Australian Government

BIOREGIONAL ASSESSMENTS

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

Context statement for the Pedirka subregion

Product 1.1 for the Pedirka 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

Eringa waterhole in the Macumba catchment, SA. April 2013

Credit: Catherine Miles (Miles Environmental Consulting)

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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.

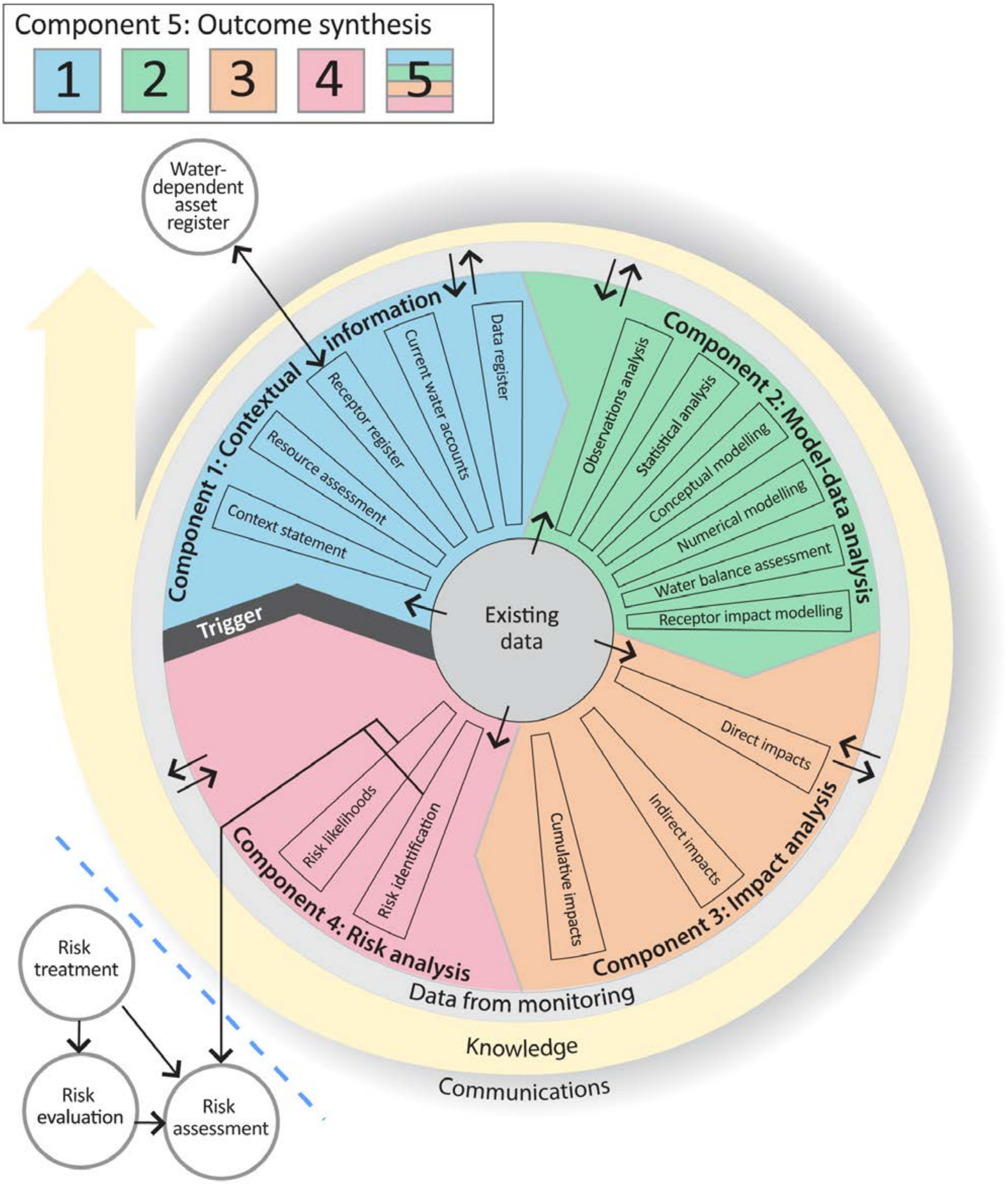

Figure 1 Schematic diagram of the bioregional assessment methodology

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.

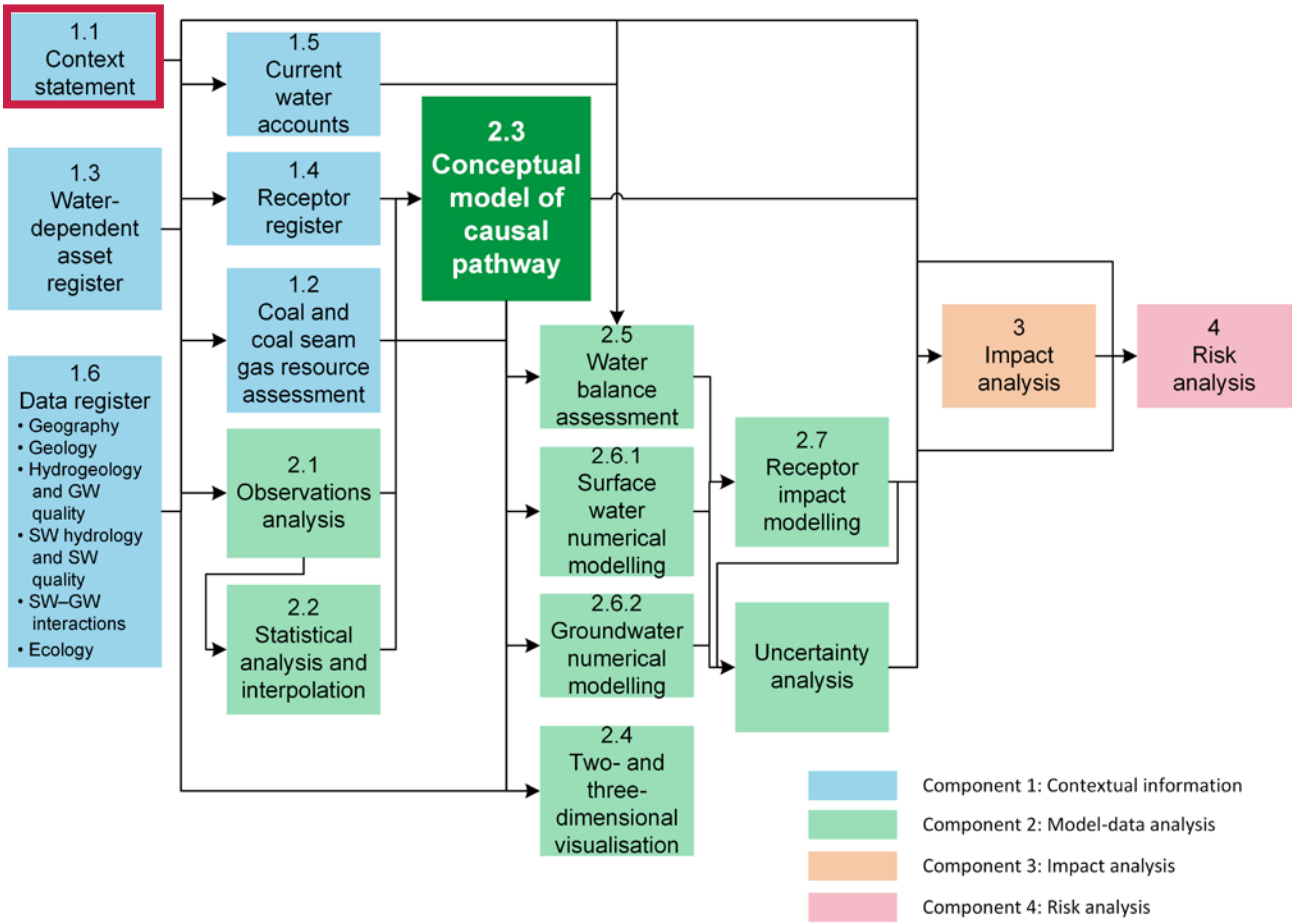

Figure 2 The simple decision tree indicates the flow of information through a bioregional assessment

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' column[b]. 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 Pedirka 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 Pedirka 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	PDF, HTML
	2.5	Water balance assessment	2.5.2.4	Cross-reference
	2.6.1	Surface water numerical modelling	4.4	Not produced
	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 Pedirka subregion	3-4	Impact analysis	5.2.1	PDF, HTML
Component 4: Risk analysis for the Pedirka 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.
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- 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 9 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 Pedirka 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 Pedirka 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 Pedirka subregion is located in SA and the NT (Figure 4), and is defined by the extent of the Pedirka geological basin (see Section 1.1.1 for further detail). The subregion spans an area of about 75,760 km^2 and is located entirely within the Kati Thanda – Lake Eyre surface drainage catchment.

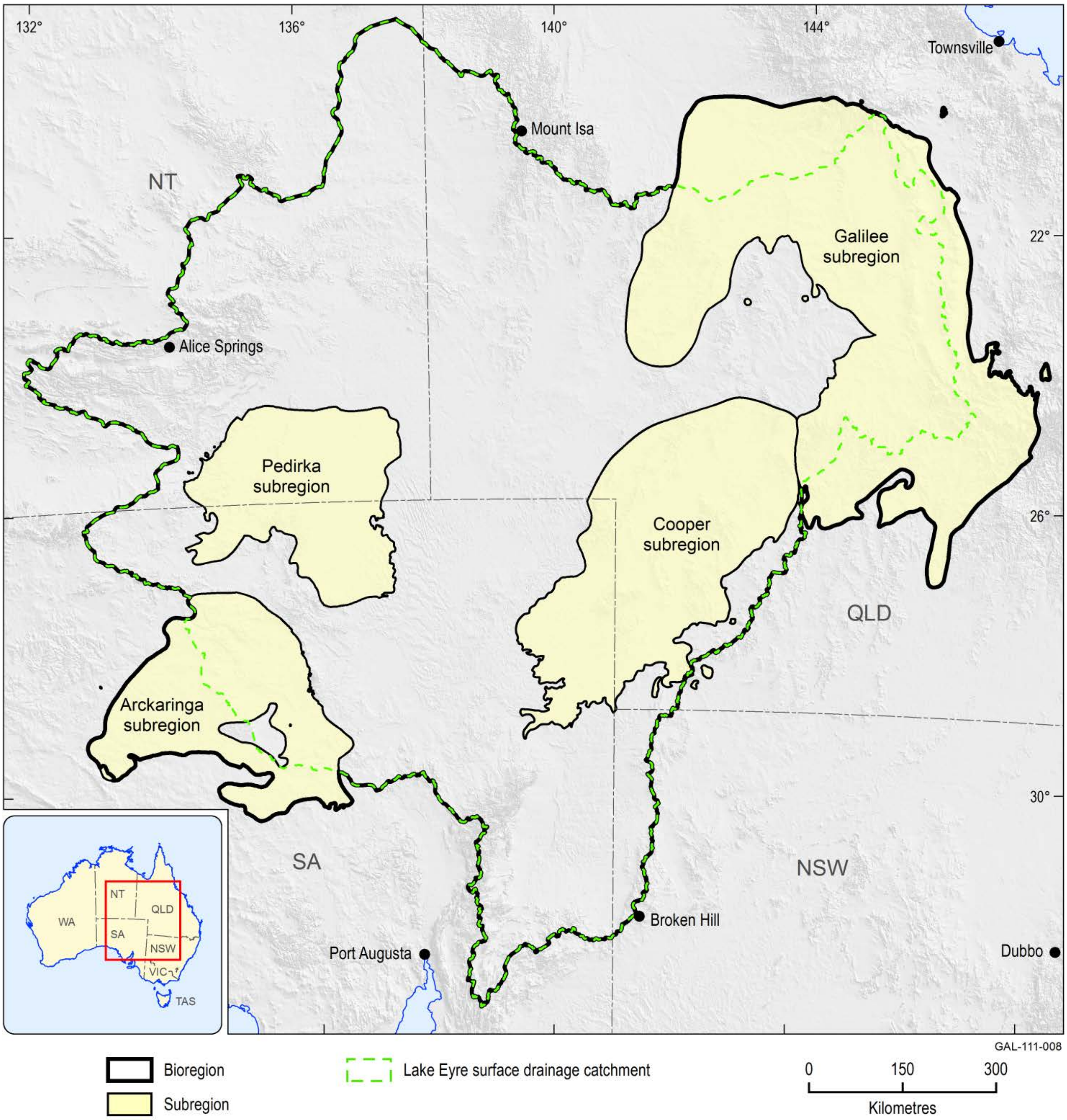

Figure 3 Lake Eyre Basin bioregion and subregions

Figure 4 Pedirka subregion showing surface water catchments

1.1.2 Geography

Summary

The topography of the Pedirka subregion (the subregion) is generally flat lying and largely covered with sandy deserts, gravelly 'gibber' plains and tablelands that support vegetation adapted to arid conditions. The subregion also has river and creek systems that only flow occasionally and form gently sloped valleys. Wind-derived sand dunes also provide notable variations in topography. The northern and western margins of the Pedirka Basin are defined by highlands and plateaux.

The Pedirka subregion falls within both the NT and SA, with a larger portion situated within the NT. The area in which the Pedirka subregion occurs is sparsely populated. Finke (Aputula) is the largest settlement with an estimated population of 240 people, with the remaining population spread between pastoral homesteads and Indigenous outstations. The Traditional Owners and custodians within the region include the Lower Southern Arrente, Andegerebenha, and Wangkangurru peoples.

Pastoral enterprise is the predominant land use in the region, with tourism also being important. A number of Indigenous free holdings can be found in the vicinity of the Pedirka subregion in the NT, while a large portion of the north-western Pedirka subregion is vacant Crown Land. The SA portion of the subregion is covered by the Witjira National Park, the Simpson Desert Recreational Reserve, and pastoral stations.

The lack of surface water resources requires that groundwater is used as the principal water supply for the subregion, with the vast majority of this water sourced from the Great Artesian Basin (GAB). The climate of the Pedirka subregion is arid; rainfall being infrequent and reliant on northern-derived monsoonal precipitation.

1.1.2.1 Physical geography

The Pedirka subregion is located centrally over the SA-NT border (Figure 5), approximately 860 km north north-west of Adelaide and 160 km south of Alice Springs. The subregion area is based on the subsurface extent of the Pedirka Basin, which covers an area of approximately 71,000 km^2.The topography of the Pedirka subregion is subdued with the predominant landscape feature being sandy deserts, gravelly 'gibber' plains and tablelands that support perennial grass and sparse chenopod, samphire or saltbush shrubland vegetation. In the centre and east of the basin, longitudinal dunes of the Simpson Desert can extend for several hundred kilometres and attain heights of up to 40 m (Ambrose, 2006). Anastomosing channels that form wide, gently sloped valleys, swales and floodplains provide much of the observed topographic variability.

The northern and western margins of the Pedirka subregion are defined by highlands and plateaux of the Newland and Musgrave Ranges, and Arunta Block (Figure 5). The tallest peak in the Musgrave Ranges is Mount Woodroffe (1435 m); Keppel et al., (2013) suggests that the topographic elevation of the ranges relative to the basinal areas provides gravitational potential to drive groundwater flow within the subregion. Of particular importance is the Dalhousie-McDills

Ridge which forms a low rise that transects the Pedirka subregion from south to north. Aeolian-driven deflation is described by Mabbutt (1977) as an important process shaping the physiology of the region; longitudinal sand dunes in the plains and lunette dunes in the vicinity of playas provide important topographic variance.

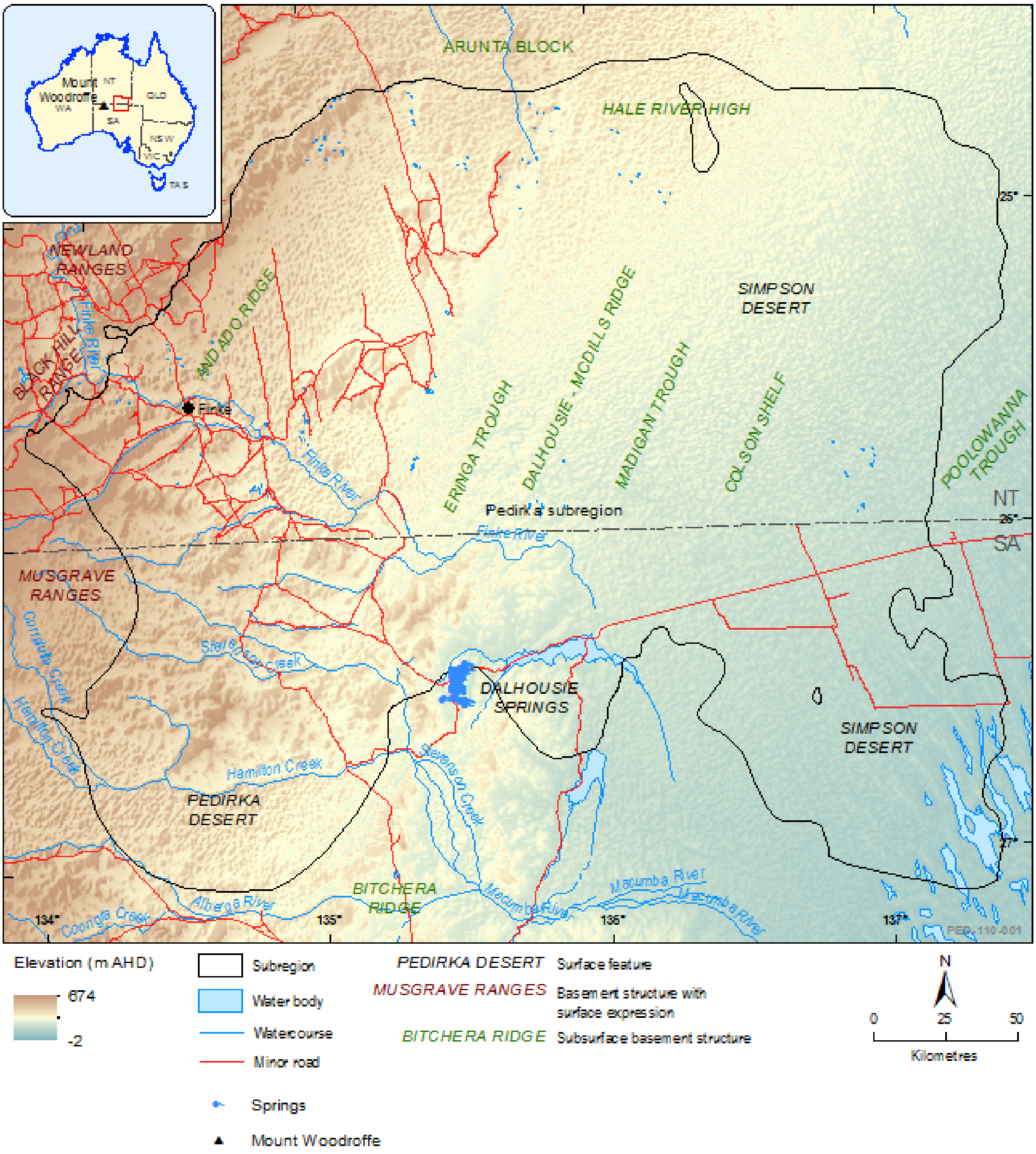

Figure 5 Physical geography of the Pedirka subregion (location of Mt Woodroffe shown in inset map)

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

1.1.2.2.1 Population

The Pedirka subregion is sparsely populated. The Australian Bureau of Statistics (ABS, 2007) estimated the population of the Peterman-Simpson area, which encompasses the Pedirka subregion, to be 2975 with a population density of less than 0.02 people per square kilometre. Finke Community (also known as Aputula) is the largest settlement with an estimated population of 240 people, with the remaining population spread between pastoral homesteads and Indigenous outstations (Fulton, 2012). The largest population centre near the Pedirka subregion is Alice Springs, located approximately 150 km to the north-west. The Traditional Owners and custodians within the region include the Lower Southern Arrente, Andegerebenha and Wangkangurru peoples. The region contains numerous sites of Indigenous significance, reflective of a long history of occupation. Such sites may include middens, quarries, worksites, campsites and burial sites.

