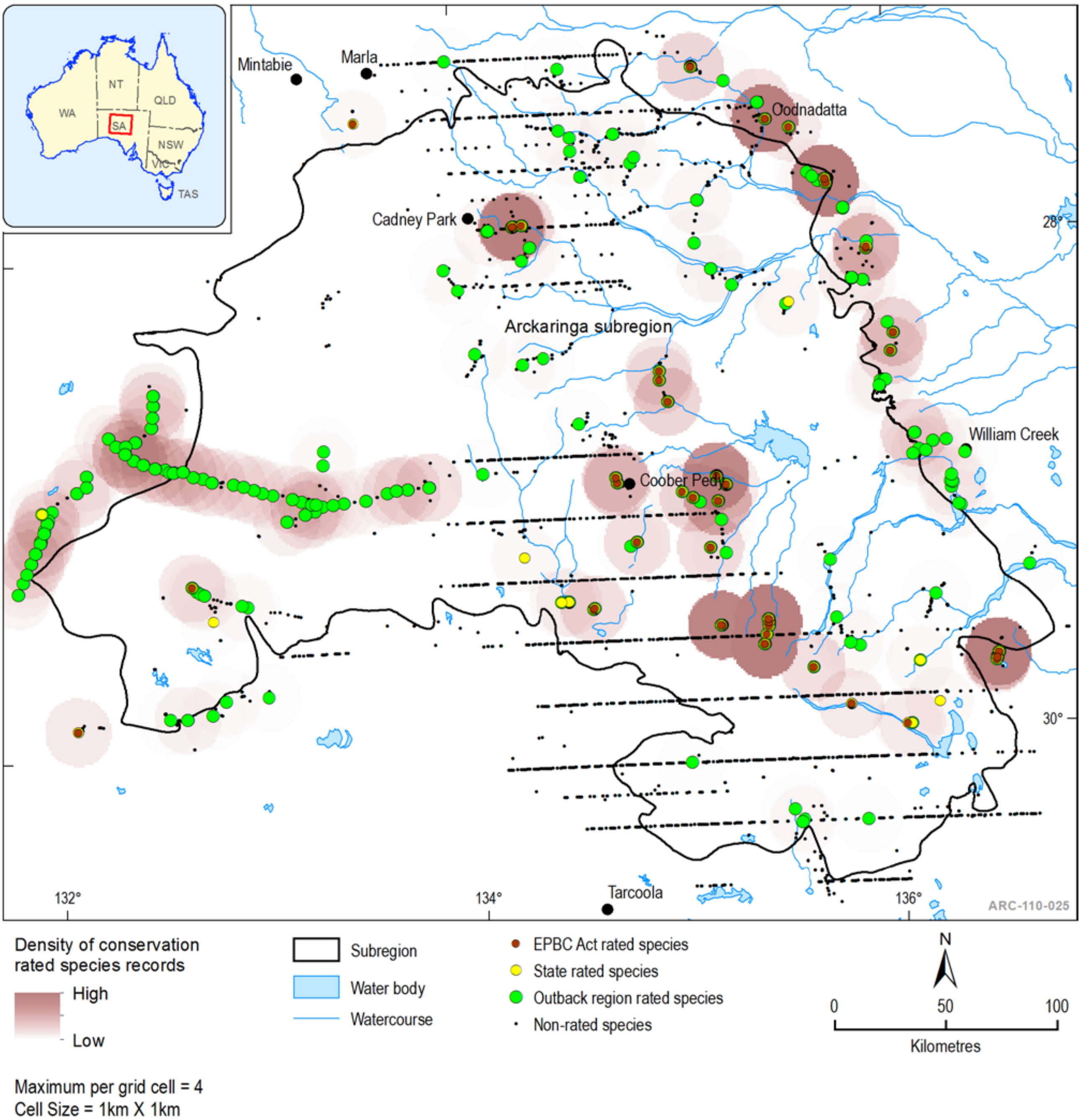

Figure 38 Distribution of significant mammals in and near the Arckaringa subregion

Flora

Within the Arckaringa subregion, approximately 1500 taxa from 90 vascular plant families have been recorded. Of these, 225 taxa have a National (EPBC - 2 taxa), State (SANPWS - 64 taxa) or Regional (Outback NRM Region - 194 taxa) conservation status rating (Table 16). Figure 39 shows the distribution of rated species records within each rating category and the density of rated species records within 1 km^2 grid cells. The highest density of rated species records (179 records) occur within a triangular area bounded by Cadney Park, Oodnadatta and Coober Pedy.

More than 50 taxa from 20 families occur in wetland, drainage-line and or halophytic habitats, including the two EPBC rated taxa, *Frankenia plicata* (Endangered) and *Eleocharis papillosa* (Vulnerable) (Table 16).

Table 16 List of vascular plants by family with conservation status ratings at the National (EPBC Act), South Australian (SA NPWS Act) or regional level (Outback NRM Region) recorded within the Arckaringa subregion

Species	Common Name	EPBC Act	SA NPWS Act	Regional Status
Abutilon oxycarpum var. incanum			R	
Abutilon oxycarpum var. oxycarpum	Straggly Lantern-bush			RA
Acacia hakeoides	Hakea Wattle			RA
Acacia nyssophylla	Spine Bush			RA
Acacia rhodophloia	Minni Ritchi		R	VU
Acacia tarculensis	Steel Bush			RA
Amaranthus interruptus	Native Amaranth			RA
Anemocarpa saxatilis	Hill Sunray			RA
Angianthus brachypappus	Spreading Angianthus			RA
Angianthus tomentosus	Hairy Angianthus			RA
Aristida arida			R	RA
Aristida inaequiglumis				RA
Atriplex eichleri	Eichler's Saltbush		R	NT
Atriplex humifusa			V	RA
Atriplex incrassata	Oodnadatta Saltbush			RA
Atriplex kochiana	Koch's Saltbush		V	VU
Atriplex morrisii			V	VU
Atriplex quadrivalvata var. quadrivalvata				RA
Atriplex quadrivalvata var. sessilifolia				RA
Atriplex turbinata				RA
Austrostipa nullanulla	Club Spear-grass		V	RA
Austrostipa plumigera			R	RA
Austrostipa vickeryana	Vickery's Spear-grass		R	VU
Baumea juncea[a]	Bare Twig-rush			VU
Bergia occultipetala[a]			V	NT
Bergia perennis ssp. exigua[a]	Perennial Water-fire			RA
Brachyscome dichromosomatica var. dichromosomatica	Large Hard-head Daisy			RA
Brachyscome eriogona			R	LC

Species	Common Name	EPBC Act	SA NPWS Act	Regional Status
Brachyscome eriogona			R	
Brachyscome tesquorum	Shrubby Desert Daisy			RA
Bulbostylis turbinata[a]			R	RA
Calandrinia corrigioloides	Strap Purslane			RA
Callitriche sonderi[a]	Matted Water Starwort		R	NT
Calocephalus knappii	Knapp's Beauty-heads			RA
Calotis kempei	Kemp's Burr-daisy			RA
Calotis scabiosifolia var. scabiosifolia	Rough Burr-daisy			VU
Carinavalva glauca				RA
Ceratogyne obionoides			R	
Cheilanthes sieberi ssp. pseudovellea				RA
Chloris truncate	Windmill Grass			RA
Commelina ensifolia	Scurvy Grass			RA
Convolvulus recurvatus ssp. nullarborensis				RA
Convolvulus tedmoorei				RA
Crassula sieberiana			E	
Crotalaria medicaginea var. neglecta	Trefoil Rattle-pod			RA
Cuphonotus andraeanus	Downy Mother-of-misery			RA
Cuphonotus humistratus	Mother-of-misery			RA
Cyperus alterniflorus f. Oodnadatta (K.L.Wilson 4612)[a]	Umbrella Flat-sedge			DD
Cyperus bifax[a]	Downs Flat-sedge		R	RA
Cyperus centralis[a]	Inland Flat-sedge			RA
Cyperus dactylotes[a]			V	VU
Cyperus nervulosus[a]			R	NT
Damasonium minus[a]	Star-fruit			RA
Darwinia salina	Salt Darwinia			RA
Dicrastylis beveridgei var. beveridgei	Sand-sage			RA
Digitaria divaricatissima var. divaricatissima	Spider Grass			RA
Dipteracanthus australasicus ssp. australasicus				RA
Dissocarpus biflorus var. villosus	Woolly Two-horn Saltbush			RA
Drosera indica[a]	Indian Sundew			RA