1.1.2.2.2 Land use

Pastoral enterprise represents the predominant land use in the subregion (Figure 6). The pastoral industry was established soon after European exploration and has a primary focus of beef-cattle production. Tourism is important to the subregion, although it is largely concentrated along the main transport routes, towns and conservation parks (Smerdon et al., 2012). A number of conservation parks are located in the vicinity of the Pedirka subregion, including the Witjira National Park (NP), Simpson Desert Conservation Park (CP), Mac Clark (Acacia Peuce) Conservation Reserve, and Simpson Desert Regional Reserve. In addition, nature tourism, bush walking, wildlife, four wheel drive experiences, camping, and Indigenous tourism all occur throughout the region. A number of Indigenous freehold lands can be found in the vicinity of the Pedirka subregion in the NT, including the Pmer Ulperre Ingwemirne Arletherre, Pmere Nyente and Aputula Aboriginal Land Trusts. A large portion of the north-eastern Pedirka subregion is vacant Crown Land (Smerdon et al., 2012). There are no active mining operations in the Pedirka subregion and the only mining of historical significance was the Rumbulara Ochre mines, which operated commercially from 1941 to 1951 (Wells et al., 1966). There is a long history of oil and gas exploration within the region, dating back to the 1960s, but no commercial development of oil or gas.

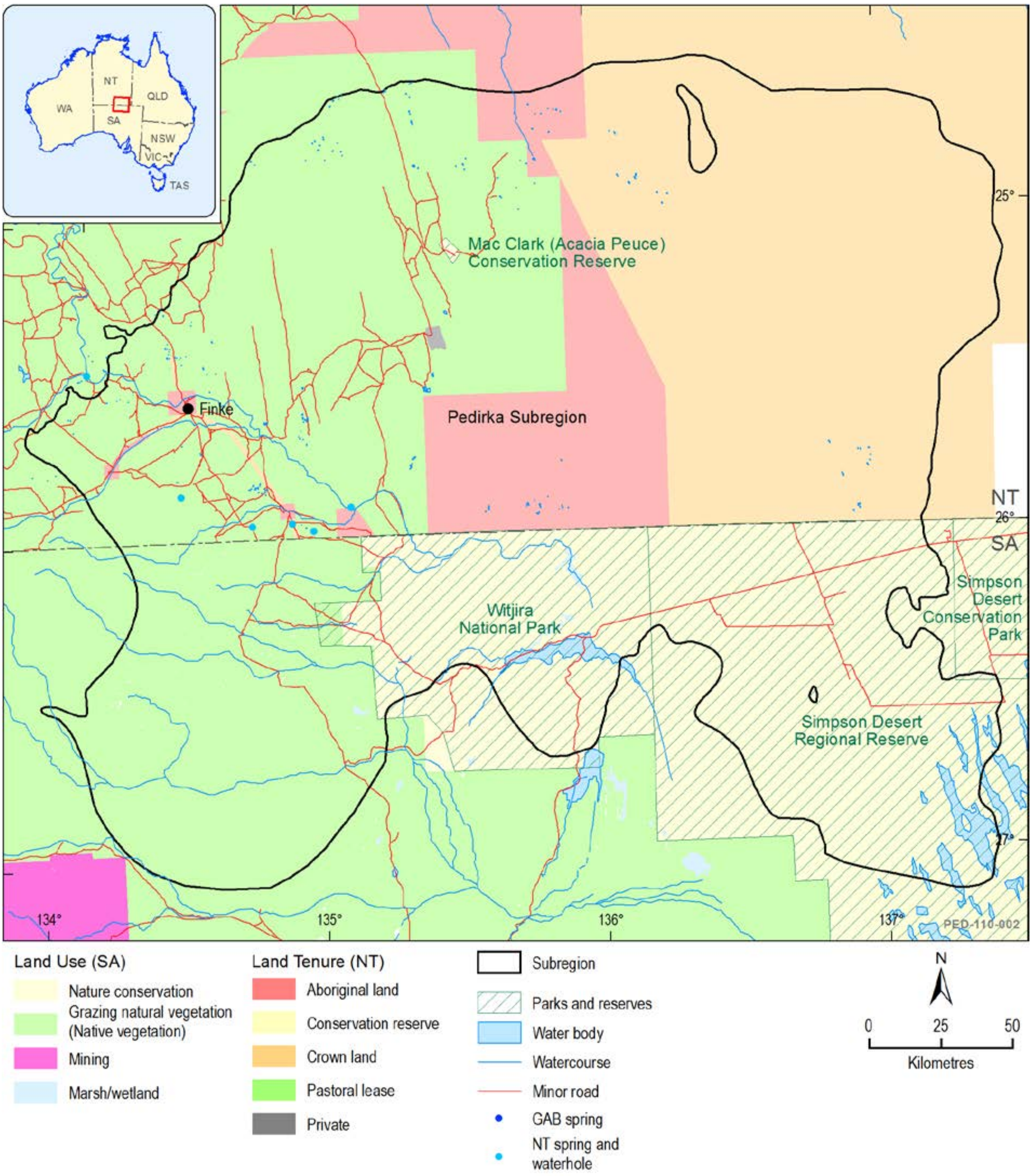

Figure 6 Land use and human geography of the Pedirka subregion

1.1.2.2.3 Water use

The Pedirka subregion has an arid climate and surface water is not relied on as a water supply beyond the harvesting of rainwater for domestic purposes. Environmentally, irregular flood events play an important role with respect to maintaining arid ecosystems and providing recharge pulses to the groundwater system where floodwaters flow over aquifer outcrops (Fulton, 2012).

Groundwater represents the principal water resource in the subregion. Fulton (2012) states that water extraction from within the NT GAB water control district was estimated at 3470 ML/year, with 2210 ML/year currently sourced from the Great Artesian Basin (GAB) and the remaining 1260 ML/year sourced from other aquifers including those within the Pedirka Basin.

With respect to groundwater extraction from the Pedirka Basin, groundwater extraction occurs exclusively from the Crown Point Formation where the aquifer is used as a source of stock water for pastoral enterprises and provides a water supply for several Indigenous outstations. It is estimated that of the 28 wells constructed within the Permian aquifer, 13 are currently operational and 15 have been abandoned or decommissioned. Well depths range from 12 metres below ground level (mBGL) to 192 mBGL and groundwater depth from 5 to 159 mBGL. Water usage within the SA portion of the subregion is largely limited to pastoral usage and tourism.

1.1.2.3 Climate

The climate of the Pedirka 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 36 °C and 39 °C, although daily maximums are regularly above 40 °C. In contrast, the minimum peak-winter monthly temperatures range from 5 °C to 8 °C, although daily minimums may drop below 0 °C. Monthly averages are shown in Figure 7.

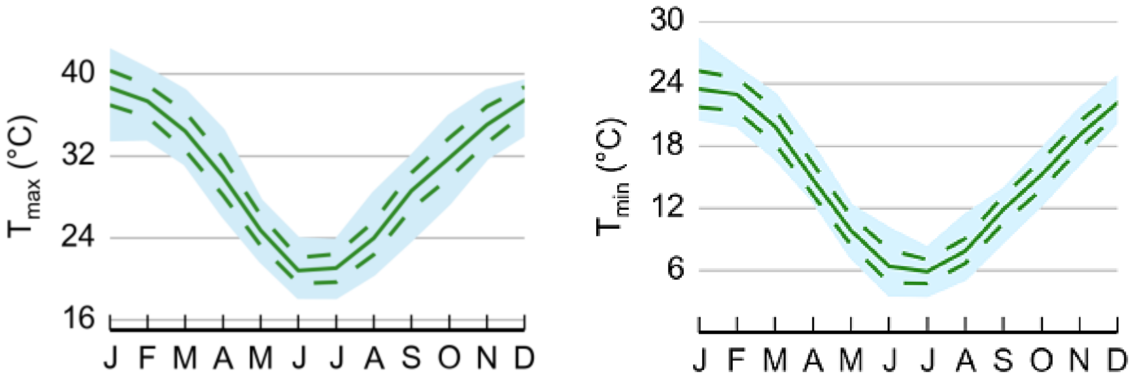

Figure 7 Monthly maximum and minimum temperatures

Source: Bioregional Regional Assessment (2014)

Mean annual rainfall varies between 140 mm in the east of the subregion to in excess of 260 mm to the west at the foot of the Musgrave Ranges (Figure 8). Averaged across the region, the long term mean annual rainfall is 161 mm. The variability of rainfall over the catchment 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 Pedirka 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.

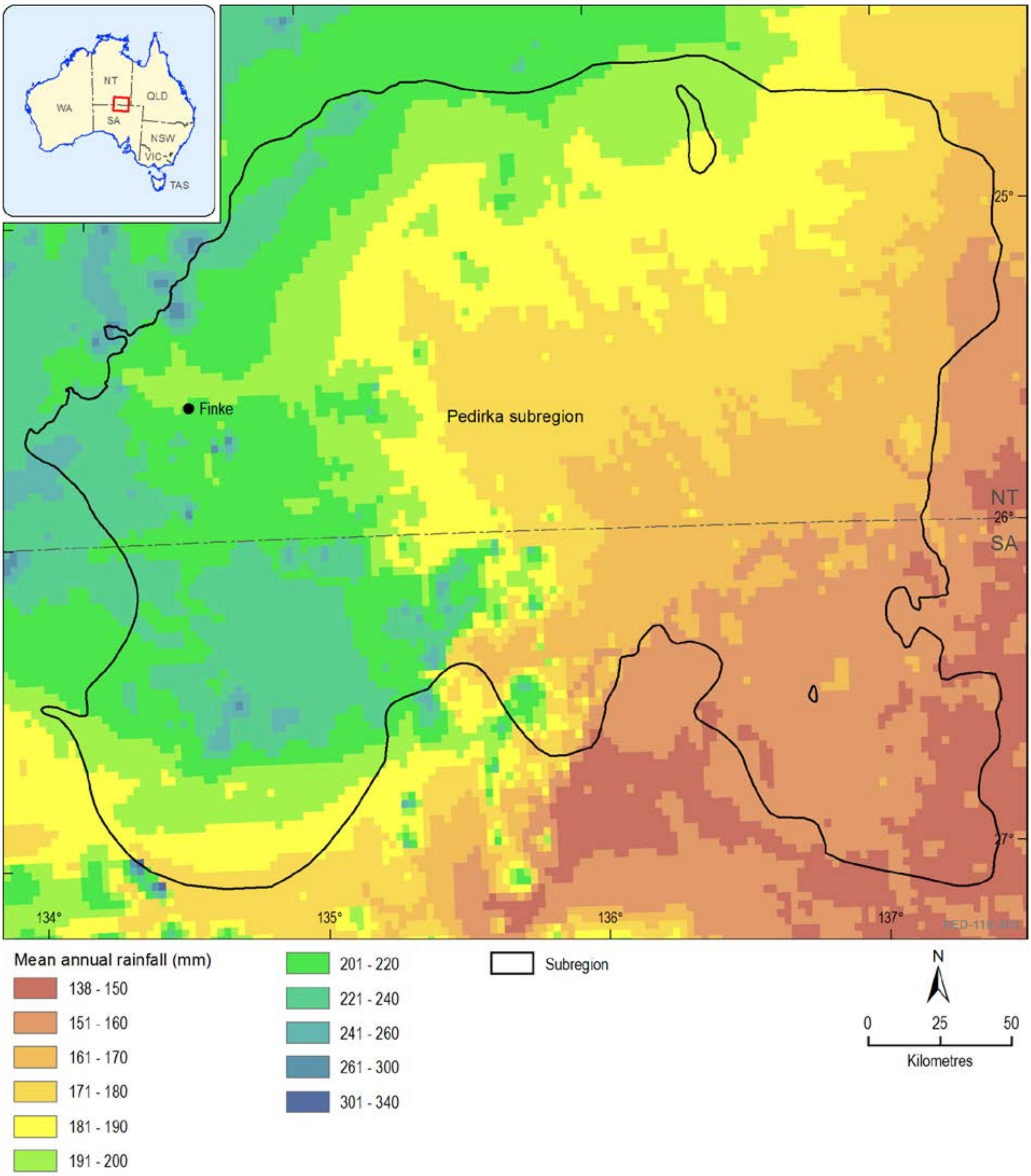

Figure 8 Mean annual rainfall in the Pedirka subregion

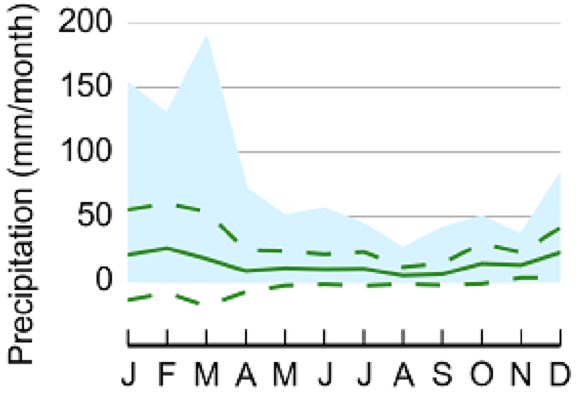

Figure 9 Monthly precipitation depths

Source: Bioregional Regional Assessment (2014)

Table 3 shows rainfall summaries for selected sites in the Pedirka 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, Andado Station, receives over 46% of its annual total in the summer months (December – February). Further south, Eringa received around 40% of annual fall in the same period, and the southernmost site, Hamilton Station, only 29% 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 Pedirka subregion

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
015595 Andado Station 1968 – present; Elevation: 194 m													
Mean rainfall (mm)	17.6	25.1	14.4	6.3	5.7	9.8	6.0	3.6	3.3	10.9	12.3	20.5	136.6
016012 Eringa 1931 – 1975; Elevation: 223 m													
Mean rainfall (mm)	11.0	22.5	6.3	10.7	9.9	9.5	5.3	9.4	7.4	7.5	3.9	12.1	113.4
016083 Hamilton Station 1930 – present; Elevation: 160 m													
Mean rainfall (mm)	15.5	15.3	28.0	16.7	11.0	10.2	9.3	7.6	5.4	7.6	11.8	12.3	151.2

As seen in Figure 11 and Figure 12, mean annual point potential evapotranspiration (PET) increases on a north-east gradient, with pan evaporation increasing west to east. PET varies from 2715 mm in the southwest to 2840 mm in the north-east. Pan evaporation ranges from 2930 mm to 3420 mm from west to east.