Species	Common Name	EPBC Act	SA NPWS Act	Regional Status
Eclipta alatocarpa				RA
Elachanthus pusillus	Elachanth			RA
Eleocharis papillosa		VU	R	RA
Eleocharis pusilla[a]	Small Spike-rush			RA
Embadium johnstonii	Johnston's Slipper-plant		R	LC
Embadium stagnense			R	
Eragrostis lacunaria	Purple Love-grass		R	RA
Eremophila arachnoides ssp. tenera	Spider Emubush			RA
Eremophila battii				RA
Eremophila decussata				RA
Eremophila dendritica				VU
Eremophila obovata ssp. obovata				RA
Eremophila paisleyi ssp. glandulosa				RA
Eremophila pentaptera			R	VU
Eremophila verrucosa ssp. verrucosa	Warty Emubush			RA
Erigeron sessilifolius				RA
Eriochlamys behrii	Woolly Mantle			RA
Eryngium vesiculosum			R	
Eucalyptus canescens ssp. beadellii	Beadell's Mallee		R	NE
Eucalyptus eremicola ssp. peeneri	Peeneri Mallee			RA
Eucalyptus gypsophila	Kopi Mallee			RA
Eucalyptus intertexta[a]	Gum-barked Coolibah			RA
Eucalyptus mannensis ssp. mannensis	Mann Ranges Mallee			RA
Eucalyptus pimpiniana	Pimpin Mallee			RA
Eucalyptus socialis ssp. eucentrica				RA
Eucalyptus trivalva	Three-valve Mallee			RA
Eucalyptus youngiana	Ooldea Mallee			RA
Frankenia cordata[a]				DD
Frankenia crispa[a]	Hoary Sea-heath			DD
Frankenia cupularis[a]			R	NT
Frankenia plicata[a]		EN	V	DD
Frankenia subteres[a]			R	NT
Gahnia trifida[a]	Cutting Grass			EN

Species	Common Name	EPBC Act	SA NPWS Act	Regional Status
Gilesia biniflora	Western Tar-vine		R	NT
Glossostigma cleistanthum[a]	Spoon Mud-mat			RA
Glycyrrhiza acanthocarpa	Native Liquorice			RA
Gnaphalium indutum ssp. indutum	Tiny Cudweed			DD
Gomphrena lanata				RA
Goodenia anfracta			R	RA
Goodenia chambersii			R	NT
Goodenia havilandii	Hill Goodenia			RA
Goodenia heteromera	Spreading Goodenia		R	RA
Goodenia modesta				RA
Goodenia occidentalis				RA
Goodenia pinnatifida	Cut-leaf Goodenia			RA
Grevillea huegelii	Comb Grevillea			VU
Gunniopsis calva				RA
Gunniopsis tenuifolia	Narrow-leaf Pigface			RA
Haloragis gossei[a]	Gosse's Raspwort			RA
Haloragis odontocarpa f. octoforma[a]	Mulga Nettle			RA
Haloragis odontocarpa f. pterocarpa[a]	Mulga Nettle			RA
Haloragis odontocarpa f. rugosa[a]	Mulga Nettle			RA
Harmsiodoxa brevipes var. brevipes	Short Cress			RA
Harmsiodoxa brevipes var. major	Short Cress			RA
Heliotropium cunninghamii	Bushy Heliotrope			RA
Heliotropium curassavicum				RA
Hemichroa mesembryanthema	Pigface Hemichroa		V	VU
Hibiscus sturtii var. muelleri	Sturt's Hibiscus			VU
Hypericum gramineum	Small St John's Wort			RA
Isolepis australiensis[a]	Southern Club-rush			RA
Juncus aridicola[a]	Inland Rush			RA
Kippistia suaedifolia	Fleshy Kippistia			RA
Lepidium papillosum	Warty Peppercress			RA
Lepidium rotundum	Veined Peppercress			RA
Lepidium strongylophyllum				RA
Leptochloa fusca ssp. fusca	Brown Beetle-grass			RA

Species	Common Name	EPBC Act	SA NPWS Act	Regional Status
Leptorhynchos baileyi	Bailey's Buttons			RA
Lipocarpha microcephala[a]	Button Rush			RA
Lythrum hyssopifolia[a]	Lesser Loosestrife			RA
Maireana carnosa	Cottony Bluebush			RA
Maireana lobiflora	Lobed Bluebush			RA
Maireana melanocarpa	Black-fruit Bluebush		R	RA
Marsilea costulifera[a]	Narrow-leaf Nardoo			RA
Melaleuca glomerata[a]	Inland Paper-bark			RA
Melaleuca nanophylla			R	
Mimulus repens[a]	Creeping Monkey-flower			RA
Momordica balsamina	Balsam Apple			RA
Myosurus australis[a]	Mousetail			RA
Myriocephalus rhizocephalus	Woolly-heads			RA
Myriocephalus squamatus	Small Poached-egg Daisy			RA
Nicotiana rosulata ssp. rosulata				RA
Nicotiana truncate			R	RA
Nymphoides crenata[a]	Wavy Marshwort		R	EN
Olearia arckaringensis				EN
Olearia ferresii	Central Australian Daisy-bush			RA
Olearia subspicata	Spiked Daisy-bush			RA
Ophioglossum polyphyllum[a]	Large Adder's-tongue		R	RA
Osteocarpum acropterum var. deminutum	Wingless Bonefruit		R	RA
Osteocarpum salsuginosum	Inland Bonefruit			RA
Peplidium sp. Marla (W.R.Barker 3535)[a]				RA
Phlegmatospermum eremaeum	Spreading Cress		R	DD
Phragmites australis	Common Reed			RA
Plantago multiscapa[a]	Many-stem Plantain		V	RA
Plantago sp. A (A.C.Robinson 704)[a]			R	
Plantago turrifera[a]	Crowned Plantain			RA
Poa fax	Scaly Poa		R	RA
Poa fordeana	Forde's Poa			RA

Species	Common Name	EPBC Act	SA NPWS Act	Regional Status
Podolepis davisiana	Button Podolepis			RA
Podolepis longipedata	Tall Copper-wire Daisy			RA
Polycarpaea breviflora				RA
Potamogeton pectinatus[a]	Fennel Pondweed			RA
Psydrax suaveolens	Narrow-leaf Native Currant			RA
Ptilotus barkeri	Barker's Mulla Mulla		R	RA
Ptilotus parvifolius	Small-leaf Mulla Mulla			RA
Ptilotus whitei	Small-leaf Mulla Mulla			RA
Pycnosorus globosus	Drumsticks		V	VU
Rhodanthe stuartiana	Clay Everlasting			RA
Rostellularia adscendens var. latifolia	Pink Tongues			RA
Ruppia maritima[a]	Sea Tassel			RA
Santalum spicatum	Sandalwood		V	NT
Schoenoplectus dissachanthus[a]	Inland Club-rush			RA
Schoenoplectus laevis[a]				RA
Schoenoplectus subulatus[a]	Shore Club-rush			RA
Scleroblitum atriplicinum	Starry Goosefoot			RA
Sclerolaena articulate	Jointed Bindyi			RA
Sclerolaena blackiana	Black's Bindyi		R	NT
Sclerolaena clelandii	Cleland's Bindyi			RA
Sclerolaena muricata var. semiglabra	Five-spine Bindyi			RA
Sclerolaena symoniana	Symon's Bindyi		V	RA
Senecio gypsicola	Gypsum Groundsel		R	RA
Senna notabilis	Showy Senna			RA
Senna planitiicola	Yellow Pea			RA
Setaria reflexa				RA
Sida corrugata var. corrugata	Corrugated Sida			RA
Sida everistiana	Everist's Sida			RA
Spergularia diandroides	Lesser Sand-spurrey			DD
Stackhousia clementii	Limestone Candles			RA
Stemodia sp. Haegii (J.Z.Weber 9055) W.R.Barkera	Haegi's Stemodia		R	RA