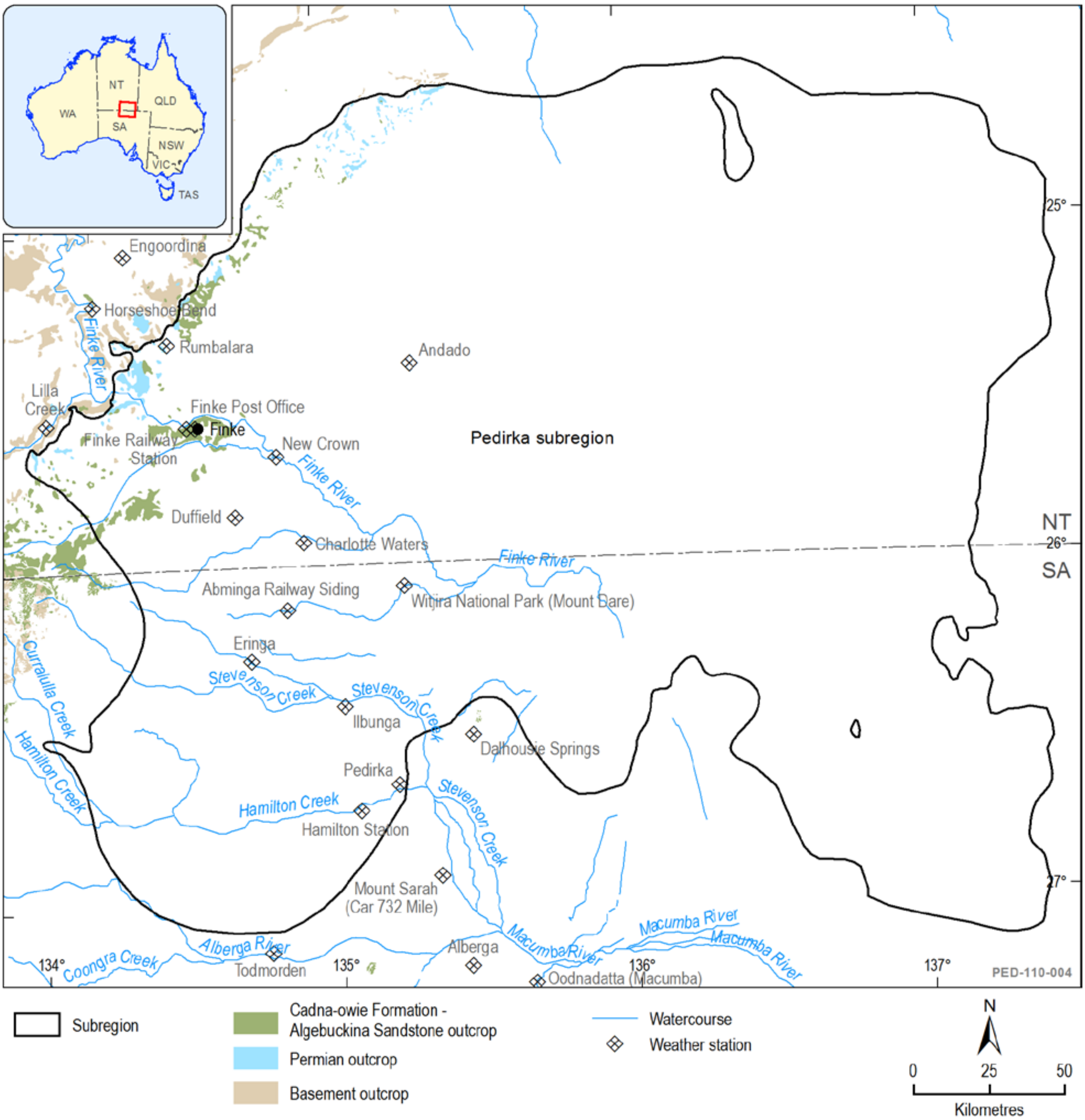

Figure 10 Location of weather monitoring stations in the Pedirka subregion

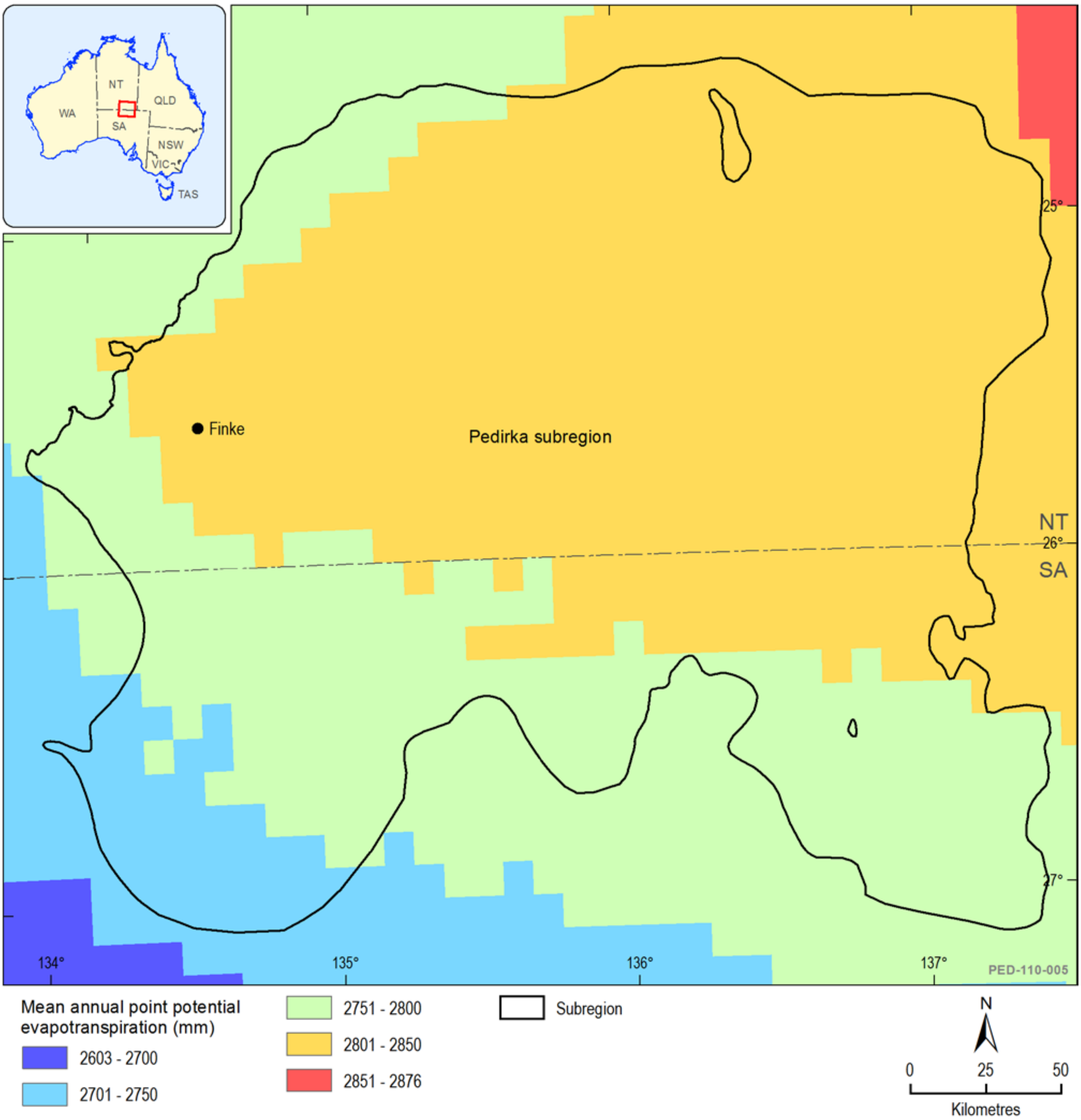

Figure 11 Mean annual point potential evapotranspiration in the Pedirka subregion

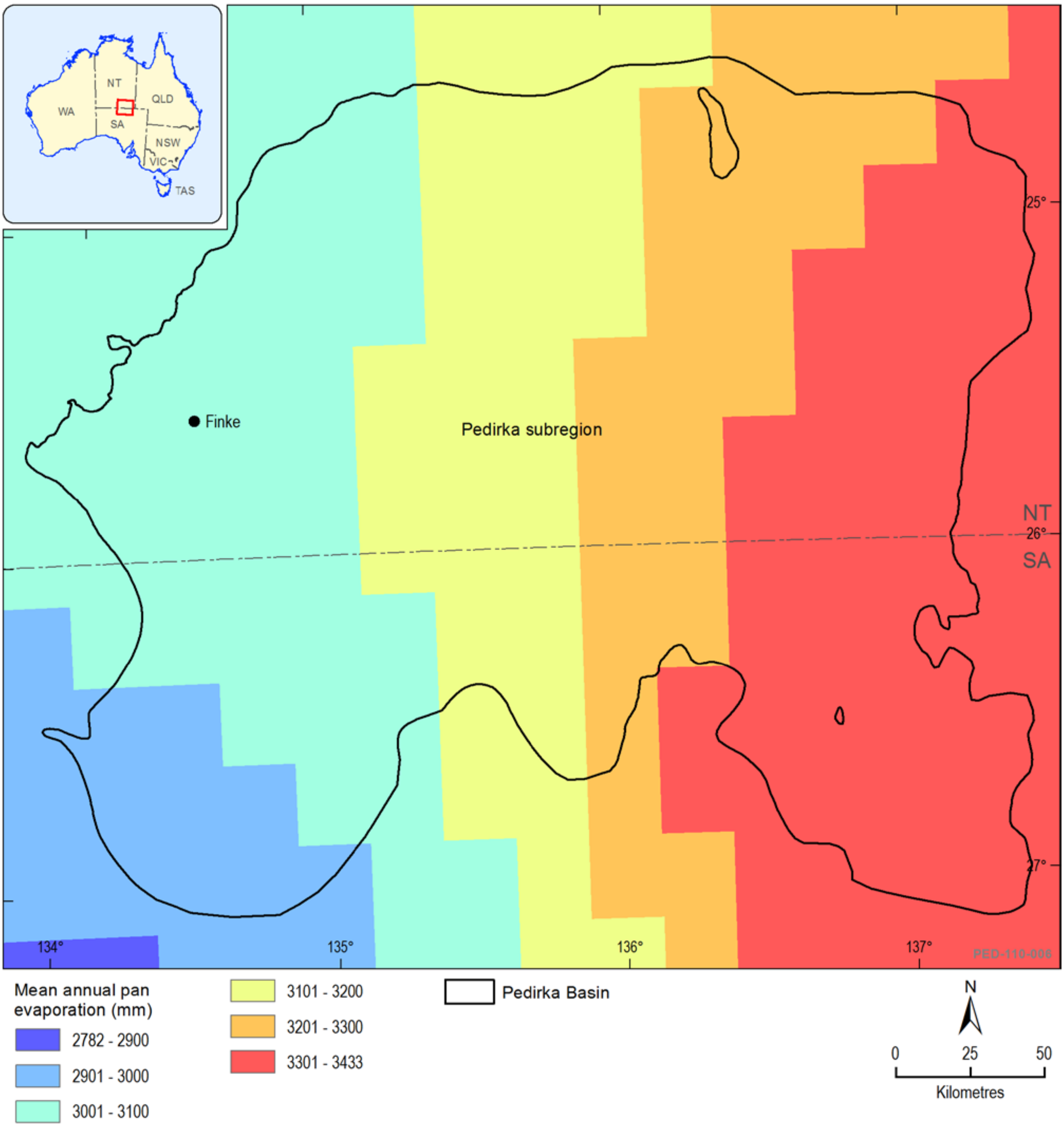

Figure 12 Mean annual pan evaporation in the Pedirka subregion

Until recently, there has been no dedicated research towards assessing the impacts of a changing climate over the Pedirka 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 in the region. 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% by 2050, with temperatures increasing by 1°C to 2.5°C by the same time horizon. Increasing temperatures will lead to increased PET, which when considered with likely decreases in rainfall will have a compounding effect in reducing runoff in the subregion.

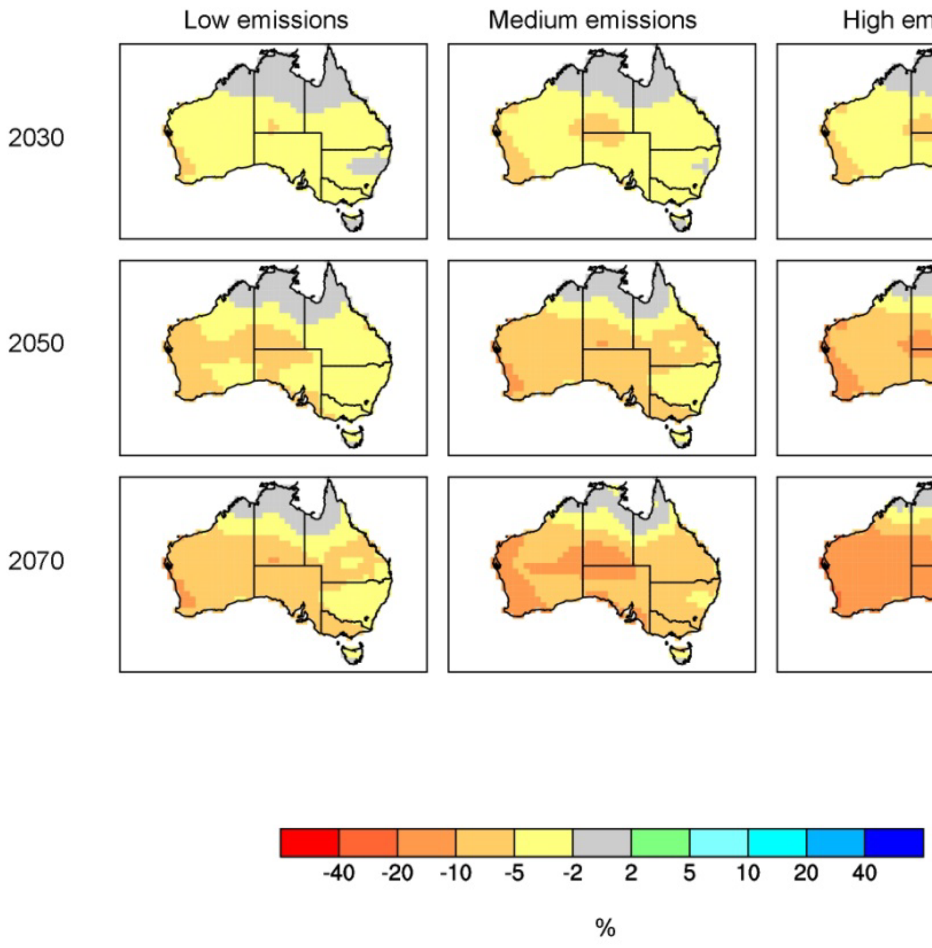

Figure 13 Percentage change in median annual rainfall totals from the baseline (1990) case for three future time horizons and three emissions scenarios

Source: CSIRO et al. (2007a)

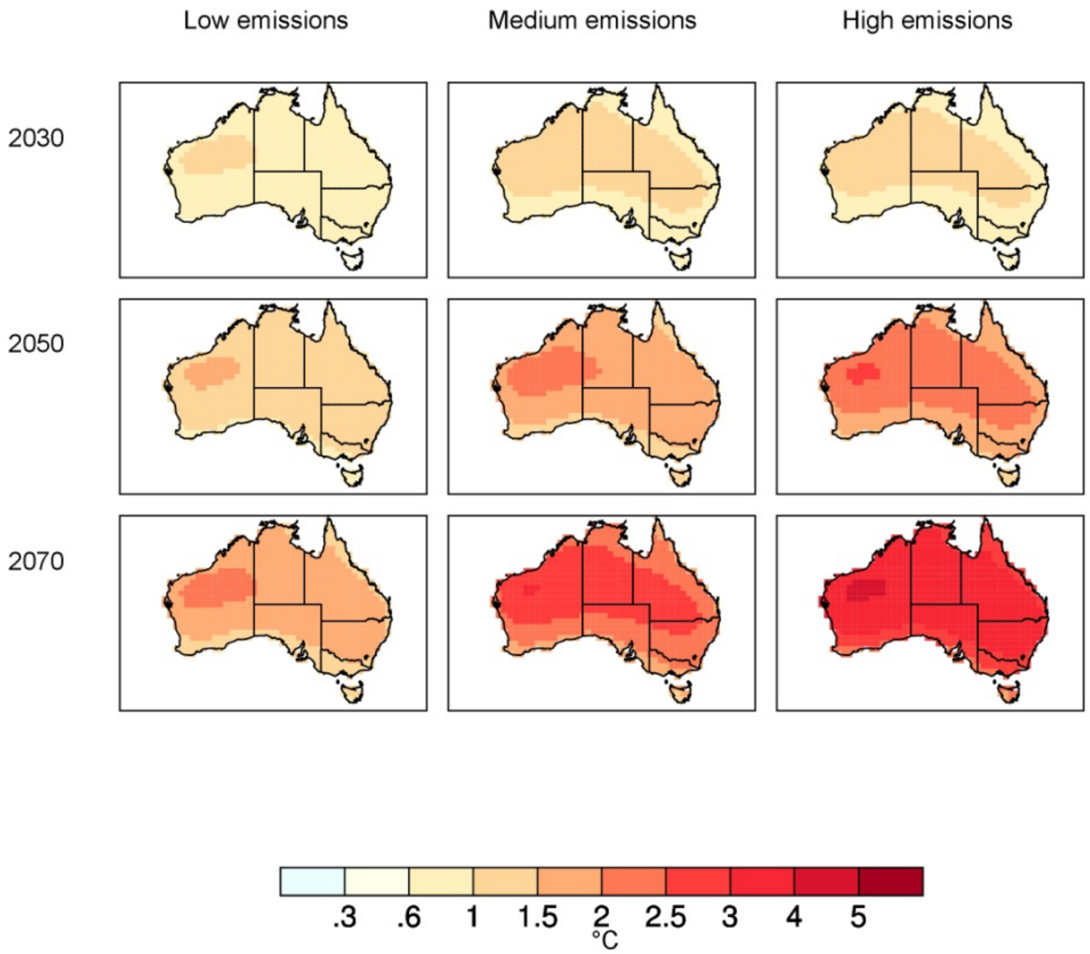

Figure 14 Percentage change in median average temperature from the baseline (1990) case for three future time horizons and three emissions scenarios

Source: CSIRO et al. (2007b)

The South Australian Government, through its Impacts of Climate Change on Water Resources Project, has recently undertaken an analysis of groundwater recharge, surface water runoff and rainfall intensity data in the South Australian Arid Lands Natural Resources Management (SAALNRM) region. This project was undertaken to determine the potential impact of climate change on the principal water resources of this region (Gibbs et al., 2012). The SAALNRM region encompasses a large portion of the north-east of SA that borders with the NT and Queensland and is inclusive of the South Australian portion of the Pedirka subregion. This report found that rainfall decreases of the kind suggested by CSIRO et al. (2007) across the NRM region led 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 (see 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 Pedirka Basin is a largely subsurface sedimentary basin comprising Early to Late Permian sediments and coal sequences that covers an area of approximately 71,000 km^2. The Pedirka Basin is centred on the SA-NT border, approximately 160 km south-east of Alice Springs.

The Pedirka Basin consists of two deep troughs that are separated by a central ridge of older rocks called the Dalhousie–McDills Ridge. A thin section of Permian sedimentary rocks over the ridge connects the two troughs. The Pedirka Basin is underlain by Early Paleozoic sedimentary rocks of the Warburton Basin and Amadeus Basin, as well as crystalline Precambrian basement rocks. Overlying the Pedirka Basin are sedimentary rocks of the Eromanga Basin (Great Artesian Basin, GAB) of Mesozoic age, as well as Cenozoic sediments.

There are two sedimentary formations within the Pedirka Basin; the Purni Formation and Crown Point Formation. The Purni Formation consists of sandstone, siltstone and claystone, as well as coal beds deposited in river and swamp-related environments. The underlying Crown Point Formation is composed of sandstone, diamictite, siltstone and shale deposited within a glacial and river environment. A well-sorted sandstone that occurs at the top of the Crown Point Formation is typically used as a marker for the end of glaciation.

Directly overlying most of the Pedirka Basin is the Eromanga Basin, which is synonymous with the GAB. In the Pedirka subregion, aquifers occur in the Winton Formation, Mackunda Formation, Cadna-owie Formation, and Algebuckina Sandstone/DeSouza Sandstone. Within deeper parts of the basin, the Triassic Simpson Basin occurs between the Eromanga Basin and Pedirka Basin strata. Overlying the Eromanga Basin are the most recent phases of sedimentation primarily deposited in episodic braided river, lake and desert environments.

The shape and structure of the Pedirka Basin 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 Pedirka Basin rocks may have also been important with respect to basin architecture. Deposition in the Pedirka Basin that included glacial, marine and finally terrestrial sedimentation appears to have ceased during the Late Permian. Since then, further deformation events have resulted in erosion and deposition of younger sedimentary rocks over the Pedirka Basin.

Within the Pedirka Basin, coal seams are a characteristic of the upper member of the Purni Formation, however economic coal seam gas plays may occur. Currently, there is no commercial exploitation of coal seam gas in the Pedirka Basin, although some exploration work has been undertaken. The Pedirka Basin is also the subject of conventional hydrocarbon exploration.

1.1.3.1 Geological structural framework

The Pedirka Basin is an intracratonic sedimentary basin comprising Early to Late Permian sedimentary rocks, including coal sequences. The Pedirka Basin is centred on the SA-NT border, approximately 860 km north-north-west of Adelaide and 160 km south-east of Alice Springs. Elevation ranges between 0 to 450 mAHD, with a mean elevation of approximately 144 mAHD. Based on newly processed geophysics and drilling data, the spatial extent of the Pedirka Basin covers an area of approximately 71,000 km^2.

The Pedirka Basin is bound to the south-west by the Musgrave Ranges and to the west by the Newland Ranges. The northern boundary is defined by the Arunta Block and a complex fault block consisting of Mesoproterozoic to Cambrian metasedimentary and volcanic rocks called the Hale River High, the location of which is controlled by the Pellinor Fault Zone (Munson and Ahmad, 2012). A major north-west structural feature called the Dalhousie–McDills Ridge dissects the basin into eastern (Madigan and Poolowanna troughs) and western (Eringa Trough) portions (Figure 15 and Figure 16). Thin Permian strata draped over the ridge connect the two troughs. The basin reaches a thickness of up to 1525 m within the Eringa Trough (Giuliano, 1988). The Poolowanna Trough occupies the far eastern portion of the basin and is separated from the Madigan Trough by the Colson Shelf, upon which approximately 135 m of Permian rocks have been deposited (Munson and Ahmad, 2012, after Central Petroleum, 2011). Sedimentary rocks within the Poolowanna Trough are largely of Triassic age (Simpson Basin), with Permian rocks occurring along the western flank of the trough.

The Pedirka Basin is separated from the Arckaringa Basin to the south and the similarly aged Cooper Basin to the east by the basement highs of the Bitchera, Muloorina and Birdsville Track ridges. Hibburt and Gravestock (1995) postulated that the Pedirka Basin was once connected to the other Permo-Carboniferous basins across these basement highs but was subsequently isolated by the erosion of Permian rocks.

The Pedirka Basin unconformably overlies the early Paleozoic Amadeus and Warburton basins and Proterozoic basement rocks and unconformably underlies the Mesozoic Eromanga Basin (Great Artesian Basin, GAB). Much of the Pedirka Basin occurs subsurface at depths greater than 400 m. Only the Crown Point Formation outcrops, restricted to the north–west margin of the basin in the NT (Munson and Ahmad, 2012) (Figure 15).

The Permian sedimentary strata of the Pedirka Basin appear to be significantly faulted, with a number of normal and reverse faults identified; resulting in vertical displacement or the removal of rocks by erosion (Figure 17). In some instances, displacement appears to have caused at least localised discontinuity within the Permian sequence; this is particularly evident in the vicinity of the Dalhousie–McDills Ridge (Figure 16). This feature may have led to the formation of partially disconnected hydrogeological sub-basins within the greater Pedirka Basin. Additionally, the base of the Permian strata forms a complex, glacially-scoured surface with significant erosional relief.

Current intraplate tectonic activity is interpreted to be a function of compression caused by the continent’s northward drift and subsequent collision with the Indonesian Archipelago, commencing approximately 43 million years ago (Sandiford et al., 2009). In the general vicinity of the Pedirka 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).

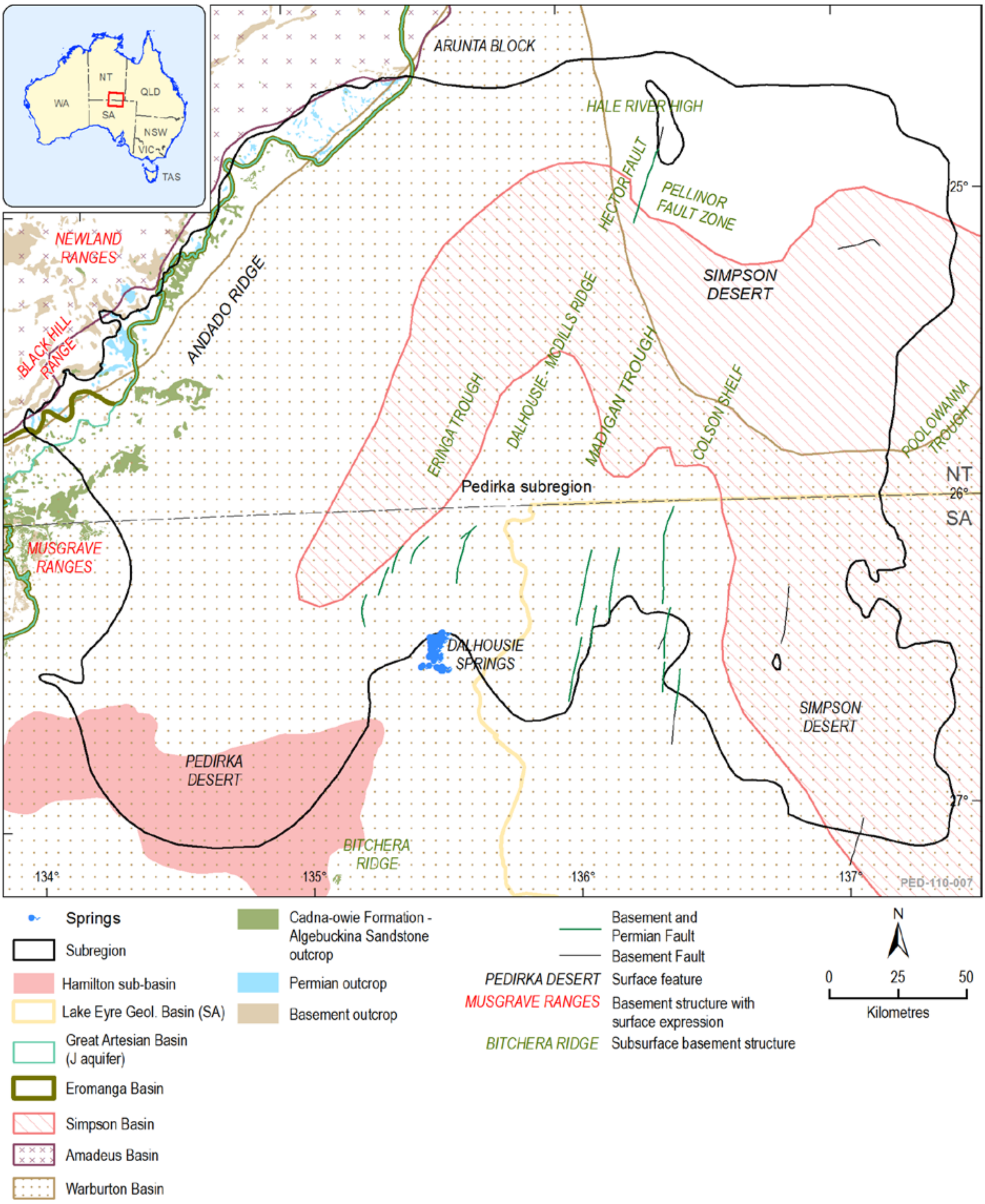


Figure 15 Structural framework of the Pedirka subregion

Note: the Lake Eyre geological basin has only been mapped for SA.

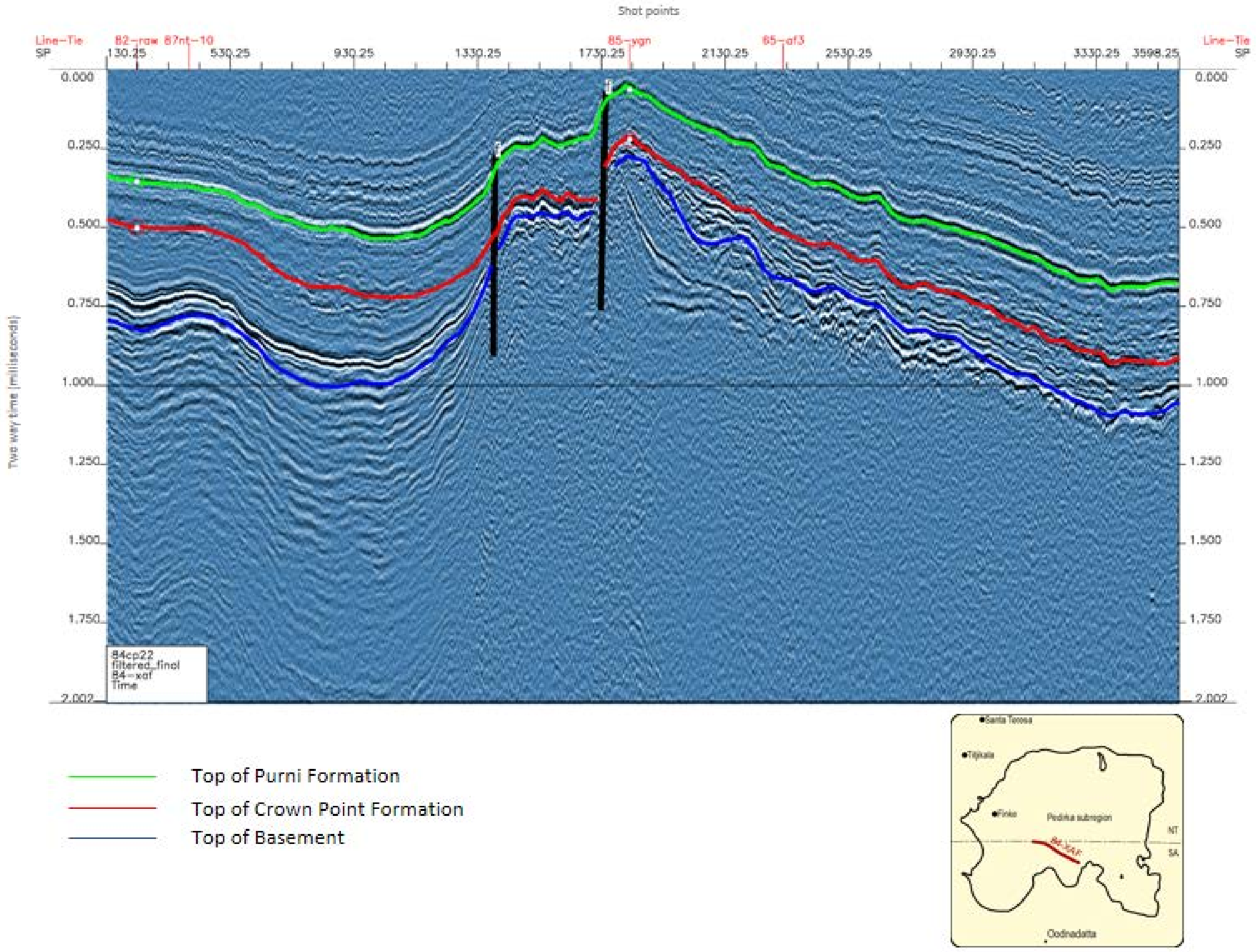


Figure 16 Seismic Line 84 XAF shows the pinching and truncation of the Permian formations by significant folding and faulting associated with the Dalhousie-McDills Ridge

Note: These faults may provide pathways for groundwater movement between the Permian aquifers and the overlying GAB aquifers, as well as the potential demarcation of sub-basins within the Pedirka Basin. Also note the significant difference in formation thickness when comparing the left (western) and right (eastern) sides of the fault block. Depth can be approximated from TWT (milliseconds) using the following formula: Depth (m) = 1.5*(milliseconds) – 328.

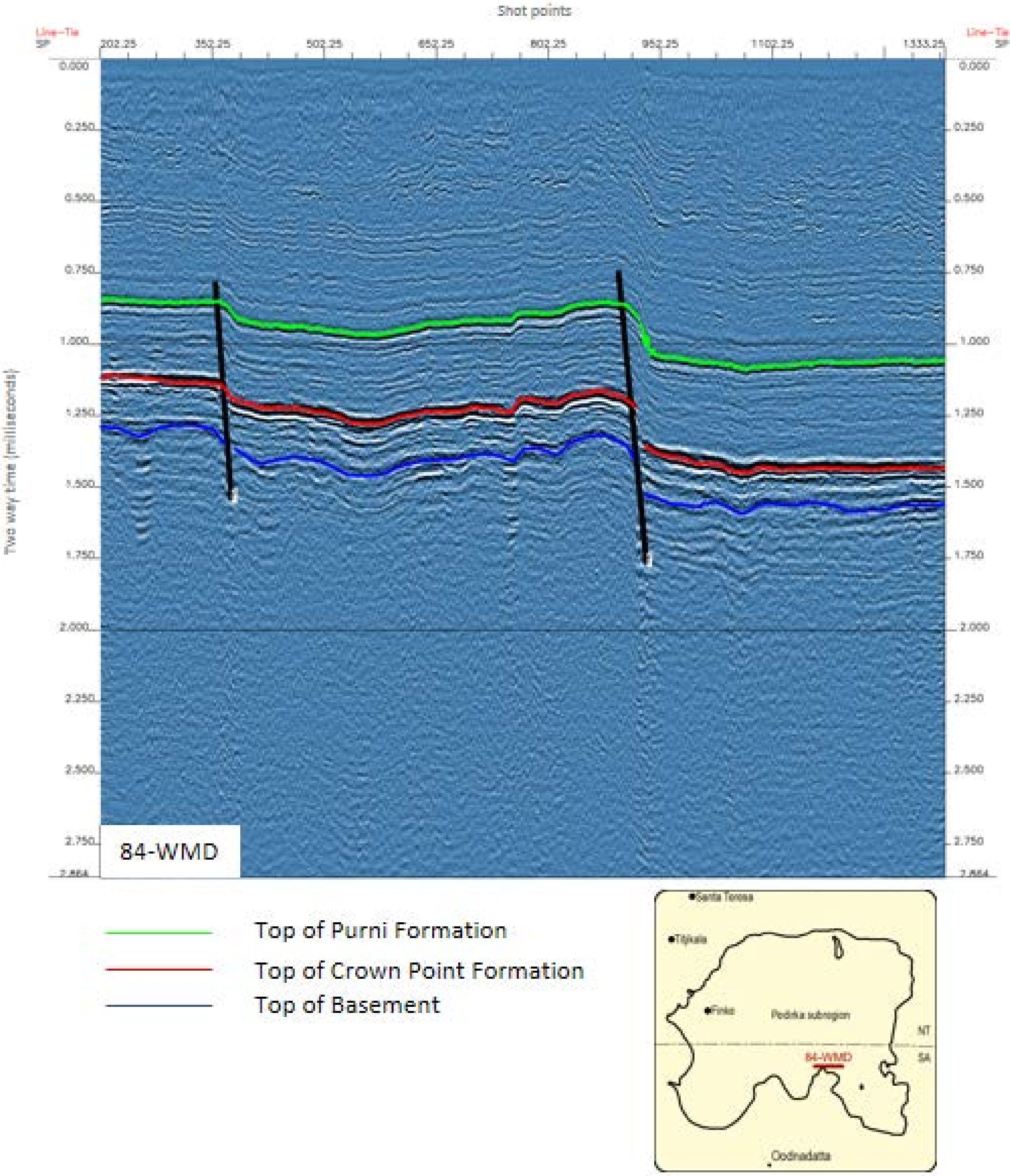


Figure 17 Seismic line 84-WMD displays an example of fault deformation within the Pedirka Basin succession

Note: Although the displacement along the fault within the western half (left hand side) is not sufficient to completely disrupt connectivity between formation strata, the displacement along the fault within the eastern half of the section is great enough to cause significant disconnection within the Permian sequence. The significance of faulting with respect to the hydrogeology of Pedirka Basin aquifers is highlighted in two ways: a) faulting may cause partitioning and therefore the formation of sub-basins and b) faulting may enable vertical connectivity between overlying or underlying aquifers. Depth can be approximated from TWT (milliseconds) using the following formula: Depth (m) = 1.5*(milliseconds) – 328.

Neotectonic expressions in the general region include reported seismic activity in the vicinity of the Hector Fault near the northern margin, as well as to the east of the eastern margin of the Pedirka Basin (Geoscience Australia, 2014). Additionally, several authors including Aldam and Kuang (1988), Karlstrom et al. (2012) and Keppel (2013) have summarised and presented evidence that GAB springs, including Dalhousie Springs located on the southern margin of the Pedirka Basin, may also be an expression of neotectonic activity.

1.1.3.1.1 Regolith/surface geology

Most of the Pedirka subregion, especially within the NT, has a regolith profile composed of aeolian sediments (Craig, 2006) (Figure 18). A notable exception to this occurs in the south-west corner of the subregion, predominantly within SA, where there are erosional landforms composed of moderately to highly weathered bedrock, or residual soil materials derived from overlying Mesozoic rocks. Depositional landforms as well as associated alluvial, colluvial and other transported sediments are primarily restricted to drainage channels. Most of these drainages have headwaters in residual and erosional landforms bordering the north-west and western margin of the Pedirka subregion (Craig, 2006). Spring-related deposits are common near Dalhousie Springs, at the southern margin of the Pedirka subregion.

1.1.3.2 Stratigraphy and rock type

1.1.3.2.1 Underlying stratigraphy

Amadeus Basin

Sedimentary rocks within the Amadeus Basin represent deposition over a time period between Neoproterozic and the Early Carboniferous and are typically marine siliciclastic and carbonate units. The Amadeus Basin can be divided into a number of sub-basins for which the stratigraphy has been mapped in detail from past hydrocarbon exploration activity. However, the stratigraphy of the south-eastern basin is the focus here given its relationship to the Pedirka Basin. In particular, the Mereenie Sandstone and units within the laterally equivalent Finke and Pertnjara groups are discussed. The Finke and Pertnjara groups were both deposited during the Late Devonian. Formations within the Finke Group (Alley and Gravestock, 1995; Geoscience Australia, 2012; Gravestock, 1995) include:

- the Horseshoe Bend Shale, composed of lacustrine, red to red-brown shale
- the Idacowra Sandstone, composed of medium- to coarse-grained sandstone with minor claystone and coal beds
- the Langra Group which is composed of light grey medium- to coarse-grained sandstone, conglomerate, micaceous siltstone shale and clay
- the Polly Conglomerate which comprises alluvial fan conglomerate containing pebbles sourced from granitoids, marble and siliciclastics and the Santo Sandstone.

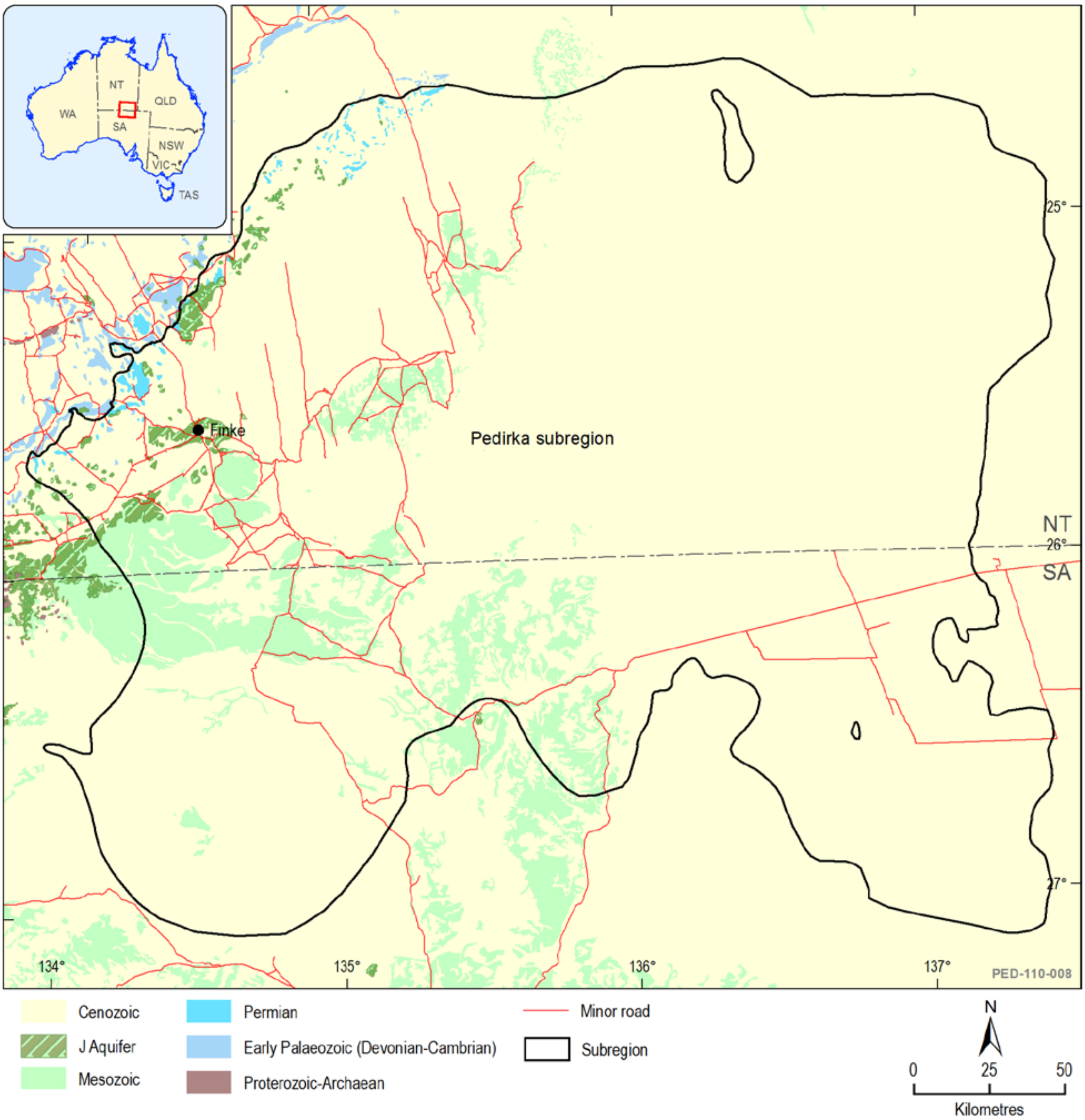


Figure 18 Surface geology of the Pedirka subregion

Source: Raymond et al. (2012)

Stratigraphic equivalents within the Pertnjara Group include the Parke Siltstone, Hermannsberg Sandstone and Brewer Conglomerate (Geoscience Australia, 2012; Young and Ambrose, 2005). The Mereenie Sandstone has been interpreted as unconformably underlying the Finke Group in SA (Alley and Gravestock, 1995), as well as the Parke Siltstone of the Pertnjara Group in the NT (Young and Ambrose, 2005). However, Geoscience Australia (2012) placed the Mereenie Sandstone within the Pertnjara Group. The Mereenie Sandstone consists of a pinkish white fine- to medium-grained, minor cross-bedded quartz sandstone and gritty bands and notable concentrations of minerals such as zircon, microcline and tourmaline interpreted to be deposited within an aeolian deltaic shallow marine environment (Alley and Gravestock, 1995). Below the Mereenie Sandstone is the Carmichael Sandstone and units of the Larapinta Group including the

Pacoota Sandstone, a pale, fine- to coarse-grained quartzitic sandstone with fossils indicative of deposition within an Ordovician marine environment (Alley and Gravestock, 1995).