Species	Common Name	EPBC Act	SA NPWS Act	Regional Status
Stenopetalum sphaerocarpum	Round-fruit Thread-petal			RA
Stylidium inaequipetalum			V	RA
Swainsona minutiflora	Small-flower Swainson-pea		V	VU
Swainsona oligophylla			R	NT
Swainsona purpurea	Purple Swainson-pea			RA
Swainsona unifoliolata				RA
Swainsona vestita			V	VU
Tecticornia cupuliformis[a]			V	RA
Tecticornia fontinalis	Mound Spring Samphire			VU
Tecticornia halocnemoides ssp. halocnemoides[a]	Grey Samphire			RA
Tecticornia halocnemoides ssp. Tenuis[a]				RA
Tecticornia indica ssp. bidens[a]	Brown-head Samphire			RA
Tecticornia pergranulata ssp. Elongata[a]	Black-seed Samphire			RA
Templetonia egena	Broombush Templetonia			RA
Thryptomene elliottii				RA
Thyridolepis xerophila				RA
Thysanotus exiliflorus	Inland Fringe-lily			RA
Trachymene cyanopetal[a]	Purple Trachymene			RA
Triglochin multifructa[a]	Water Ribbons			VU
Typha domingensis[a]	Narrow-leaf Bulrush			RA
Typhonium alismifolium[a]			R	RA
Vigna lanceolata var. latifolia	Maloga Bean			RA
Vittadinia arida				RA
Wahlenbergia aridicola	Dryland Bluebell			RA
Wahlenbergia gracilenta	Annual Bluebell			RA
Wahlenbergia preissii				VU
Wurmbea deserticola	Desert Nancy		R	RA
Wurmbea nilpinna			V	VU
Wurmbea stellata	Star Nancy		R	RA
Zygophyllum angustifolium	Scrambling Twinleaf			DD
Zygophyllum aurantiacum ssp. simplicifolium				RA

Species	Common Name	EPBC Act	SA NPWS Act	Regional Status
Zygophyllum crassissimum	Thick Twinleaf		R	RA
Zygophyllum glaucum	Pale Twinleaf			RA
Zygophyllum humillimum	Small-fruit Twinleaf		R	NT
Zygophyllum hybridum			R	RA
Zygophyllum kochii	Koch's Twinleaf			RA
Zygophyllum marliesiae	Square-fruit Twinleaf			RA
Zygophyllum tesquorum				RA

[a]Wetland, drainage-line or floodplain dependant taxa are indicated

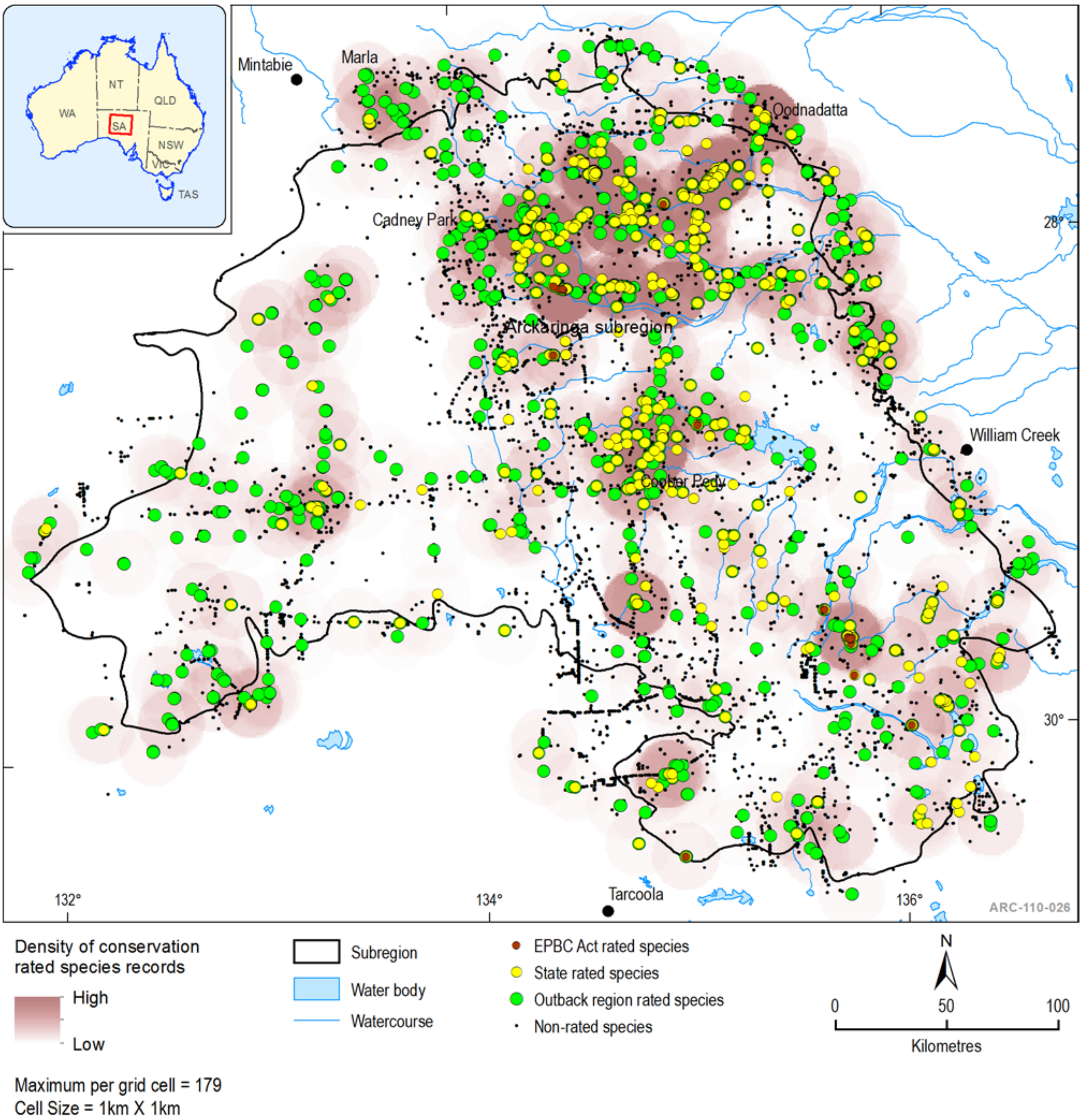

Figure 39 Distribution of significant flora in the Arckaringa subregion

1.1.7.3 *Aquatic species and communities*

The aquatic ecological systems of the Arckaringa subregion can be broadly grouped into the groundwater-dependent GAB springs, the surface water dependent aquatic ecosystems of the western LEB catchments, and the surface water-dependent ecosystems to the west of the LEB. The following sections describe each of these groupings, firstly in terms of the broader aquatic ecosystems and habitats and secondly in relation to the species and communities therein. The aquatic biota of isolated endorheic systems and salt lakes and their catchments are very poorly understood and in the Arckaringa subregion have not been studied.

Because the GAB springs are decoupled from regional climatic rainfall changes, they provide evolutionary refugia for relict and short-range endemic species that have limited capacity to persist or disperse without permanent water. The GAB spring ecosystems are therefore highly vulnerable because (for the most part) their biota cannot re-populate springs once they become locally extinct. Perennial waterholes in arid zone river systems provide ecological refuges for obligate aquatic species and are responsive to local and regional climatic conditions (Davis et al., 2013). Within the Arckaringa subregion there are no known permanent surface water-driven waterholes, however Algebuckina Waterhole, 2 km downstream in the Neales catchment is not known to have dried out in living memory. However, other semi-permanent waterholes and GAB springs also provide various refuge roles that sustain surface water biota (McNeil et al., 2011a). Populations of aquatic biota have distinct assemblages and distributions at different scales (e.g. spring vent, spring group, waterhole, and catchment) depending on their dispersal mechanisms and capacity to withstand conditions within those environments. The relationship between hydrological connectivity and dispersal between catchments can only be determined by genetic studies and is a priority for further research (Davis et al., 2013). The long term persistence of the species and communities of the Arckaringa subregion aquatic ecosystems is dependent on maintaining the environmental drivers that support the metapopulation dynamics and requirements of biota through connectivity, refuges, resistance and resilience (Davis et al., 2013). Therefore, the discussion below identifies both the species and communities within the aquatic ecosystems as well as the processes and habitat requirements that are critical to their survival.

Using data sourced from the Biological Database of South Australia and *Atlas of living Australia*, the distribution of threatened fish species for the Arckaringa subregion are shown in Figure 40. All records from sites within a 5 km buffer of the subregion are displayed and shown as having a conservation ranking if they have a threatened status of critically endangered, endangered, vulnerable or rare under Commonwealth and State legislation, together with Regional ratings.

1.1.7.3.1 Fish

Thirteen taxa from seven families have been recorded from the subregion. Seven of these are regarded as Rare at the regional level (Table 17). Figure 5 shows the distribution of rated species records within each rating category and the density of rated species records within 1 km^2 grid cells. The highest density of fish records are to the south-west of Oodnadatta in the Neales catchment (Figure 40). The only introduced species recorded in the region is Eastern Gambusia (*Gambusia holbrooki*)

Table 17 List of fish by family with conservation status ratings at the National (EPBC Act), South Australian (SA NPWS Act) or regional level (Outback NRM Region) recorded within the Arckaringa subregion

Species	Common Name	EPBC Act	SA NPWS Act	Regional Status
Amniataba percoides	Barred Grunter			RA
Bidyanus welchi	Welch's Grunter			RA
Chlamydogobius eremius	Desert Goby			RA
Craterocephalus centralis	Finke Hardyhead			
Craterocephalus eyresii	Lake Eyre Hardyhead			RA
Gambusia holbrookia	Eastern Gambusia			
Leiopotherapon unicolor	Spangled Perch			NT
Macquaria ambigua ambigua	Callop			
Melanotaenia splendida tatei	Desert Rainbow Fish			RA
Melanotaenia splendida tatei	Desert Rainbow Fish			RA
Nematalosa erebi	Bony Bream			RA
Nematalosa erebi	Bony Bream			
Neosilurus gloveri	Dalhousie Catfish			

[a]introduced species

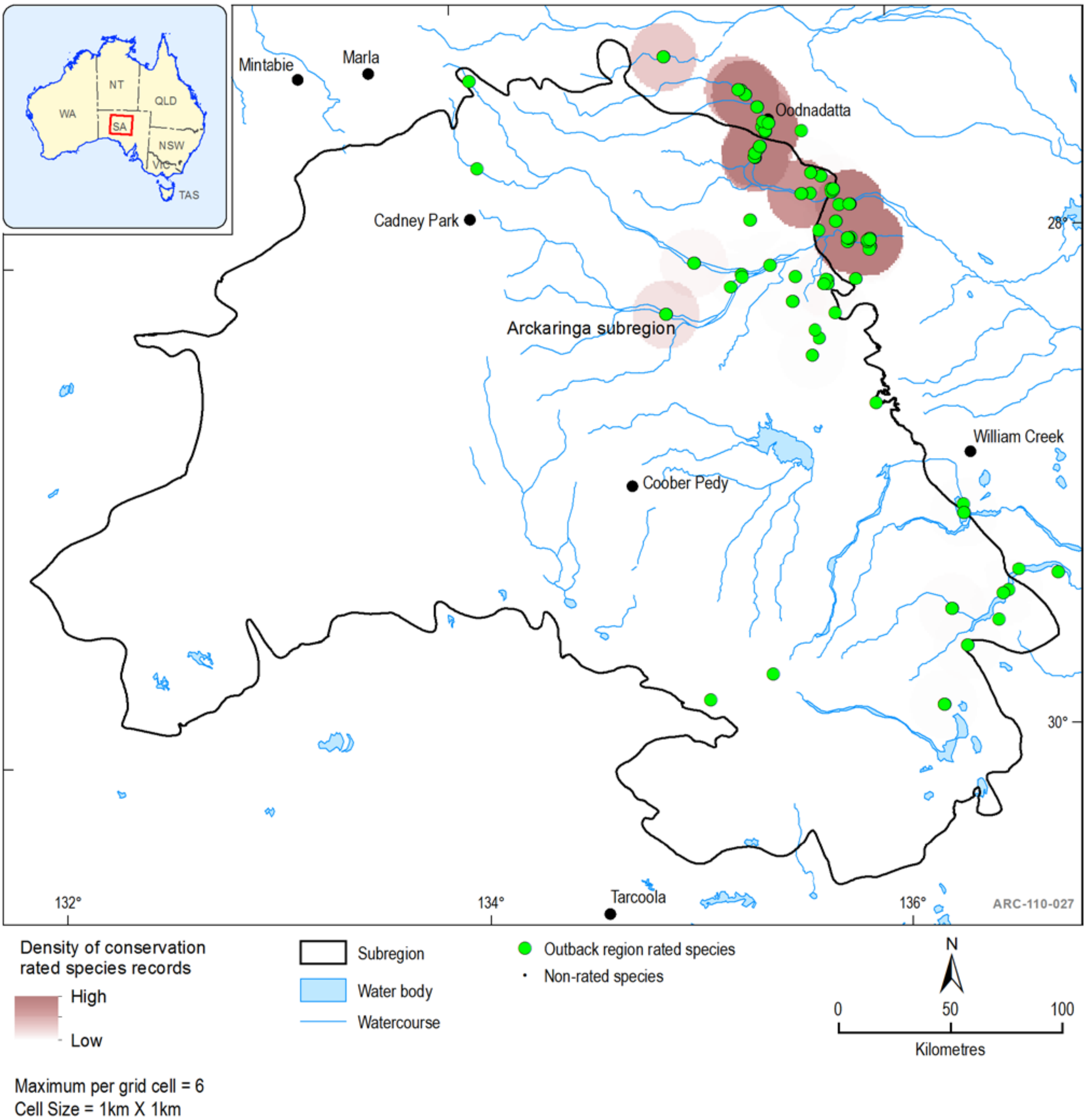

Figure 40 Distribution of fish species in the Arckaringa subregion (only major creeks, rivers and waterbodies shown)

1.1.7.3.2 Amphibians

Four taxa from two families of amphibians have been recorded in the subregion however none has any conservation status at the national, state or regional level (Table 18).

Table 18 List of amphibians by family recorded within the Arckaringa subregion

Species	Common Name
Cyclorana maini[a]	Main's Frog
Cyclorana platycephala[a]	Water-holding Frog
Litoria rubella[a]	Desert Tree Frog
Neobatrachus sudelli[a]	Sudell's Frog

[a]Wetland, drainage-line or floodplain dependent taxa are indicated

1.1.7.3.3 Groundwater-dependent aquatic ecosystems

Function of Great Artesian Basin springs

Spring ecosystems dependent on discharge from the GAB are rated as nationally endangered and are protected under the EPBC Act. GAB springs from the Lake Eyre supergroup of springs are also listed in the directory of important wetlands in Australia and occur within and to the east and south-east of the Arckaringa subregion (Figure 41). The hydrogeology of the GAB relating to these springs is discussed in section 1.1.4.

Gotch (2013a) developed a spring nomenclature to provide a common language to describe GAB springs in SA (Table 19) based on previous work by Ponder (1986) and Fatchen and Fatchen (1993). A similar nomenclature is adopted in Queensland based on Fensham and Fairfax (2003), however the latter used distance definitions to separate between spring groups and between spring complexes. Gotch (2013a) surveyed 4516 springs vents in 103 spring groups in SA (Table 22) with 3793 vents found in the Lake Eyre supergroup. 85 spring complexes are entirely active, 17 entirely inactive, and the remaining 14 contain both active and inactive springs (Fensham et al., 2005).

Table 19 Spring classification hierarchy and definitions

Classification	Definition and description
Supergroups	Clusters of spring complexes; there are 13 supergroups across the GAB, with three found in SA.
Complexes	Clusters of spring groups that share similar geomorphological settings and broad similarities in water chemistry.
Groups	Clusters of springs that share similar water chemistry and source their water from the same fault or structure.
Spring	Individual wetlands comprising one or more vents and tails joined together by permanent wetland vegetation.
Vents	Individual point discharges of water from the GAB, varying in size and structure: some are discrete discharges of water as if coming from a pipe, while others may be several metres across with no clear point of discharge within the region—the spring vent is the minimum unit used when describing the number of springs from a legislative perspective and in accordance with water allocation planning.
Tails	Wetlands associated with flow away from the vent.

Source: Gotch (2013a, p. 15, Table 2.2)

The term ‘mound spring’ has historically been used to describe GAB springs, however not all springs form the characteristic mound. Green et al. (2013) presents a hierarchical classification for

GAB springs in SA consistent with the Australian National Aquatic Ecosystems (ANAE) classification framework (AETG 2012a), incorporating the national attributes at the 'higher levels'. The 'lower levels' provide greater differentiation for GAB springs, with attributes for hydraulic environment (artesian or non-artesian), structural linkage to aquifer source and seven surface morphology types (Table 9) (Green et al., 2013). Carbonate mounds are common throughout the Lake Eyre supergroup, but there are also a significant number of sand mounds and peat and fen bogs (Green et al., 2013).

Table 20 Different surface morphology types for artesian GAB Springs

Surface morphology type	Description
Carbonate mound	Characterised by rocky travertine positioned above the surrounding terrain, typically forming a raised vent area that may or may not be accompanied by a travertine tail feature.
Carbonate terrace	Lateral flow of groundwater deposits travertine terraces. Can be raised above the surrounding landscape, but does not form the distinctive mound.
Rocky seep	Groundwater seeps from rocky cracks and fissures. Significant deposits of travertine are not associated with this morphological type.
Peat/Fen bog	Spring substrate is largely organic in origin and can form large mounds.
Clay swelling	Groundwater emerging just below the surface creates a swelling mound of mud/clay with little or no water discharge. The mound is quite plastic and will deform under pressure, often releasing more water.
Mud mound	Formed as groundwater, emerges below the surface into unconsolidated soil. A mound is formed as mud is forced upwards under pressure of the discharging groundwater.
Sand/silt	Forms when wind-blown sand is deposited around wet vegetation and then is expanded as more vegetation grows on the substrate. The resulting wetland vegetation may deposit large amounts of organic matter and form a peat/fen bog at the vent.