The Amadeus Basin has been the subject of exploration for conventional petroleum hydrocarbons since the early 1960's (Pegum, 1997). Currently there are two major petroleum hydrocarbon producing fields in the Amadeus Basin. Both fields are associated with anticline structures and are located approximately 240 km and 120 km west of Alice Springs respectively.

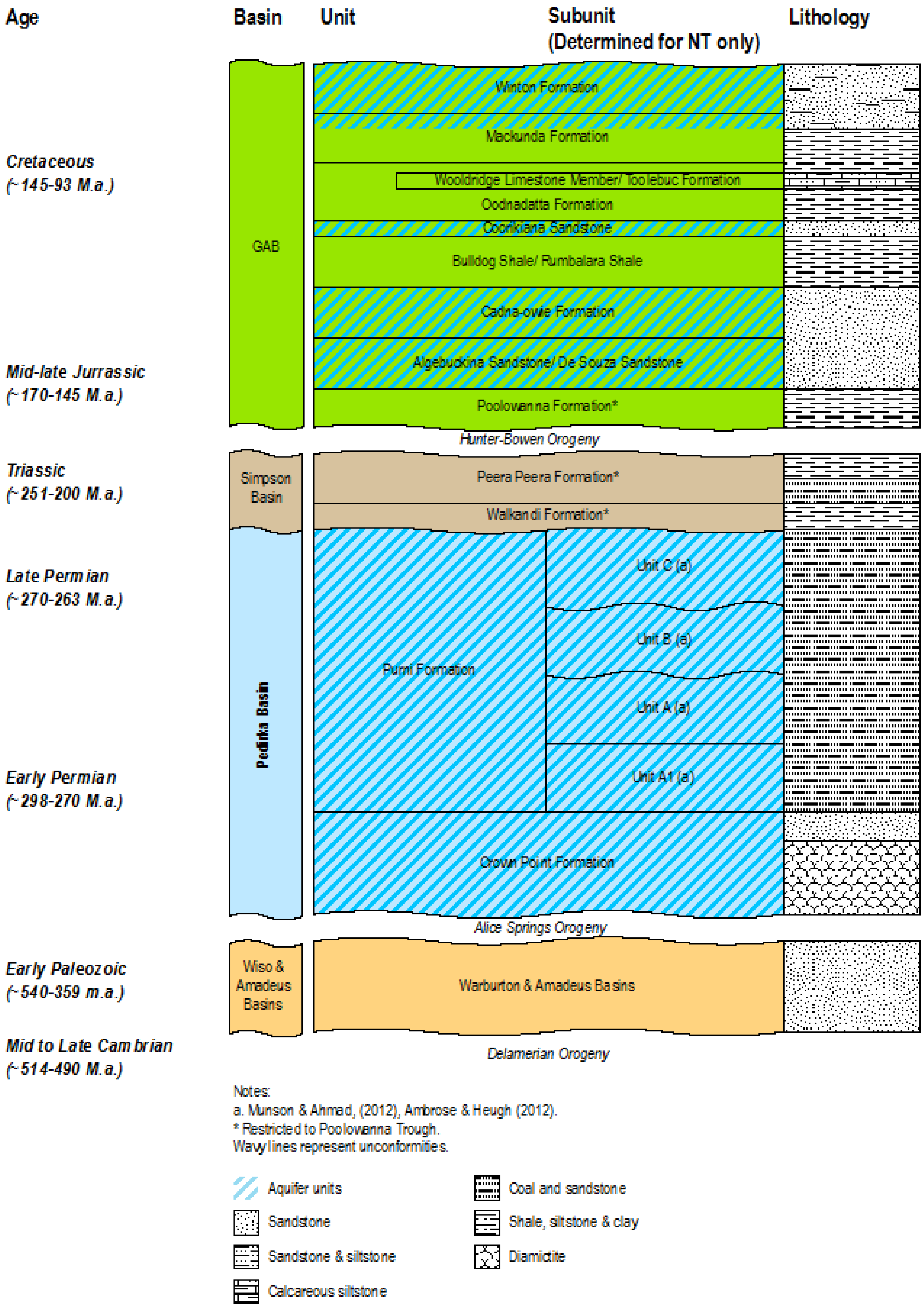
Warburton Basin

Sedimentary rocks of the Warburton Basin are primarily Cambrian to Ordovician, although Devonian-aged sediments within the Finke Group are present in the NT. Gravestock et al. (1995) presented evidence for five separate depositional sequences in the Warburton Basin, although the depositional record has not necessarily been completely preserved. Simplistically, these sequences include a basal suite of shallow marine sediments, followed by a marine prograding sequence through to deep marine organic-rich limy mudstone and shale. A marine regression sequence then follows into a shallow marine sequence. Additionally, volcanolithic units occur (Gravestock, 1995; Radke, 2009). A paucity of exploration has meant that only a few formations have been named to date (Radke, 2009):

- Kalladeina Formation comprising limestone, dolomite, shale, siltstone, sandstone and minor tuff
- Dullingari Group composed of pyritic shale, siltstone with minor indurated or bioturbated sandstone and siltstones
- Pando Formation that consists of clean and glauconated sandstone with interbeds of siltstone and shale.

Pedirka Basin

The current stratigraphic nomenclature for Pedirka Basin was first proposed by Wells et al. (1966), while Jacques (1966) recognised two formations; the Crown Point Formation and overlying Purni Formation (Figure 19). The differentiation of the Purni Formation as separate from the Crown Point Formation in SA was first published in SA by the South Australian Department of Mines (1972) and was formally defined by Youngs (1975).



Notes:
a. Munson & Ahmad, (2012), Ambrose & Heugh (2012).
* Restricted to Poolowanna Trough.
Wavy lines represent unconformities.

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

Source: modified from Wohling et al. (2013)

Crown Point Formation

The Crown Point Formation (Wells et al., 1966) consists of glacio-fluvial and glacio-lacustrine sandstone and shale. The formation unconformably overlies sedimentary rocks associated with the Early Paleozoic Amadeus and Warburton basins and underlies the Purni Formation. The formation comprises extensive diamictite, conglomerate, fluvioglacial and glacio-lacustrine sandstone, ripple-laminated sandstone and siltstone, and clay-rich rhythmite (Giuliano, 1988). Coarser grained rocks such as conglomerate, coarse sandstone and diamictite are associated with depositional highs, whereas finer grained mudstone is more commonly associated with basinal lows such as the Eringa Trough (Hibburt and Gravestock, 1995). The lithological similarity between the Crown Point Formation and Boorthanna Formation in the Arckaringa Basin has led to the interpretation that these formations are lateral equivalents (Alexander and Jensen-Schmidt, 1995).

A well-sorted sandstone that occurs at the top of the Crown Point Formation is typically used as a marker for the end of glaciation. Several workers (Ambrose and Heugh, 2012; Ambrose 2006 and Munson and Ahmad, 2012) have considered this sandstone as a distinct formation and have named it the Tirrawarra Sandstone, suggesting it is the equivalent of the Tirrawarra Sandstone in the Cooper Basin. After logging of core from Mount Hammersley 1, New (1998) subdivided the Crown Point Formation into three sub-units on the basis of lithological variation and log character. The basal unit (Unit C) consists of sandstone with interlaminated and interbedded siltstone. The middle unit (Unit B) consists predominantly of siltstone and claystone, whereas the uppermost unit (Unit A) consists of sandstone and interbedded siltstone.

Spatially, the Crown Point Formation is widespread and outcrops along the north-western margin of the Pedirka Basin where it borders the Newland Ranges. With respect to palynological interpretation, the Crown Point Formation has been assigned to zone PP1 (Asselian), although a broader Late Carboniferous to Early Permian age has also been ascribed (Munson and Ahmad, 2012).

Purni Formation

The Purni Formation (Youngs, 1975) disconformably underlies Jurassic rocks of the Eromanga Basin in the western Pedirka Basin, and underlies Triassic Simpson Basin strata in the eastern half and deeper parts of the Eringa Trough. The Purni Formation consists of fluvial and paludal (swamp) interbedded sandstone, siltstone and claystone, as well as coal beds within the paludal sequences. Youngs (1975) and Hibburt and Gravestock (1995) suggested that the South Australian occurrence of the Purni Formation can be further subdivided into three sub–units based on the proportion of carbonaceous shale, lenticular or cross-bedded sandstone and coal seams. The upper and lower units are dominated by carbonaceous shale and coal respectively, whereas cross-bedded sandstone predominates in the middle facies.

Conversely, in the NT, Ambrose and Heugh (2012) and Munson and Ahmad (2012) described four sub–units (Units A1, A, B and C) based on facies description, palynology, and coal seam correlation:

- The basal unit A1 consists of sandstone interbedded with siltstone and finer sandstone. Coal seams are thin, but the presence of higher carbonaceous content is used to discriminate between the Purni Formation and underlying glacial sequences
- Unit A consists of thick coal seams and interbedded clastics that conformably overly Unit A1
- Unit B is thought to disconformably overly Unit A, and consists of interbedded siltstone, sandstone and coal
- Unit C contains a sequence of interbedded coal and clastic sedimentary rock that are bound at the top and base by unconformities.

A similar characterisation of four sub-units (Units I to IV) was first proposed by Faridi (1986). As well as discriminating between subgroups, Munson and Ahmad (2012) described how palynological work has extended the Purni Formation to cover most of the Permian time period, whereas most previous interpretations had this unit restricted to the Early Permian (Sakmarian). Consequently, those interpretations that broadly describe the Purni Formation as the lateral equivalent of the Mount Toondina Formation (e.g. Youngs, 1975) require review. They suggest that with further work, the Purni Formation could be elevated to Group status, with the identified sub-units reclassified as formations in their own right. Similarly, further work is required to correlate sub-formational units in the NT and SA portions of the Pedirka Basin.

1.1.3.2.2 Overlying stratigraphic units

Simpson Basin

The Simpson Basin overlies the eastern extent of the Pedirka Basin and consists of two sedimentary formations: the Walkandi Formation and Peera Peera Formation. The Peera Peera Formation overlaps conformably above the Walkandi Formation and consists of three main facies. The lowest facies type consists of grey shale, siltstone, minor sandstone and coal, the middle facies comprises fine-grained sandstone and the uppermost facies is composed of a black carbonaceous silty shale. The depositional environment is interpreted to be fluvial-floodplain-lacustrine and therefore, will have inherent heterogeneity (Questa, 1990).

The Walkandi Formation consists of beds of red-brown shale, green siltstone and fine-grained sandstone of possible lacustrine origin (Moore, 1986) and is largely restricted to the Poolowanna Trough region at the centre of the Pedirka Basin. Work presented by Questa (1990), Ambrose and Heugh (2012) and Munson and Ahmad (2012) suggested that the Simpson Basin sequences should be included as part of the Pedirka Basin; abandonment of the name ‘Simpson Basin’ is suggested, with Questa (1990) suggesting that group status within the Pedirka Basin sequence be more appropriate. It is also noted that the Australian Stratigraphic Units Database (Geoscience Australia, 2014) discusses these Triassic units as part of the Pedirka Basin. However, for the purposes of this report, these stratigraphic units are considered as separate basin as proposed by Hibburt and Gravestock (1995).

Eromanga Basin (GAB)

Directly overlying most of the Pedirka Basin is the Eromanga Basin. Krieg et al. (1995), Ollier (1995), Toupin et al. (1997) and Wopfner and Twidale (1967) described the formation of the Eromanga Basin as being triggered after general uplift within central Australia during the Triassic that coincided with continental down-warping to the north-east. Consequently, 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. Primary facies changes, especially across basement highs, give rise to complex hydrostratigraphy (Keppel et al., 2013).

The Eromanga Basin is synonymous with the sedimentological extent of the Great Artesian Basin (GAB) throughout the Pedirka subregion. The GAB has been referred to as both a geological basin and hydrogeological basin. Geologically, the GAB describes a terrestrial to marine Jurassic-Cretaceous super basin that covers much of eastern and central Australia (Keppel et al., 2013). A number of GAB aquifers and confining layers exist in the Pedirka subregion (Table 4).

Cenozoic sediments

The most recent phases of sedimentation have been primarily deposited as episodic braided fluvial and lacustrine sediments. Cenozoic sedimentation may be divided into two depositional episodes; sedimentation that occurred during the Paleogene and Neogene periods, prior to upwarping at 15 to 5 Ma and those associated with the current hydrological system. The Cenozoic sediment may provide discrete aquifers in areas covered by the Lake Eyre Basin. In the vicinity of the Pedirka subregion, Cenozoic sedimentary basins include the Lake Eyre (geological) Basin, Aremra Basin and Hamilton sub-basin.

Sediments associated with the Lake Eyre (geological) Basin were primarily deposited in three phases of episodic braided fluvial and lacustrine sediments. Sediments are generally less than 200 m thick, although thicknesses >350 m occur in places (Drexel and Preiss, 1995), and occupy a large area in the north-east corner of SA and the south-east corner of the NT.

Sediments within the Lake Eyre (geological) Basin have been described in most detail to date. The Eyre Formation is the oldest sequence, deposited during the Late Paleocene and the Mid Eocene. Sediments consist of mature, pyritic carbonaceous sand. The Namba Formation and lateral equivalents represent the middle phase of sedimentation which occurred between the mid-Oligocene and Pliocene. Sedimentation consists largely of white, green and grey clay, fine-grained sand and carbonate with minor conglomerate. The Wipajiri, Tirari and Kutjitara formations and the Simpson Sand are the names given to Pliocene to Quaternary aged sediments in the Kati Thanda – Lake Eyre region and areas north (Callen and Benbow, 1995). These sediments largely consist of red-brown arenite, fine-grained lacustrine sediments, aeolian and evaporite sediments, as well as calcrete and gypcrete horizons.

Table 4 Summary of hydrostratigraphy of the Eromanga Basin (Great Artesian Basin within the Pedirka subregion)

Period	Formation name	Lithology description	Depositional environment	Hydrogeological characteristics
Cretaceous	Winton Formation (Rolling Downs Group)	Non-marine shale, siltstone, sandstone, and minor coal seams	Low energy, fluvial, lacustrine, and paludal	Confined lenticular aquifers, discharge in eroded anticlines
	Mackunda Formation (Rolling Downs Group)	Partly calcareous, fine-grained sandstone, siltstone and shale	Sub-tidal marine and shore faces and marks transition from marine to freshwater	Confined minor aquifer, no known natural discharge
	Oodnadatta Formation (Rolling Downs Group)	Laminated, claystone and siltstone, with interbeds of fine-grained sandstone and limestone	Low energy, shallow marine	Confining layer with minor aquifers
	Wooldridge Limestone Member/ Toolebuc Formation (Rolling Downs Group)	Calcareous sandy siltstone/Carbonaceous clayey mudstone and calcareous shale	Low energy, shallow marine. Woodridge Limestone Member from shallower more oxygenated areas of the basin	Confining layer
	Coorikiana Sandstone (Rolling Downs Group)	Predominately carbonaceous, clayey, fine-grained sandstone and siltstone	High energy, marine, shore face and gravel bars	Confined minor aquifer
	Bulldog Shale / Rumbalara Shale (Rolling Downs Group)	Grey marine shaly mudstone, micaceous silt and pyrite are also present, with very minor silty sand. Rare lodestones	Low energy, marine, cool climate	Main confining bed for the Jurassic-Cretaceous aquifers
	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 is a good aquifer, high yields and good water quality.
Jurassic	Algebuckina Sandstone / De Souza Sandstone	Fine to coarse-grained sandstone, with granule and pebble conglomerate	Low gradient fluvial including rivers, floodplain. Both arid and wet climates	Major GAB aquifer, high yielding bores
	Poolowanna Formation	White–pale grey sandstone, interbedded with dark grey and brown siltstone and shale. Minor coal seams	Fluvial and floodplain	Confining bed

Source: Keppel et al. (2013) after Drexel and Preiss (1995), Radke et al. (2000) and Shepherd (1978)

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 Pedirka Basin, as well as determining the economic potential of any contain 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 Pedirka Basin.

After a number of Archean cratons amalgamated to form the Australian continent (Powell and Pisarevsky, 2002; Powell et al., 1993), a series of tectonic events commencing in the Late Cambrian resulted in the development of the structural architecture underpinning the Pedirka Basin. Pedirka Basin architecture is largely controlled by Proterozoic and Early Phanerozoic tectonics and the deep-seated structures that formed during these times.

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, Amadeus and Warburton. The eastern Australian margin at that time was defined by a complex rift system. An interpreted triple rift junction in the vicinity of this margin is inferred to have occurred near the present day Pedirka Basin and southern Cooper Basin (Questa, 1990).

Deformation associated with the Delamerian Orogeny (Late Cambrian) saw the conversion of eastern Australia to a convergent plate margin. Development of the eastern plate margin proceeded via the episodic accretion of magmatic arcs as terranes. The Delamerian Orogeny 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 Fold Belt. Cotton et al. (2006) also suggested that the deep crustal scale, length and planar form of these structures were favourable for reactivation during several later phases of tectonism.

Following the Delamerian Orogeny, deposition of sediments within a fore-arc basin associated with terrane accretion occurred during the Late Cambrian to Ordovician, forming clastic sedimentary deposits of early Paleozoic basins which, in part, underlie Permian strata in central Australia. The Pertnjara Orogeny during the Early to Mid Devonian resulted in uplift and erosion in the Pedirka Basin region. In particular uplift during these times formed the Black Hills Range, the north-western boundary of the Eringa Trough, and provided a source of sediment during the Late Devonian (Finke Group).

Cotton et al. (2006) suggested that north-west orientated compression and uplift associated with the Alice Springs Orogeny (Devonian and Carboniferous), had a great influence on the structural grain of the Permo-Carboniferous basins (Cooper, Pedirka and Arckaringa) of central Australia. In particular, the Alice Springs Orogeny resulted in further remobilisation of Archean basement and over-thrusting causing high amplitude folding of existing basinal strata. This resulted in the formation of domal trends such as the Gidgealpa—Merrimelia—Innamincka (GMI) Ridge, Dalhousie–McDills Ridge and Birdsville Track Ridge that controlled the position of depocentres for Permo-Carboniferous sedimentation (Karlstrom et al., 2013; Questa, 1990). Gravestock (1995) described crustal shortening of up to 20 km and uplift of 3 km as a consequence of this event.