Source: Green et al. (2013, p. 20)

The Gotch (2013a) survey recorded vent position and elevation to a very high degree of accuracy as well as other baseline information on the condition and ecological values such as flow status, water chemistry, stock damage, and species inventory. Some spring groups remain unsurveyed or surveyed to a lower level of accuracy. Elevation of the spring vent is a key attribute as it can be subtracted from the source aquifer pressure to determine the groundwater pressure above the spring surface (Green and Berens, 2013). The pressure above spring surface is an indicator of the vulnerability of spring discharge to reduction in groundwater level, with excess head values of five metres or less indicative of springs at very high risk of ceasing to flow due to reductions in groundwater pressure (Green et al., 2013). The pressure above spring surface has been calculated for the majority of surveyed GAB springs in the artesian zone in SA based on the potentiometric map for the J-K aquifer (see Green et al., 2013 pp. 29-35).

The area of the wetland has been shown to vary over time both between seasons, mainly driven by the phenology of the dominant vegetation species, and over longer time periods, mainly in response to rainfall variation (White et al., 2013). Some vents within a spring group may be permanently connected, either by discharging to the same pool, by overland flow or by saturated soil conditions. Because of intra- and inter-annual variation (White et al., 2013), vents within a spring group that are not permanently connected may become connected seasonally or ephemerally. Within a spring wetland, there is variation in water chemistry and soil conditions which drives variation in plant species composition (Clarke et al., 2013) and habitats. The flow rate of a spring is one of the main determinants of the total wetland area, the connectivity of the wetland system, the water and soil chemistry (Green et al., 2013), and range of vegetation and habitats (Clarke et al., 2013) present within a wetland. Therefore, the ecological values of GAB springs, including those with a relatively high pressure above the spring vent, can be impacted by relatively small reductions in pressure and hence flow.

GAB springs can range from a small soak to large wetland areas supported by numerous vents. Species diversity has been shown to be positively correlated with the number of vents in a spring group (Ponder 1986; Clarke et al., 2013). Vents commonly discharge in a pool that spills over to the tail wetland. Because the conductivity of each spring vent varies, the rate of flow for any given spring vent cannot be determined from excess head alone (Green and Berens, 2013). Spring flow rates are difficult to measure on-ground, however wetland area has been found to provide a surrogate for spring flow rate and can be monitored by remote sensing methods (White and Lewis, 2011, 2012).

The LEB Springs Assessment project has been funded by the Australian Government Department of the Environment through the Office of Water Science to improve the level of knowledge about GAB springs in and near the Arckaringa and Pedirka subregions to inform the Lake Eyre Basin Bioregional Assessment. The focus of this project is on collating existing knowledge about GAB springs and associated wetland habitats, collecting new hydrogeological and ecological knowledge to address knowledge gaps, and assimilating data into hydrogeological and eco-hydrological modelling. The LEB Springs Assessment is being undertaken by the South Australian Government Department of Environment, Water and Natural Resource and the Queensland Department of Science, Information, Technology, Innovation and the Arts and is scheduled for completion in 2015.

Lake Eyre supergroup of springs

GAB springs in the Lake Eyre supergroup are surrounded by extremely arid environments, effectively existing as aquatic islands within a sea of desert. The isolation of springs and their persistence over hundreds of thousands of years of increasing aridity has contributed to high numbers of relict and short-range endemic species (Davis et al., 2013; Gotch 2013b). Fensham et al. (2010) provides a conservation ranking for spring complexes based on the presence of significant species, particularly endemic species, and condition of the wetland environment (Table 21). The highest rank for an individual spring within a complex is applied to the entire complex (Fensham et al., 2010). Within the Lake Eyre supergroup, Coward Springs complex is ranked 1a, and another 64 spring complexes are ranked 1b (Table 21). The nationally endangered endemic GAB spring plant, the Salt Pipewort (Eriocaulon carsonii), is found at Hermit Hill, North West, Old Finniss, Sulphuric, West Finniss, Gosse spring groups/complexes in the Lake Eyre supergroup (Niejalke field data and Fatchen and Fatchen, 1993 in Fensham et al., 2010). Springs in the Lake Eyre supergroup also support three GAB spring endemic crustaceans, two endemic arachnids, 11 endemic molluscs and one endemic flatworm (listed in Fensham et al., 2005; 2010). There are, however, limitations in identifying ecological values by endemism and species presence as not all springs have been comprehensively surveyed, and some biotic groups have been better surveyed and classified taxonomically than others. A recent survey and genetic analysis of invertebrate fauna of Lake Eyre supergroup springs identified 42 new 'evolutionarily significant units', sixteen of which were restricted to only one spring complex (Guzik and Murphy, 2013). This research indicates it is likely that the diversity of short-range endemic species has probably been substantially under estimated. Guzik and Murphy (2013) identified highly vulnerable spring groups and complexes within the Lake Eyre supergroup based on the presence of evolutionary significant units (Table 22).

Many western GAB springs contain microstromatolites which are poorly understood (Gotch 2013b) but are thought to play an important role in the formation of spring mounds (Keppel et al., 2013). A range of waterbirds have been observed at springs with larger wetlands, including four species listed under international treaties (Badman, 1987, 1985).

Table 21 Conservation ranking criteria for Great Artesian Basin spring complexes

Ranking	Criteria	Number of spring complexes in Lake Eyre Supergroup
1a	Contains at least one endemic species not known from any other location.	1
1b	Contains endemic species known from more than one spring complex; or have populations of threatened species listed under State or Commonwealth legislation that do not conform to Category 1a.	64
2	Provides habitat for isolated populations of plant and/or animal species; populations of species not known from habitat other than spring wetlands within 250km.	4
3	Contains intact springs without identified biological values but includes springs that are not highly degraded and may have important ecological values with further study.	27
4	All springs are highly degraded.	3
5	All springs are inactive.	17

Source: Fensham et al. (2010)

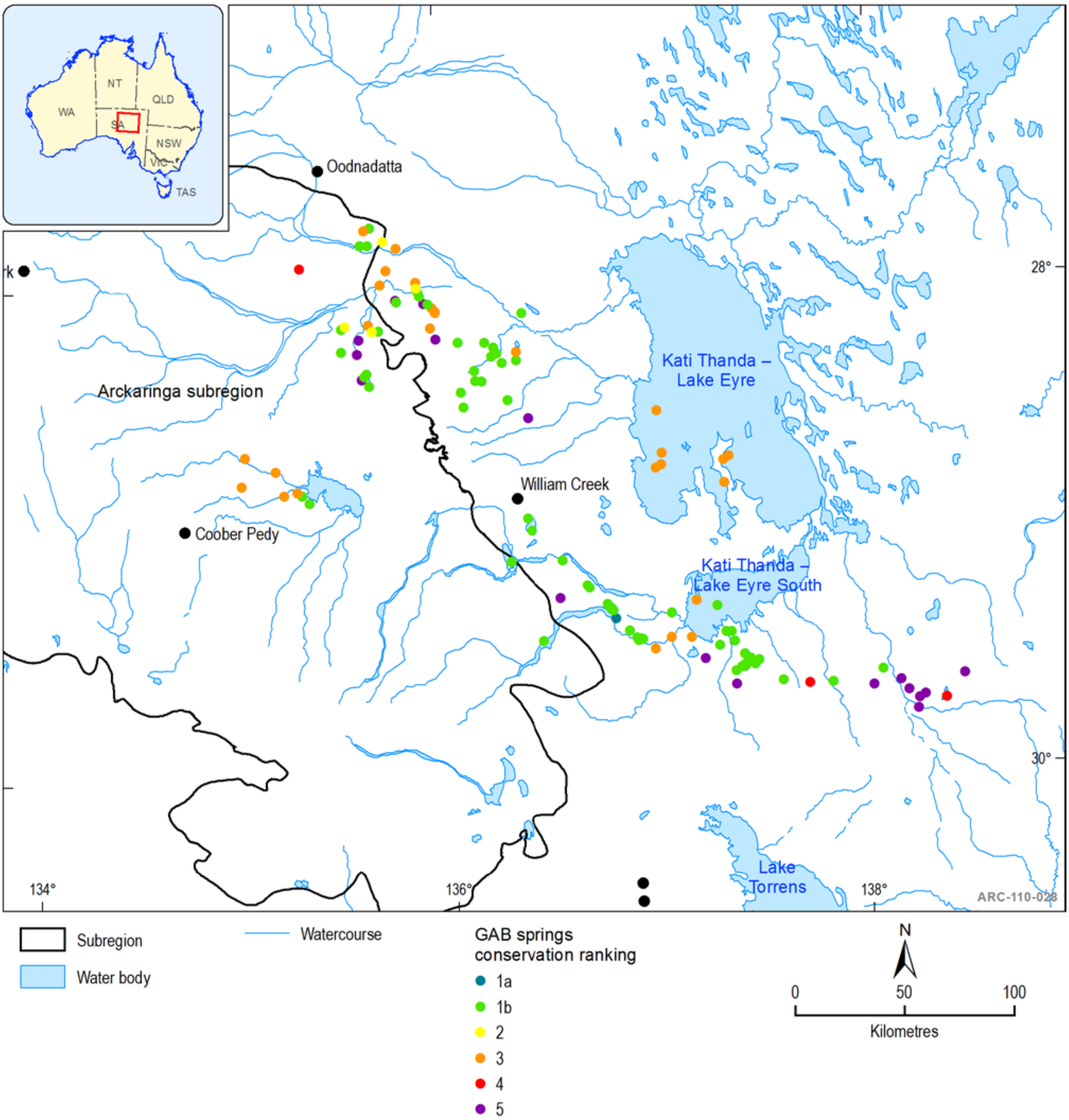

Figure 41 Great Artesian Basin Springs of the Lake Eyre supergroup showing conservation rank (see Table 21)

Table 22 GAB spring groups and complexes within and near to Arckaringa subregion with high invertebrate endemism

Spring complex	Spring groups scoring high or mod high	Total number of evolutionarily significant units
Neales River	NHS, NTF, NTM	17
Francis Swamp	None	4
Beresford Hill	BBH	7
Strangeways	CSS	8
Coward Springs	CBC, CCS, CHS, CJS, CKH	16
Peake	EFS	8
Hermit Hill	HBO, HDB, HHS, HOF, HOW, HSS, HWF	9

Source: Guzik and Murphy (2013, Appendix 2, pp. 138-141)

Recent studies of aquatic invertebrate fauna in GAB springs in SA have found there is very little dispersal between springs (Guzik and Murphy, 2013). Genetic studies of plant species disjunct from their main range in coastal Australia found they are genetically distinct from their major coastal populations, having become isolated a long time ago (Clarke et al., 2013). Genetic differences between populations at different GAB spring groups also indicated there is limited dispersal of these flora between spring groups (Clarke et al., 2013). Some GAB springs are located in watercourses, lakes and on floodplains; these are therefore connected to the surface water system and to one another during flow events (McNeil et al., 2012). This connectivity provides opportunities for obligate aquatic biota to disperse between springs, as well as providing refugia for aquatic biota normally found in surface water ecosystems (depending on the water chemistry of the springs). The Desert Goby (*Chlamydogobius eremius*) is the principal native fish resident within GAB springs of the Arckaringa subregion, however in some springs the Desert Goby has been displaced by the introduced livebearer *Gambusia holbrooki* (McNeil et al., 2011a, 2012). The connectivity of GAB springs and surface water systems is not formally recorded (see section 1.1.6). Bore drain wetland ecosystems have low ecological values, with only a reduced diversity of GAB spring flora that does not include the unique relict and endemic species found in natural GAB spring wetlands (Fensham and Fairfax, 2003; Gotch 2013b). Bore drain fish communities are typically depauperate and dominated by Gambusia holbrooki (e.g. One Mile, Old Peake, Big Blythe) (McNeil et al., 2012). Some bore drain wetlands are, however, valued by the community, including residents and tourists (Phipps 2008) and some may possibly have been constructed to enhance the flow of pre-existing spring vents that may have held cultural significance (Louise Hercus pers. comm. 2013).

1.1.7.3.4 Non-Great Artesian Basin groundwater-dependent ecosystems

Several non-GAB groundwater-dependent ecosystems (GDE) occur on the eastern side of the Davenport and Denison Ranges; these include mountain block spring systems such as Tarlton Springs and Edith Springs. These sites are very poorly understood, with very little data for them. Surveys undertaken by Gotch (2013a) have mapped some of them as part of the wider GAB spring mapping and they have had their spider fauna sampled (Gotch unpublished data). Other less obvious GDEs include some ephemeral waterholes along creeks and rivers of the Neales catchment, discussed below.

1.1.7.3.5 Lake Eyre Basin surface water dependent aquatic ecosystems

Function of Lake Eyre Basin river systems

In contrast to the GAB and its dependent aquatic ecosystems, the variability, ephemerality and salinity of the surface water systems in the Arckaringa subregion has limited their potential for development, resulting in the hydrology of these systems being largely unaltered. Consequently, all catchments of the LEB have been assessed to be in good health (at the reach scale), based on the available monitoring data (LEBSAP, 2008). The conservation risk of the LEB's ecosystems have been assessed to be of least concern according to IUCN criteria (Pisanu et al. 2014) and few aquatic species are rated as vulnerable or endangered (Gillam and Urban, 2013). This contrasts to other major drainage systems in Australia, (such as the Murray Darling Basin (MDBC, 2008)), and many international river systems, making the LEB unique nationally and internationally (LEBSAP, 2008). The maintenance and protection of refugia (e.g. waterholes) and processes (such as flooding and connectivity) are critical to ensuring the ongoing persistence of species and ecosystems in arid-zone rivers (Costelloe and Russel, 2014). This will enable species within these systems to persist through the dry phases (resistance) and disperse and rebuild populations during wet periods (resilience) (McNeil et al., 2011a).

The ecological processes occurring in the LEB river systems are driven by highly variable hydrology and climate, and the hydrological and geomorphological processes that determine the range of aquatic ecosystem habitats and the connectivity of habitats. Ecological processes are influenced by high levels of disturbance and variability. To survive in the LEB, species have evolved life strategies that enable them to survive long periods of little to no flow, harsh environmental conditions, and unpredictable flow events (Arthington and Balcombe, 2011). Large floods trigger spectacular booms in biotic production in the LEB (e.g. Kingsford et al., 1999; Balcombe and Arthington, 2009), although the booms in the western catchments are not as spectacular compared with the larger eastern catchments (Reid et al., 2004; Kingsford and Porter, 2008). However, the periods of no flow are as critical in dictating the biotic assemblages that exist in arid environments (Arthington et al., 2005; Rolls et al., 2010). The longer periods of no flow last, the fewer submerged habitats exist and the smaller they become, leading to higher densities of biota, and the more saline and oxygen depleted the remaining habitats become (Arthington and Balcombe, 2011). Species must be able to survive by having desiccation resistant life stages (i.e. survive as eggs or seeds in dry soil), migrating to other areas, becoming temporarily locally extinct and re-populating during the next flow events, or be able to survive in refugia. During extended droughts when obligate aquatic species exist only in Ark refuges, they are completely reliant on those refugia and vulnerable to catchment-wide extinction should the integrity of the refugia be impacted (McNeil et al., 2011a). Local flow events sustain species which are entirely dependent on permanent water by freshening refuges, extending their duration and providing short-term connectivity that enables migration between nearby refugia. While low and no flow phases exert stresses on the biota of aquatic ecosystems, LEB biota have adapted to these unique conditions over millennia of increasingly harsh environmental conditions (Davis et al. 2013).

Because of the extreme fluctuations in flood and drought that drive the boom and bust ecology of the LEB, and associated fluctuations in species populations (Bunn et al., 2006; Kingsford et a., 1999; Balcombe and Arthington, 2009), it is difficult to determine whether ecosystems are healthy or impacted (Sheldon, 2005) and the extinction risk status of species (Costelloe and Russel 2014. During extended droughts when obligate aquatic species exist only in Ark refuges, they are completely reliant on those refugia and vulnerable to catchment-wide extinction should the integrity of the refugia be impacted (Arthington et al., 2005; Costelloe and Russel, 2014). Indicators of 'condition' (e.g. species diversity, fish health, riparian vegetation health, water quality) in refuges decline as the waterbody evaporates and animals converge on the waterholes for food and water (Sheldon, 2005; Arthington et al., 2005). When floods occur, the diversity, abundance and health of flora and fauna increases (e.g. Costelloe et al., 2004; Balcombe and Arthington, 2009; Arthington and Balcombe, 2011).