The period of tectonic stability following the Alice Springs Orogeny lead to glaciogenic and quiescent marine conditions followed by lacustrine, fluvial and backswamp sedimentation, forming the Crown Point and Purni formations of the Pedirka Basin.

Munson and Ahmad (2012) suggested that sedimentation in the Pedirka Basin continued throughout the Permian period. The initial onset of the Hunter-Bowen Orogeny, at the end of the Early Permian, re-activated pre-existing structural features and caused subsidence in the Poolowanna Trough region to the east of the Pedirka Basin, to which sedimentation shifted during the Triassic, forming the Simpson Basin sedimentary sequence (Figure 20). Sedimentation in the Pedirka Basin region ceased altogether during the Middle Triassic as a consequence of compression associated with the Hunter-Bowen Orogeny.

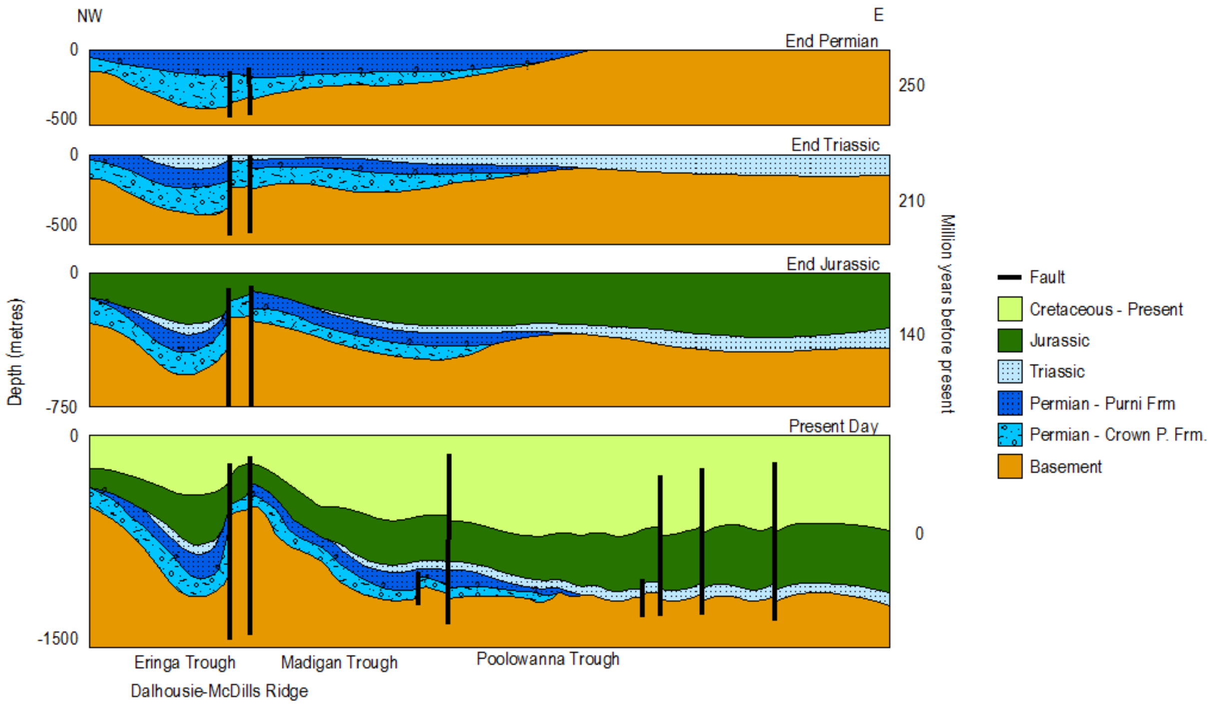


Figure 20 Schematic structural history, Pedirka Basin subregion

Source: Wohling et al (2013). modified after Questa (1990)

Post-Paleozoic, further periods of tectonic quiescence and down-warping have resulted in basinal sedimentation during the Mesozoic (Eromanga Basin) and Paleogene to Neogene (Lake Eyre Basin). Compression and uplift events during the Early Cenozoic (approximately 50 Ma) and in the last 15 to 5 Ma have caused further deformation of Permo-Carboniferous sediments, 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). Deformation included re-activation of pre-existing faults as well as associated folding (Figure 20). Current intraplate 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).

1.1.3.4 Coal and hydrocarbons

Within the Pedirka Basin, coal seams are a characteristic of the upper member of the Purni Formation. Coal resources associated with the Purni Formation may be found in both the western (Eringa Trough) and eastern (Madigan Trough) depocentres (Figure 21). The western depocentre contains up to 1000 m of Permo-Carboniferous strata at depths of less than 1500 m. In contrast, the eastern depocentre contains a Permo-Carboniferous sedimentary package between 300 and 400 m thick, at depths exceeding 2000 m (DMITRE, 2012).

Currently, most of the coal in the eastern Pedirka Basin appears to be too deep for coal seam gas extraction using existing technologies, although some thermogenic coal seam gas plays may be present. In contrast, although coals within the western depocentre not as deep as those within the eastern deocentre, they are generally determined to be too immature for thermogenic gas generation. That being said, extraction of biogenic coal seam gas may be viable if suitable trap sites can be identified. It is noted that slightly elevated mud gas contents were reported from Purni coals at depths of approximately 600 and 1500 m from drill-holes Mt Hammersley and Purni 1, respectively. Additionally, it is currently considered that the paucity of knowledge, remoteness and depths of coal resources within the Pedirka Basin would preclude economically viable extraction at least in the near term.

Based on palynological studies, the age of the Purni Formation covers a time period inclusive of most of the Permian, with coal seams in the upper member of the Purni Formation more likely to be Guadalupan epoch (approximately 270 Ma to 260 Ma). By contrast coal seams of the lower member of the Purni Formation are likely to be of Sakmarian age (approximately 295 to 290 Ma) (Munson and Ahmad, 2012). Information from structural and tectonic studies (refer to Section 1.1.3.2) suggests that sedimentation associated with the Pedirka Basin continued throughout the Permian, eventually shifting eastward and continuing through the Triassic to form the Simpson Basin succession.

Thermal history modelling of apatite fission tracking results from petroleum exploration wells drilled within the Eringa Trough and outcrop samples presented by Tingate and Duddey (2006) suggested that the base of the Permian in the deepest part entered the upper part of the oil generation window in the Permian and passed through the main oil window in the Cretaceous. Evidence for a recent increase (<5 Ma) in geothermal gradient is not thought to have had sufficient time to increase the thermal maturity of most formations within the Pedirka subregion (Tingate and Duddey, 2006).

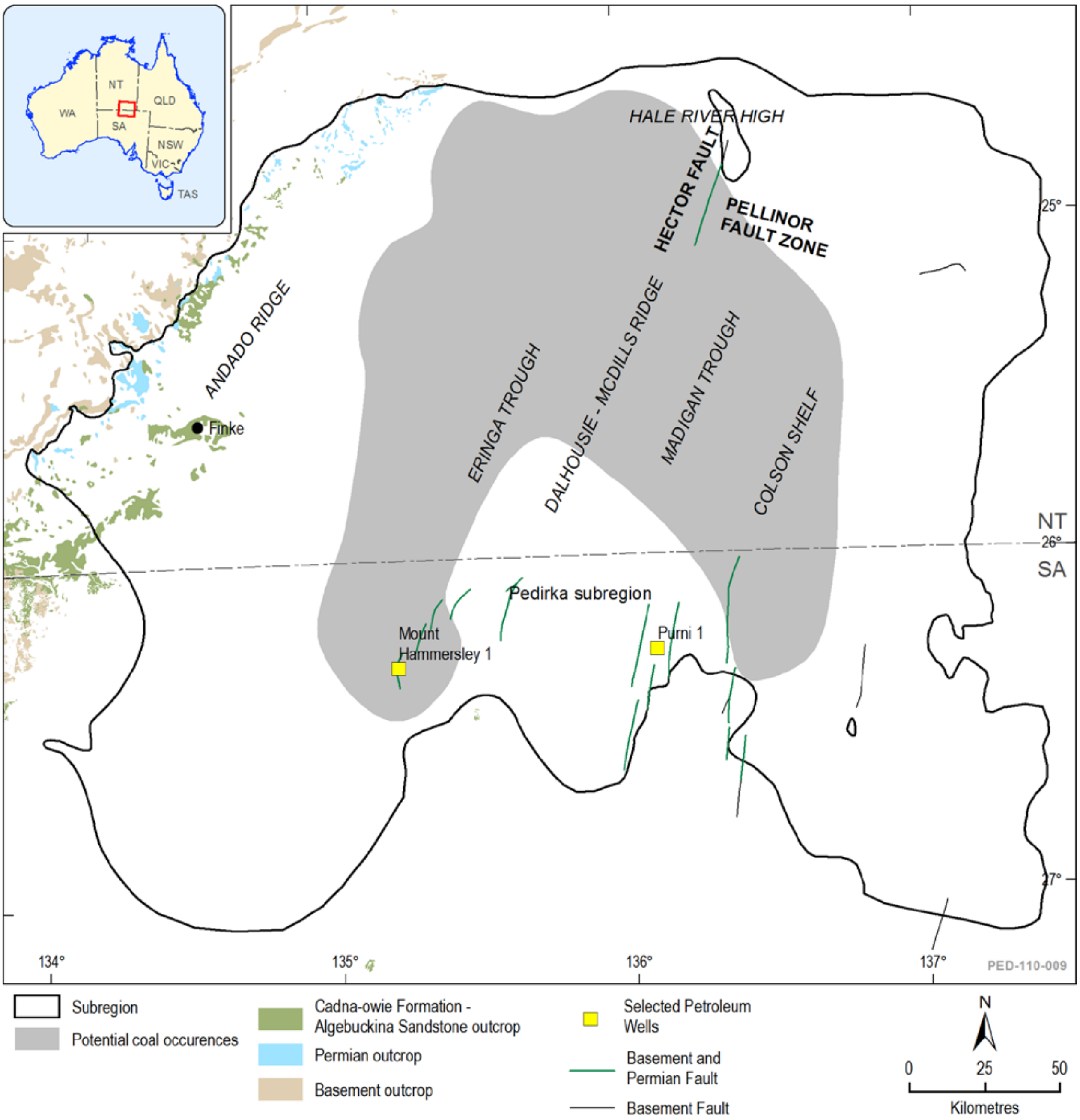


Figure 21 Defined area in which coal resources of the Pedirka subregion may be found

Source: Wohling et al. (2013)

1.1.3.5 *Potential basin connectivities*

The Pedirka Basin is currently conceptualised as a single continuous flow system. Therefore lateral connectivity with either overlying or underlying basins where hydrogeologically similar lithological units abut is considered possible (Figure 22 and Figure 23). Additionally, a review of the Permian strata presented in Wohling et al. (2013) revealed significant faulting and folding. The faulting structures identified suggest that cross-formational flow between Permian formations, the overlying GAB sequence and underlying Finke Group aquifers may be significant. Such cross-formational flow via faulting was proposed by Wolaver et al. (2013), who suggested a deeper source of groundwater was co-contributing along with GAB-derived groundwater to discharge at the Dalhousie Spring Complex. It was suggested by Wolaver et al. (2013) that this deeper groundwater was being derived from Permian aquifers.

Beyond this information there is little additional groundwater knowledge to establish vertical gradients. Furthermore, there have been no dedicated studies to investigate hydraulic connectivity between the Pedirka Basin and neighbouring basins.

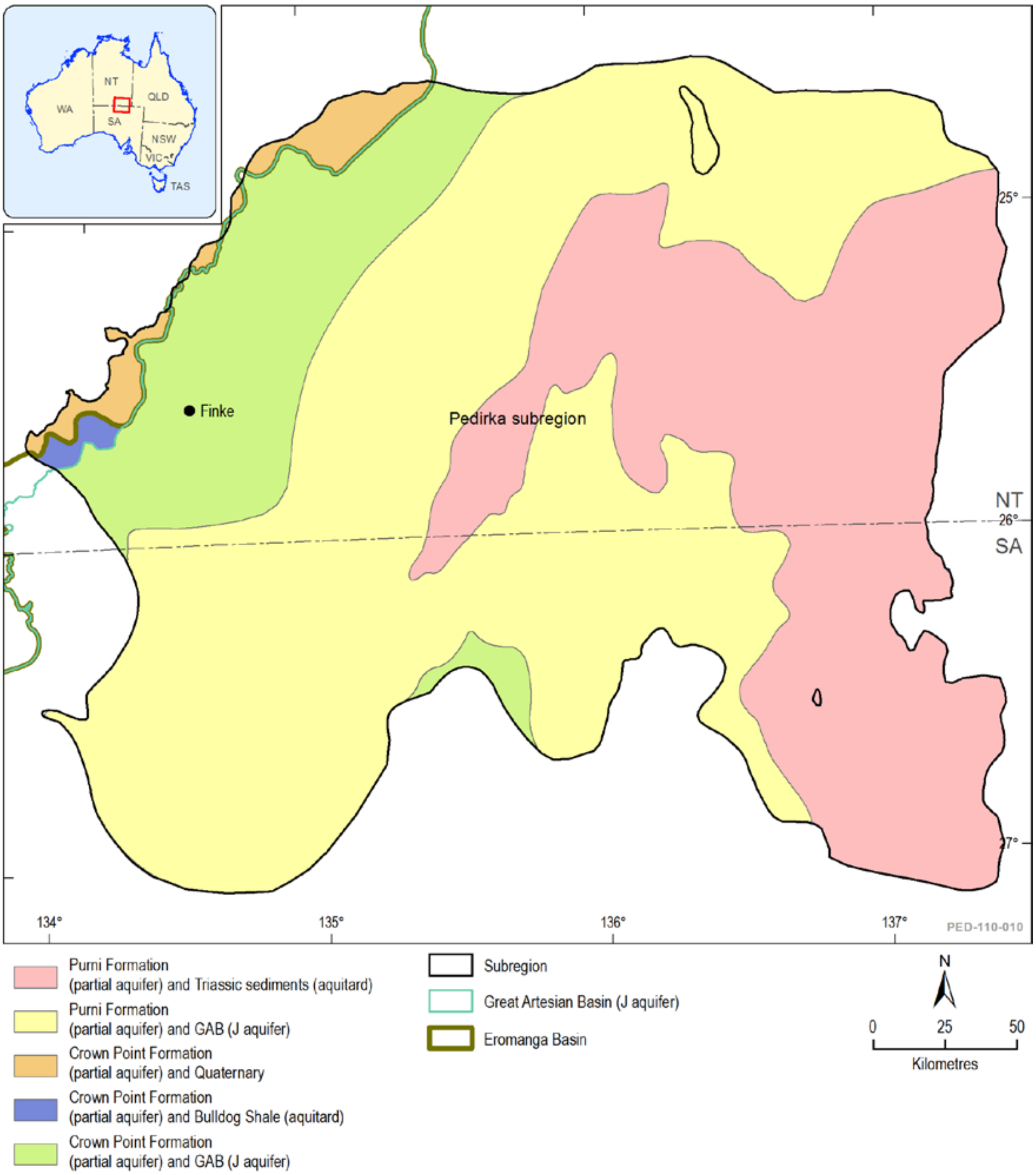


Figure 22 Possible connectivity relationships between the Pedirka and overlying basins

Note: The presented interpretations in this figure are based upon the architecture and composition of the Pedirka Basin as currently understood at the time of this report. Work determining the architecture of the Pedirka Basin is ongoing and subsequent information may alter interpretations of the structure, extent, basin architecture and hydrogeology of the Pedirka Basin in the future.

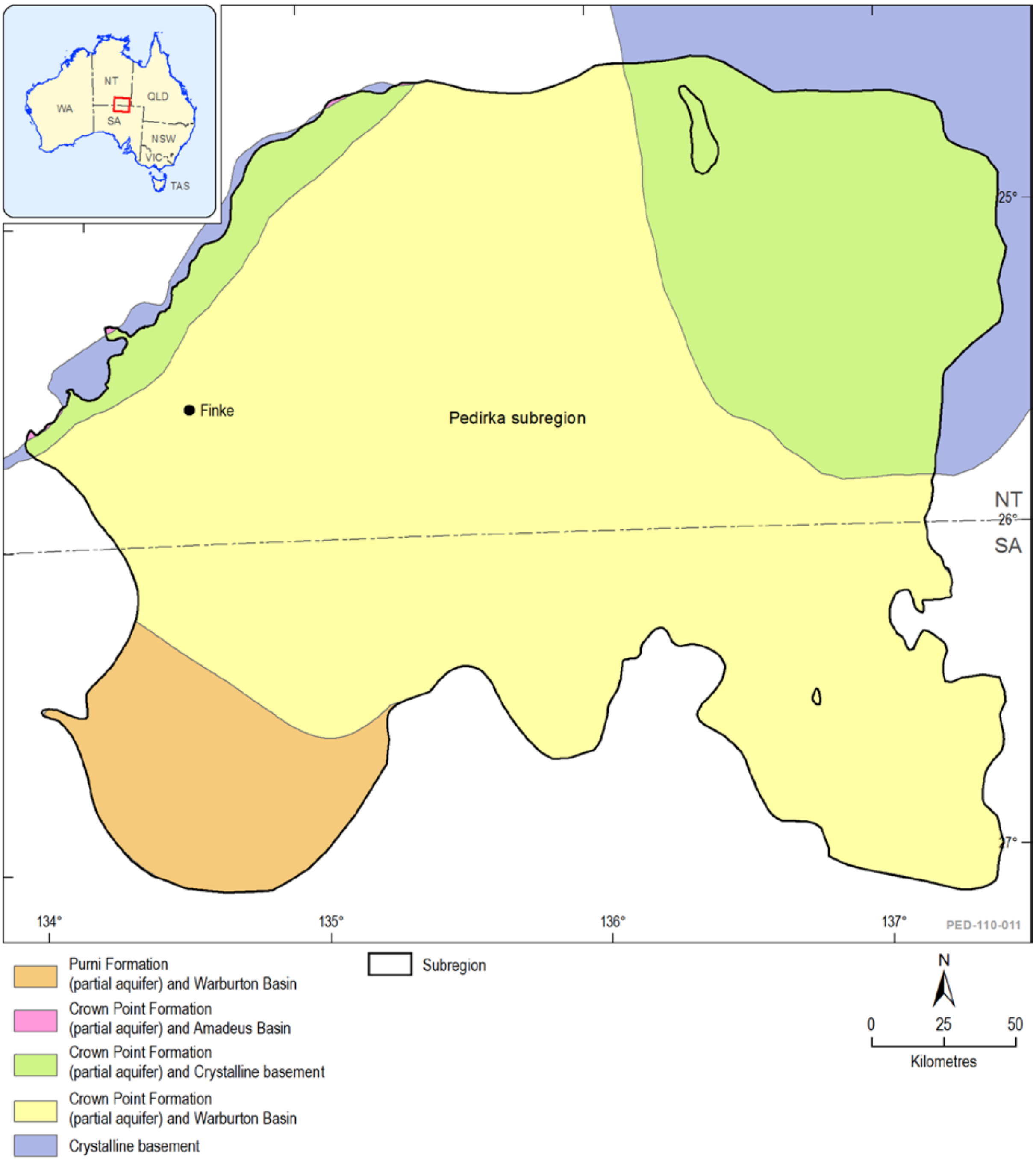


Figure 23 Possible connectivity relationships between the Pedirka and underlying basins

Note: The presented interpretations in this figure are based upon the architecture and composition of the Pedirka Basin as currently understood at the time of this report. Work determining the architecture of the Pedirka Basin is ongoing and subsequent information may alter interpretations of the structure, extent, basin architecture and hydrogeology of the Pedirka Basin in the future.