In the LEB, maintaining the health of the rivers and wetlands is an obligation under the LEB Intergovernmental Agreement and therefore assessments of the health of rivers and wetlands are required. However, the extreme spatial and temporal variability found throughout the LEB (Bunn et al., 2006; Kingsford et a., 1999), coupled with data deficiencies and an understanding of the system functions that is still evolving, have provided challenges to developing a method for assessing river health (Sheldon, 2005). Therefore, a Strategic Adaptive Management (SAM) approach has been adopted that incorporates Thresholds of Potential Concern (TPCs) to assess river health (Thoms et al., 2009). The TPCs describe the limits of acceptable change beyond which the systems shift to an 'undesirable' state (Thoms et al., 2009) and are therefore suited to systems that are still in a 'desired' state. The LEB Rivers Assessment (LEBRA) monitoring program involves annual monitoring of a primary set of primary indicators: fish, water quality, and hydrology (DSEWPAC 2011, 2012, 2013). Within the Arckaringa subregion, the Neales River catchment is the only catchment to be included in the LEBRA. LEBRA monitoring data are summarised in Cockayne et al., (2012, 2013) but has not been interpreted in terms of condition reporting.

Within the Arckaringa subregion, only the Neales catchment has been the subject of any assessment and monitoring of the aquatic biota through the ARIDFLO project (Costelloe et al., 2004), LEBRA (McNeil et al., 2008, 2009; Cockayne et al., 2012, 2013), (see Figure 42) Critical Refugia Project (McNeil et al., 2011a) and EPA monitoring (Goonan et al., 2003; EPA 2012). There is limited spatial distribution in the data and no time series data for the biota of surface water-driven aquatic ecosystems in other catchments of the Arckaringa subregion.

The LEB Rivers Monitoring (LEBRM) project has been funded by the Australian Government Department of the Environment through the Office of Water Science to improve the level of knowledge about surface water dependent aquatic ecosystems in and near the Arckaringa and Pedirka subregions to inform the Lake Eyre Basin Bioregional Assessment. The focus of this project is on collating existing knowledge; collecting new hydrological, geomorphological and ecological knowledge; and hydrological modelling and hydro-ecological analysis. The LEB Rivers Monitoring project is being undertaken by the South Australian Government Department of Environment, Water and Natural Resource and is scheduled for completion in 2015. The Goyder Institute for Water Research is undertaking an LEB project that builds on the LEBRM and LEBRA projects to develop a suite of indices to inform management decisions and condition monitoring.

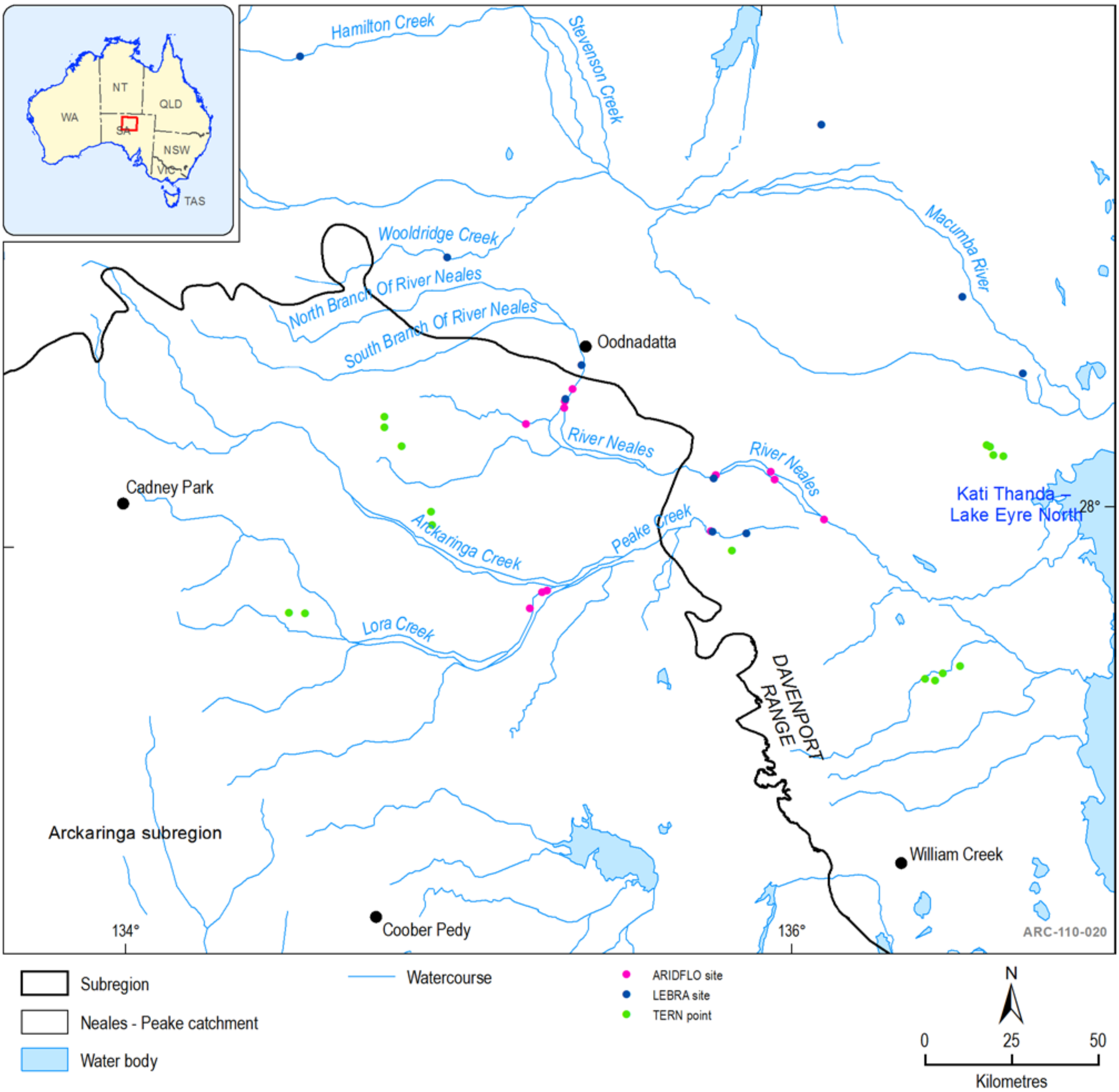

Figure 42 Location of aquatic ecosystem monitoring sites

Neales catchment

The Neales catchment is highly ephemeral, with only one known potentially permanent fresh waterhole, Algebuckina Waterhole. Ten native and one introduced fish species (*Gambusia holbrooki*) have been found in the Neales catchment (Costelloe et al., 2004; McNeil et al., 2011a; Cockayne et al., 2013; Table 23). None of the native species are rated as threatened nationally or at a state level, however all are rated as regionally rare (Gillam and Urban, 2013). These species are a subset of those species found in the eastern catchments and it is assumed that there may have been some migration between catchments across Kati Thanda – Lake Eyre during extremely large simultaneous flood events in the past, but that Kati Thanda – Lake Eyre is generally too salty when it fills for this to occur. Genetic studies are required to determine the relationship between the Neales catchment fish population and populations in other LEB catchments. Current genetic programs being undertaken at Monash and Flinders

Universities may provide insight into these patterns of Basin scale connectivity. Distinct assemblages of biotic groups occur in the Neales catchment compared with the larger eastern catchments of the Cooper and Georgina-Diamantina associated with higher ephemerality and higher salinities (Costelloe et al., 2004; Madden et al., 2002). For fish, the community comprises a subset of the more hardy species found in the eastern catchments, however the genetic linkages between populations in separate catchments is currently unknown.

Table 23 Riverine fish fauna found of the Neales catchment

Species	Common name
Amniataba percoides	Barred Grunter
Bidyanus welchi	Welch's Grunter^
Chlamydogobius eremius	Desert Goby^
Craterocephalus eyresii	Lake Eyre Hardyhead^
*Gambusia holbrooki**	Eastern Gambusia*
Leiopotherapon unicolour	Spangled Perch
Macquaria ambigua s-sp. B	Lake Eyre golden perch^
Melanotaenia splendida tatei	Desert Rainbow Fish^
Nematalosa erebi	Bony Bream
Neosilurus hyrtlii	Hyrtl's Catfish
Porochilus argenteus	Silver Tandan

Source: Cockayne et al., 2013 Appendix A, updated from Unmack and Wager (2000). Exotic/introduced species are indicated*, endemic to the LEB are indicated^

During periods of extended drought conditions, Algebuckina Waterhole supports the entire fish diversity of the Neales catchment (McNeil et al., 2011a, McNeil and Schmarr, 2009), providing an ‘Ark refuge’ (Robson et al., 2008); it is therefore of critical ecological value (Costelloe and Russel 2014) (Figure 43). Water quality monitoring has shown that Algebuckina and Peake Crossing waterholes come under considerable pressure during dry periods, evidenced by nutrient enrichment and low macroinvertebrate numbers (EPA, 2013). When sufficient rainfall allows for in-channel connectivity to occur, fish species radiate out from Algebuckina to recently inundated waterholes. Fish establish populations in progressively distant habitats following predictable patterns of species resilience, with more resilient species establishing first, followed by less resilient species (McNeil and Schmarr, 2009; Kerezsy et al., 2013). Saline waterholes also persist through droughts; however these are only able to support highly tolerant species and fit the description of ‘polo club refuges’ (Robson et al., 2008; McNeil et al., 2011a). In addition, at least two spring-fed pools in the Peake Creek adjacent to Freeling Springs are also likely to serve as permanent refugia for five of the smaller bodied species, but not for the entire riverine community (McNeil et al., 2012). It is probable that stable and shallow bore and spring habitats also serve as key refuges for the pest fish Gambusia holbrooki that, during periods of connectivity, seed the riverine ecosystem with new recruits (McNeil and Costelloe, 2011). It appears, however, that the combination of a natural and variable flow regime and an intact native fish fauna prevent the dominance of Gambusia through the broader riverine ecosystem (Puckridge et al., 2000; McNeil et al., 2012).