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1.1.4 Hydrogeology and groundwater quality

Summary

The behaviour of groundwater within the Pedirka Basin is poorly understood; the availability of data is too limited to determine if the formations act as a single flow system or as separate, discrete aquifers. The quality of groundwater extracted from the Crown Point Formation is fresh to brackish, but is generally of reasonable quality. Salinities from drill stem test data closer to the centre of the Pedirka Basin provide slightly higher salinities. Groundwater from the Crown Point Formation aquifer forms two distinct groups with respect to major ion composition.

In the vicinity of the Pedirka subregion, there are two recognised main aquifer units within the Great Artesian Basin (GAB). The Mackunda and Winton formations form an upper aquifer unit (K aquifer), while a deeper aquifer (J aquifer) occurs within the Cadna-owie Formation and Algebuckina Sandstone/DeSouza Sandstone. The J aquifer forms the only regionally extensive water resource of generally fresh to brackish quality in the Pedirka subregion.

Regional groundwater flow direction in the Pedirka Basin and the J aquifer is broadly to the south-east, with flow emanating from the north-west margin of the basins. Groundwater recharge to Pedirka Basin aquifers is postulated to occur in focused areas such as rivers that flow over outcrop and via direct infiltration of rainfall. On a regional scale, the Dalhousie Springs complex may act as a point of discharge for Permian aquifers as well as GAB aquifers, while at a local scale small waterholes may act as points of discharge. Discharge is also likely to occur as cross-formational flow. It is currently thought that significant recharge to the J aquifer along the western margin occurred in wetter climatic periods of time than what is currently being experienced. The present day volume of recharge is considered to be significantly less than natural discharge; although modern recharge may have localised significance for the maintenance of springs. Diffuse recharge rates in the Pedirka subregion have been determined to be negligible. In contrast, locally significant active ephemeral river recharge has been identified. Discharge from the J aquifer occurs in the vicinity of GAB springs located to the south and south-east of the Pedirka subregion and potentially via upward leakage into the K aquifer, but only where faulting has deformed overlying confining layers.

Overlying the GAB, important local scale water resources occur in shallow, disconnected Cenozoic aquifers. Water quality and recharge processes in the Cenozoic aquifers are highly influenced by proximity to surface water systems. Little is known about groundwater discharge from the shallow aquifers, though it is likely to be via semi-permanent waterholes and via evapotranspiration.

Little is known about the prevalence and nature of intra-basinal aquifer connectivity within the Pedirka Basin, however the Purni and Crown Point formations may act as regional-scale aquifers in at least partial connectivity. Additionally, the significant faulting and folding identified may have formed pathways for groundwater to migrate between aquifers or conversely led to the formation of hydrogeological sub-basins.

1.1.4.1 Groundwater systems

The Pedirka Basin is one of a series of stacked sedimentary basins extending from the Neo-Proterozoic Amadeus Basin through to the Quaternary surficial Lake Eyre Basin. Aquifers occur in all major basin sequences, though due to the significant burial depth there is a paucity of data associated with the Amadeus and Warburton basins where they underlie the Pedirka Basin. With respect to water quality, availability and existing extraction the Great Artesian Basin (GAB) is the most significant and extensive water resource in the region. At a local scale, aquifers within the shallow Quaternary and Tertiary deposits, and the Crown Point Formation within the Pedirka Basin, also provide an important supply of stock and domestic groundwater.

1.1.4.1.1 Pedirka Basin

The behaviour of groundwater within the Crown Point and Purni formations is poorly characterised. An estimated 28 bores have been constructed in the Crown Point Formation and only two bores in the Purni Formation; all groundwater infrastructure is located on the western edge of the basin in the NT. The availability of data is too limited to determine if these formations operate as a single homogenous flow system or as separate, discrete, aquifers.

As previously mentioned, with respect to groundwater extraction and therefore information concerning groundwater characteristics from the Pedirka Basin, groundwater extraction occurs exclusively from the Crown Point Formation. Well yields range from 0.2 to 2.5 L/second, with an average of 1.3 L/second. It is worth noting that the majority of wells are used for stock water supply and the estimated well yield generally reflects the water requirement rather than the true yield potential of the aquifer. Petroleum well completion reports document a hydraulic conductivity range of 0.08 to 1.66 m/day and a porosity range from core analysis of 10 to 32%. No estimates of aquifer parameters from groundwater-focused investigations are available.

Information on the groundwater characteristics of the Purni Formation is extremely limited. There is currently no extraction from this formation and no published assessment of groundwater depths, bore yield or aquifer parameters. Petroleum and gas well completion reports estimate hydraulic conductivity for the Purni Formation at between 0.11 and 2.44 m/day with a porosity range from core analysis of 16 to 25%.

1.1.4.1.2 Cenozoic aquifers

Important, local scale water resources occur in shallow, disconnected Cenozoic aquifers. These include the Hamilton sub-basin, Tertiary paleovalley systems and Quaternary alluvial aquifers associated with the present day surface water drainage (Figure 24). Of particular note are Cenozoic alluvials associated with the Finke River, given the relationship between the Finke River and recharge to the GAB. These aquifers are generally porous media, of limited thickness (<100 m) and not regionally extensive. Very limited information is available on aquifer parameters or bore yields for the Cenozoic aquifers. Groundwater extraction is limited and is predominantly used for stock and domestic supply.

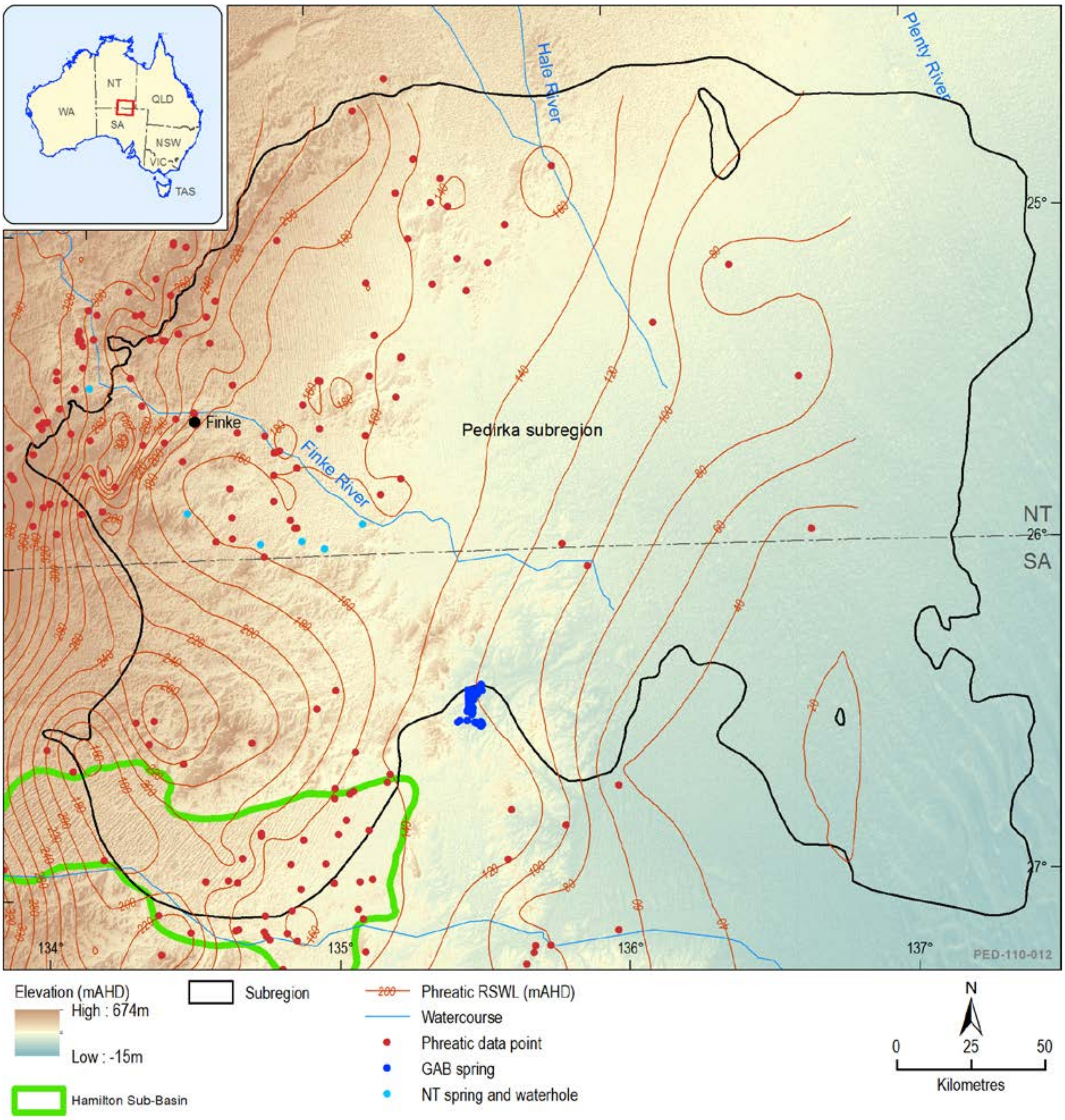

Figure 24 Interpreted watertable contours for the Pedirka subregion

Note 1: Although the watertable 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.
Note 2: 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

Where it overlies the Pedirka Basin the GAB consists of an upper sequence of Cretaceous marine clays, silts and shales known collectively as the Rolling Downs Group and a lower sequence of Cretaceous to Jurassic terrestrial sediments that form a significant aquifer unit (the J aquifer). Within the Rolling Downs Group the Mackunda Formation and lower portions of the Winton Formation form an upper aquifer unit (the K aquifer) (Habermehl, 1980). The Bulldog Shale, Oodnadatta Formation and lateral equivalents separate the upper and J aquifers and form the main confining beds for the GAB sequence.

The J aquifer is an unconfined to confined artesian aquifer, comprising the Algebuckina Sandstone, Cadna-owie Formation and their lateral equivalents. It forms the only regionally extensive water resource with a high beneficial use (Figure 25). The J aquifer is a porous media sandstone aquifer which shows dual porosity behaviour at a local scale (Fulton, 2013). Typical bore yields range from

1 to 5 L/second, though yields of up to 125 L/second have been reported in free flowing bores (Humphreys and Kunde, 2004). Regionally, the J aquifer has reported porosities of between 10 and 29% (average of 23%) with an observed decrease in porosity with greater burial depth of the aquifer (Radke, 2000). Within the Pedirka Basin, transmissivity for the J aquifer is in the order of 2500 m^2/day, hydraulic conductivity 11 m/day and storage coefficients of 1.2×10^{-3} (Fulton, 2013). Water level depths range from over 150 mBGL on the western margin of the GAB to more than 60 m above ground surface (artesian) in the south-east of the Pedirka Basin.The K aquifer is an unconfined to confined sub-artesian aquifer, consisting of disconnected sandstone aquifers within the Rolling Downs Group. The K aquifer is discontinuous across the Pedirka Basin and water quality is much more variable than the J aquifer, ranging from <1000 to >100,000 mg/L (Keppel et al., 2013). In comparison to the J aquifer, extraction from the K aquifer is very limited. The aquifer is generally used where accessibility of water is a greater driver than water quality (e.g. road construction). Tight shales of the Oodnadatta Formation and Bulldog Shale form an aquitard with extremely low vertical hydraulic conductivities (1×10^{-13} to 4×10^{-14} m/s, Love et al., 2013a) that limits cross-formational flow between the J and K aquifers. However, potential for cross-formational flow exists where bore construction is poor or bore casing is corroded. Several such cases are documented in the NT portion of the GAB (Fulton, 2013).

In SA, all groundwater resources within the GAB and Far North Prescribed Wells Area (FNPWA) are subject to license and allocation regulations governed by the FNPWA Water Allocation Plan. In the NT, all water resources (groundwater in all aquifers and surface water) that fall within the geographic extent of the NT GAB Water Control District are managed under the GAB NT Water Allocation Plan.

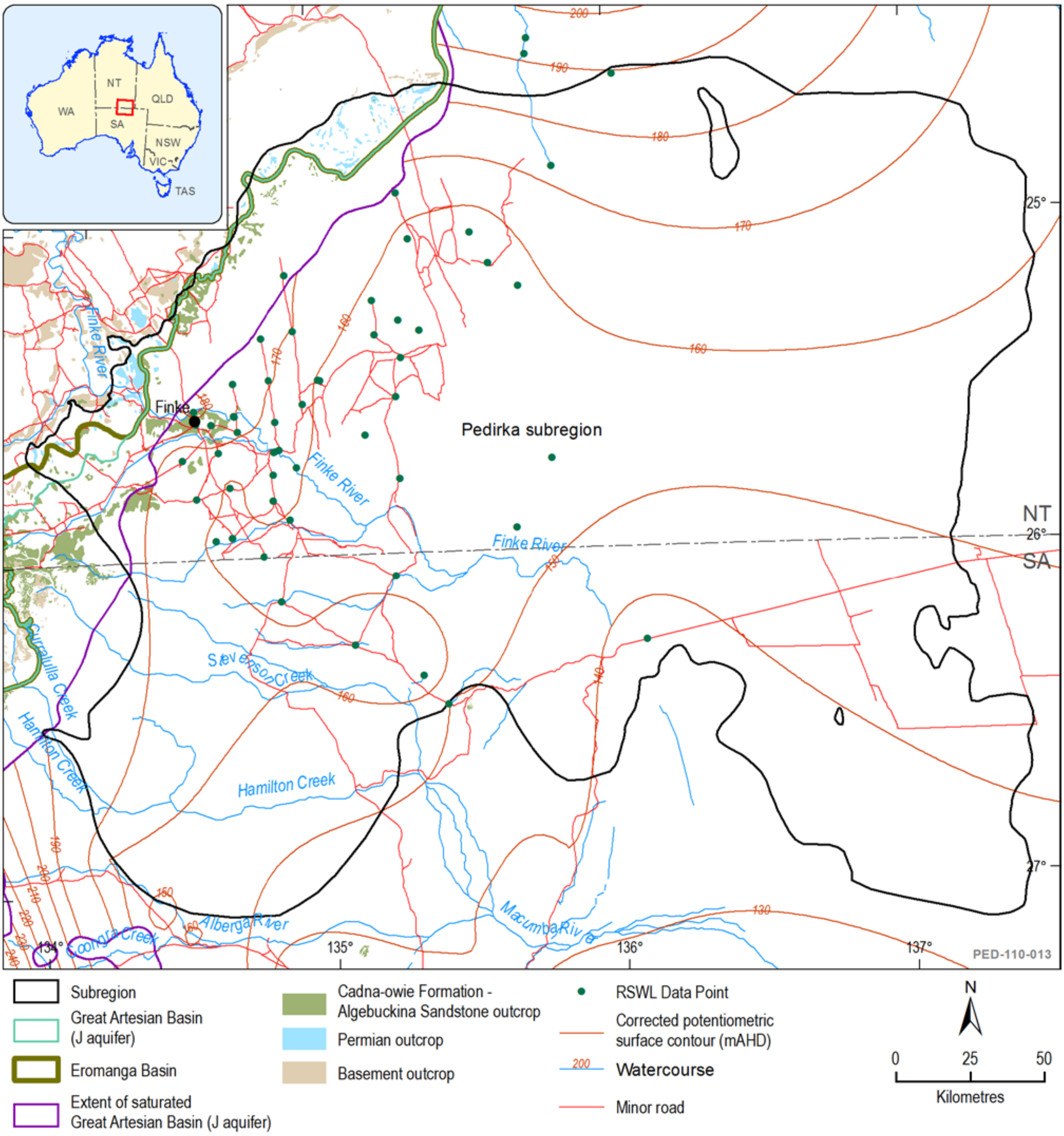

Figure 25 Density and temperature corrected potentiometric surface of the J aquifer clipped to the extent of the Pedirka Basin showing some of the basin margin and key discharge features

1.1.4.1.4 Amadeus Basin and Warburton Basin

The western Pedirka Basin overlaps the eastern extent of the Neo-Proterozoic to Cambrian aged Amadeus Basin. The hydrogeology in the centre and west of the basin, where it is used for town water supply (Alice Springs) and oil and gas production (Palm Valley), is better characterised than the eastern region, where data are limited to regional studies (Lau and Jacobson, 1991) and drilling records from the NT groundwater database. Approximately 26 bores have been constructed in the Langra Formation where the Amadeus Basin outcrops immediately to the west of the Pedirka Basin in the NT. The Langra Formation comprises layers of sandstone, siltstone and conglomerate; extraction from the formation is exclusively for stock and domestic supply. Average bore yields range from 2.2 to 12.6 L/second, with an average water level depth of 45 m.

Existing knowledge of the Warburton Basin is derived from the petroleum and gas industry, as the basin occurs at significant burial depth beneath the Lake Eyre, Eromanga and Pedirka Basin sequences. There are no groundwater wells screened in the Warburton Basin and as such no reliable information on the hydraulic behaviour of formations within the basin.

1.1.4.2 Groundwater quality

1.1.4.2.1 Pedirka Basin

Hydrochemistry data are only available for 21 wells screening the Crown Point aquifer, all of which are located on the north-west margin of the Pedirka Basin (Figure 26). The salinity of groundwater samples ranges from 93 to 7910 mg/L with an average water quality of 2470 mg/L. Lowest salinity groundwater is encountered in wells adjacent to the Finke River and Goyder Creek, where five wells contain potable groundwater (salinity <500 mg/L). It is currently speculated that the Finke River may provide recharge to the Crown Point Formation, although this requires further work to substantiate. The salinity is greatest in the northernmost wells where it approaches 8000 mg/L, exceeding the recommended guideline for beef cattle with no loss of production or condition (5000 mg/L, ANZECC & ARMCANZ 2000). Outside the north-west region of the basin only drill stem tests (DST) from oil exploration wells provide a semi-quantitative measure of groundwater quality. Six chemical analyses from DST’s undertaken in the central and eastern region of the basin report a salinity range of 1100 to 15,000 mg/L with an average of 8900 mg/L. There are limited data available beyond major ion chemistry and physical parameters for the Crown Point Formation and no hydrochemistry data available for the Purni Formation.

Groundwater from the Crown Point aquifer forms two distinct groups with respect to major ion composition: Group 1 with a calcium-bicarbonate ($Ca\text{-}HCO_3$) dominant water type and Group 2 with a sodium-chloride (Na-Cl) dominant water type (see inset, Figure 26). Group 1 groundwater samples are sourced from bores located adjacent to the Finke River and Goyder Creek on the north-west margin of the basin. The $Ca\text{-}HCO_3$ dominance, low salinity and high carbon-14 (^{14}C) concentration in these samples are consistent with recharging groundwater and suggest that the local drainage provides an active recharge sink to the Crown Point aquifer in this area. At a local scale the Crown Point aquifer forms an important water supply to pastoral activities as the groundwater quality from underlying aquifers in the Warburton Basin and fractured basement is marginal. The aquifer may also operate as a water source to semi-permanent waterholes located in the bed of the Finke River. Group 2, consisting of all other groundwater samples from the Crown Point aquifer, have a predominance of sodium and chloride, higher salinity and lower ^{14}C concentrations. Broadly this suggests a more evolved groundwater with a longer residence time in the aquifer than Group 1. Acknowledging the spatial limitations of the dataset, groundwater samples from Group 2 are more representative of the regional groundwater composition of the Crown Point aquifer.