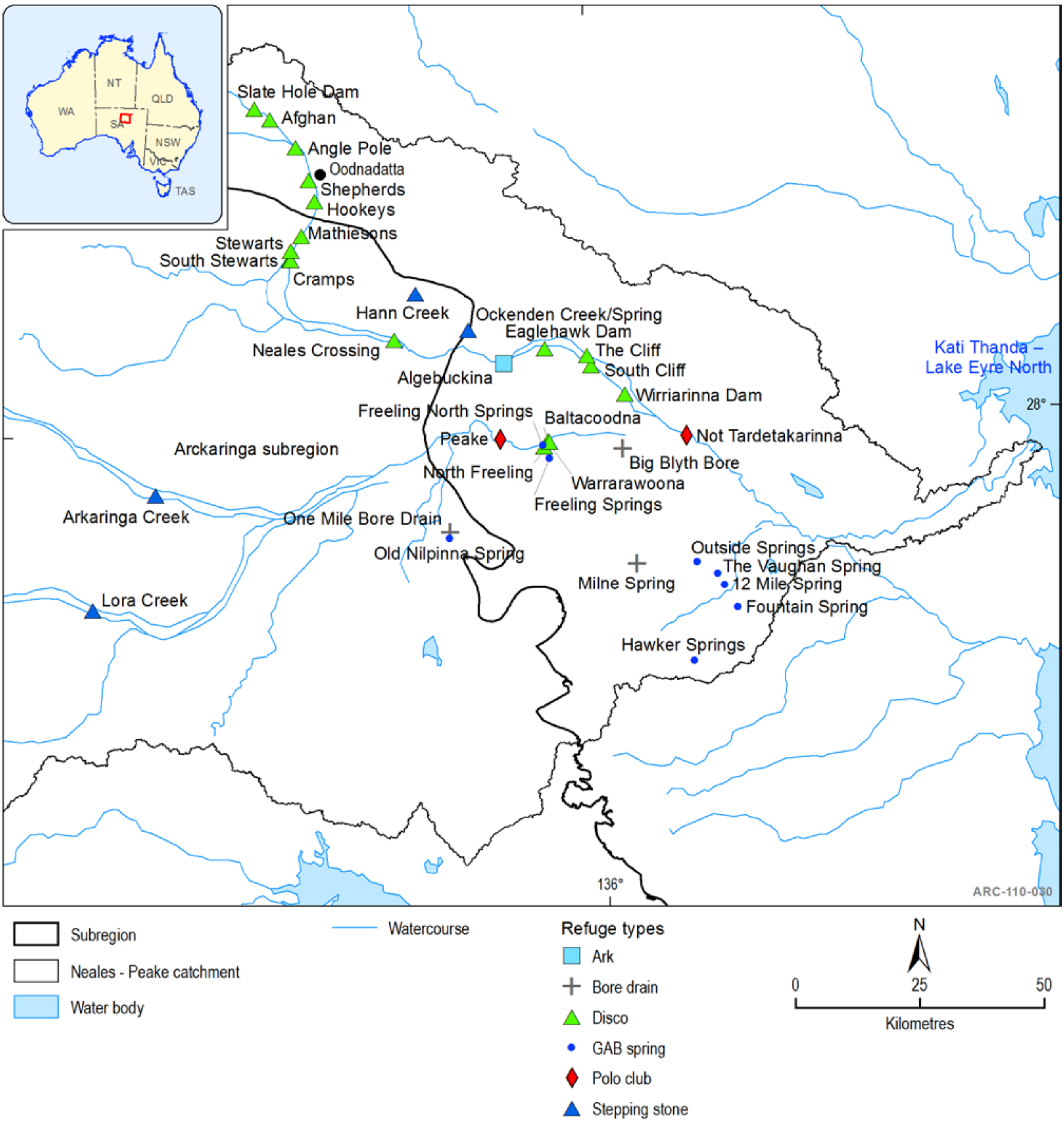

Figure 43 Distribution of aquatic refuge types in the Neales catchment (note that not all GAB springs and bores shown are hydrologically connected to the surface water system)

Other refuge types within the Neales catchment are 'disco' refuges (non-permanent waterholes where fish rebuild populations during extended wet periods) and 'stepping stones' – temporary habitats used during migration but insufficient to support populations for any extended period (McNeil et al., 2011a). Many farm dams have been sampled and their fish assemblages are representative of natural disco-type refugia (McNeil et al., 2009), however, their role as refugia is not known.

While the Neales catchment has been found to support a range of waterbird species, the diversity (44 species) and abundance of waterbirds was the lowest of the SA LEB reaches studied in

ARIDFLO, probably due to the relatively small area of suitable habitat. However, NPWSA rated bird species were found: Freckled Duck, Brolga (both vulnerable), and Blue-billed Duck (rare) (Reid et al., 2004). Floods in western catchments, including the Neales catchment in 2000, contributed to partial filling of Kati Thanda – Lake Eyre which resulted in a major breeding event for Banded Stilts (*Cladorhynchus leucocephalus*) (Reid et al., 2004), a vulnerable (NPWSA) migratory waterbird.

Other Lake Eyre Basin catchments

The aquatic ecosystems and their species composition in other catchments of the LEB in the Arckaringa subregion are poorly documented. Spangled Perch (*Leiopotherapon unicolor*), Desert Goby (*Chlamydogobius eremius*), and Lake Eyre Hardyhead (*Craterocephalus eyresii*) have been observed at road crossings in Margaret Creek and Stuarts Creek (McNeil pers. com. 2013; SARDI unpublished data), indicating permanent refugia must exist in this catchment. It is likely that GAB springs on Billa Kallina Station may support permanent pools upstream of the crossing (Lloyd Sampson pers. com., 2013); further survey work is required to confirm if this is the case. There are also GAB springs in close proximity to the watercourses in the Warinner Creek catchment, but nothing is documented about the aquatic ecology of this catchment.

Floodplain and swamp ecosystems are considered to be under threat because their high productivity and presence of water results in heavier grazing pressure by stock and pest animals (DEH & SAAL NRMB 2009).

The endorheic Lake Cadibarrawirracanna catchment is included within the LEB, but is not hydrologically connected with Kati Thanda – Lake Eyre. Nothing is documented about the aquatic ecosystems of this catchment other than from one-off biological surveys; however it is likely that the lake may support biota tolerant of extreme drought and salinity and possibly migratory waterbirds when it occasionally fills.

1.1.7.3.6 Surface water dependent aquatic ecosystems outside the Lake Eyre Basin

In the part of the subregion that is outside the LEB, there are only very minor surface water dependent aquatic ecosystems that are poorly documented. These consist of dune lakes and depressions in the Great Victoria Desert IBRA bioregion and minor drainages and gilgais and cracking clay plains in the Stony Plains IBRA bioregion. These systems only flow or fill very occasionally from local rainfall and are too shallow to hold water for long, however they support some desert fauna such as frogs, lizards and zooplankton. Flora species adapted to survive in these conditions provide resources for fauna species. These lakes are also critical breeding habitat for burrowing frogs and essential habitat for nomadic waterbirds. The cracking clay plains and gilgai systems are a conservation priority in the Stony Plains as they support nationally threatened fauna, the Plains Rat (*Pseudomys australis*) and Thick-billed Grasswren (*Amytornis textilis modestus*) (DEH & SAAL NRMB, 2009). There is little hydrological connectivity between the aquatic ecosystems outside the LEB.

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