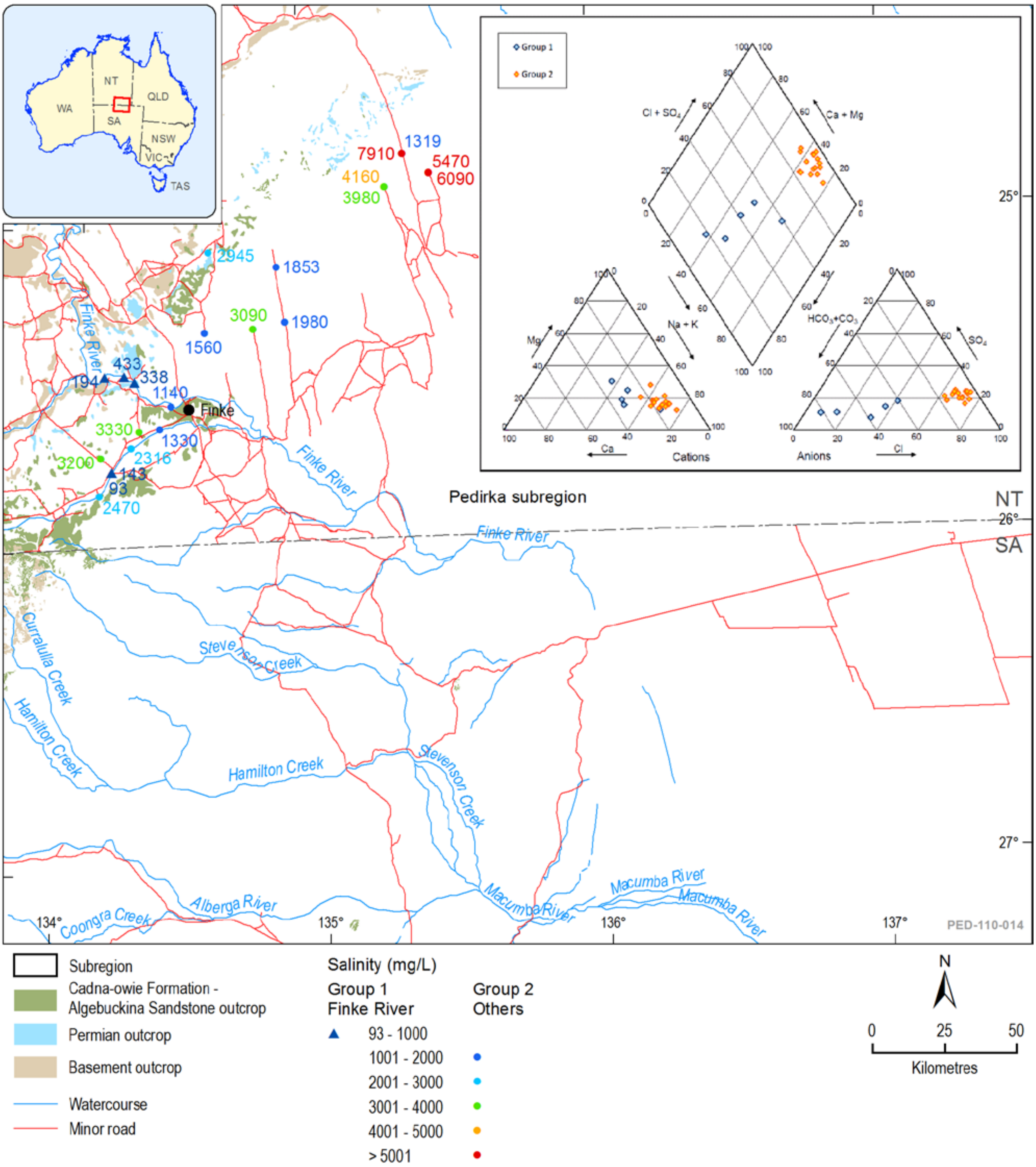

Figure 26 Water quality with two groupings of data (Finke River bores and all other bores)

Inset: Tri-linear piper diagram, groundwater in the Permian aquifer.

1.1.4.2.2 Great Artesian Basin

Groundwater in the J aquifer emanating along the western margin of the GAB has a sodium-chloride-sulfate (Na-Cl-SO4) water type that is distinct from the sodium-chloride-bicarbonate (Na-Cl-HCO3) ionic signature characteristic of water derived from the eastern margin (Habermehl, 2002). Salinity from the J aquifer within the Pedirka Basin ranges from 240 to 5100 mg/L, spatially the lowest salinities occur around the recharge zone of the Finke River. This area and the recharge zone along the Plenty River north of the Pedirka Basin are also characterised by lower chloride, cation and bicarbonate concentrations. There is a pronounced trend of increasing cation and chloride concentrations along flow path away from the western margin and toward the regional discharge features of Dalhousie Springs and Kati Thanda – Lake Eyre (Smerdon et al., 2012). Groundwater quality in the K aquifer is much more variable, ranging from less than 1000 to in excess of 100,000 mg/L (Love et al., 2013b).

Isotope hydrology supports the flow patterns and directions determined from hydraulic head data. Modern groundwater has been identified through the use of ^{14}C, sulfur hexafluoride (SF_6) and chlorofluorocarbons (CFCs) around the Finke River and the Plenty River indicating active, modern recharge to the J aquifer (Love et al., 2013b). Away from the basin, margin studies have used a range of isotopic techniques including chlorine-36 (^{36}Cl), helium-4 (^{4}He) and krypton-81 (^{81}Kr) to determine groundwater residence times for groundwater in the western GAB. Estimates range from 225,000 years (Collon et al., 2000) to over 2,000,000 years (Torgersen et al., 1991).

The J aquifer provides the primary water source for pastoral enterprise in the Pedirka subregion and also the town water supply for Indigenous communities, outstations and domestic supply for pastoral homesteads. From an environmental perspective, the J aquifer is the source of water for the iconic western margin GAB springs. The most significant with respect to discharge volume is Dalhousie Springs, which is located just beyond the southern margin of the Pedirka Basin. Love et al. (2013a) determined that Dalhousie Springs is sustained by water recharged along the western margin of the GAB. In addition Wolaver et al. (2013) presented evidence that Permian aquifers could also be contributing some groundwater discharge at Dalhousie Springs and Ransley et al. (2012) suggested groundwater discharge within the Dalhousie Springs region may also be sourced from Finke River bed underflow.

1.1.4.2.3 Cenozoic aquifers

Water quality in the Cenozoic aquifers is highly variable; salinities ranging from 300 to 10,240 mg/L with an average concentration of 2380 mg/L. The presence and quality of groundwater in the shallow alluvial aquifers in particular, is strongly influenced by surface water processes and is highly variable at a local scale. Potable water often halos watercourses (e.g. Finke River) but deteriorates in quality rapidly with distance from the river (Fulton, 2013). The alluvial aquifers also provide a conduit between the surface water processes and the GAB aquifers (see the Plenty River case study in Love et al., 2013b). Areas where good quality groundwater resources occur in Cenozoic aquifers include the Hamilton sub-basin in SA, the mid regions and flood-out of the Finke River, and the Indida and Andado swamps in the NT. The flood-outs and swamps represent important ecosystems and shallow aquifers underlying these areas are likely to help sustain vegetation between infrequent flood events. Several paleovalley deposits have been identified on the Geoscience Australia Paleovalley Map (Bell et al., 2012), however, little is known about the water quality attributes of groundwater in these aquifers.

1.1.4.2.4 Warburton and Amadeus Basin aquifers

Water quality data for the Amadeus Basin formations is based exclusively on the Langra Formation where it outcrops in the north-west of the Pedirka Basin. Lau and Jacobson (1991) report a salinity range of between 290 and 12,900 mg/L with an average concentration of 4650 mg/L. No water quality data are available for the formation further east under the main body of the Pedirka Basin. There is also no water quality data available on the Warburton Basin formations.

1.1.4.3 Groundwater flow

1.1.4.3.1 Pedirka Basin

A time composite potentiometric surface constructed from 21 groundwater levels and five DST formation pressures has been used to infer generalised flow directions within the Pedirka Basin (Figure 27). The regional groundwater flow direction is to the south-east, with flow emanating from the north-west margin of the basin, an area that coincides with the surface expression of the Crown Point Formation. This flow pattern suggests that the Permian aquifer either receives active recharge or recharge has occurred along this margin under wetter climates in the past; under the second scenario, the groundwater flow pattern would reflect a paleo-head distribution. The highest groundwater elevations occur where the Finke River flows through a region of outcropping Crown Point Formation and suggests potential recharge interaction between the river and the Permian aquifer.

Data coverage is very poor over most of the Pedirka Basin except for the north-west margin. The Dalhousie-McDills Ridge is a major structural feature bisecting the centre of the basin, which may cause flow partitioning within the Permian aquifer. Unfortunately, the data density is too low to prove or disprove the influence of this feature. Likewise, data coverage is too poor to discern the groundwater flow pattern along the south-west margin around the Dalhousie Springs complex. DST data in the east of the basin infers a flow direction from the centre to the south-east extension of the basin. The basin is very deep in this area and is overlain by 2000 m of Cretaceous and Jurassic sediments. Due to the burial depth it would seem more likely that any terminal discharge from this area would take the form of formation throughflow, rather than spring flow or other surface expression.

Recharge is postulated to occur through two mechanisms: direct infiltration of rainfall (diffuse recharge) and focused recharge where surface water features contact the Permian aquifer in either outcrop or sub-crop (Figure 28). A saturated chloride mass balance (CMB) approach estimated diffuse recharge along the north-west margin of the basin at between 0.02 and 0.16 mm/year. This is around an order of magnitude less than CMB estimates of recharge to the GAB aquifer in the same area (<0.1–1.5 mm/year, Love et al., 2013b). Results suggest that at present diffuse recharge to the Pedirka Basin aquifers is effectively zero though, given the generalisations and uncertainties characteristic of the data used in the assessment, it must be emphasised that the rates obtained are order of magnitude estimates only. The groundwater chloride, carbon-14 and hydraulic head distribution all suggest that focused recharge is occurring to the Crown Point aquifer through the Finke River and Goyder Creek. Existing data are insufficient to estimate a recharge rate to the Crown Point aquifer through this mechanism or to confidently delineate the recharge zone. Potential also exists for focused recharge along the lower Hale River and Coglin Creek in the NT and headwaters of the Stevenson and Alberga systems in SA.

There is limited information documenting groundwater discharge from the Permian aquifers in the Pedirka Basin. On a regional scale, Love et al. (2013a) suggests the Crown Point Formation, in addition to the GAB, may represent a potential source of discharge to the Dalhousie Springs complex

(Figure 28). At a local scale, a series of waterholes identified in the bed of the Finke River in the NT may reflect a small scale flow system with local discharge from the Crown Point aquifer. At present it is not clear whether these discharge features are associated with the Crown Point Formation or the Finke River alluvial system. In addition, the number of waterholes, their size, permanence, water quality attributes, the nature of the connection with the groundwater system and their ecological significance remain unknown. Discharge is also likely to occur as cross-formational flow; however, no studies were identified that characterised the direction or magnitude of this discharge component.

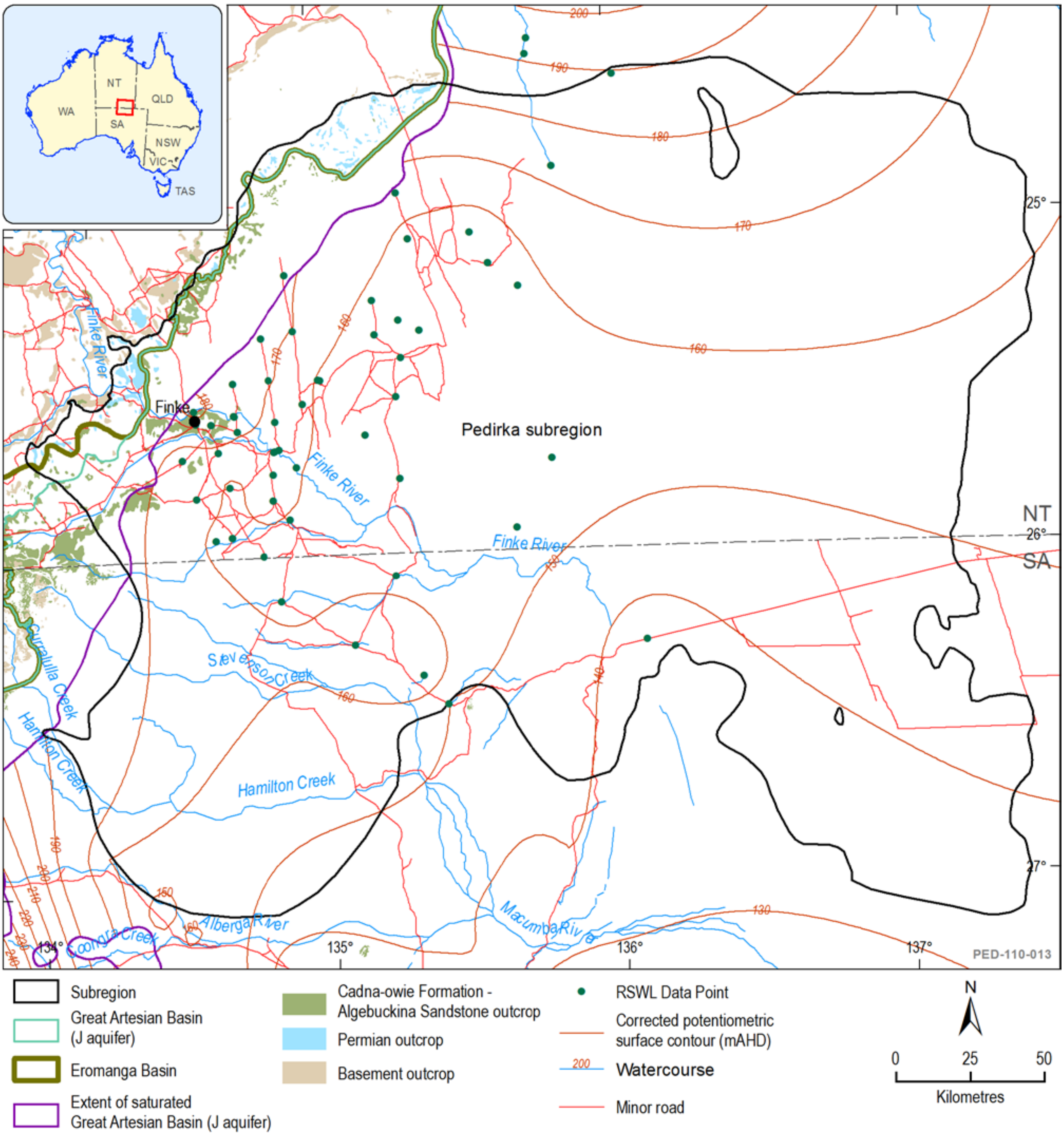

Figure 27 Water level data and time composite interpreted potentiometric surface for the Pedirka Basin

Note: Due to a paucity of adequate results, head data has not been corrected for density or temperature. Potentiometric surface contours for the GAB included for comparison.

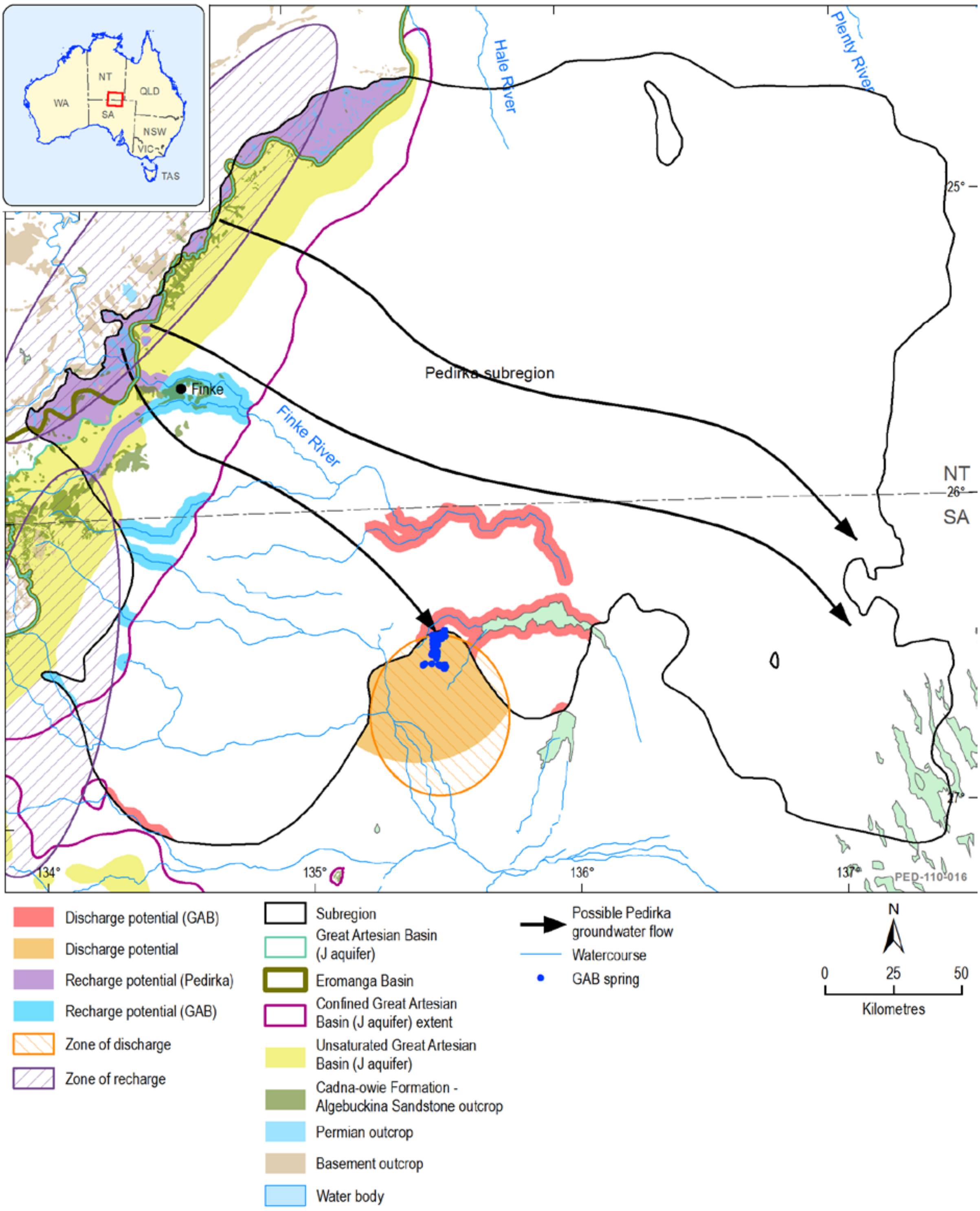

Figure 28 Conceptualised hydrogeological elements of the Pedirka subregion

1.1.4.3.2 Cenozoic aquifers

Limited groundwater monitoring and water level data exists for the Cenozoic aquifers, however, they can be reasonably characterised as local aquifers with small scale flow systems. Recharge processes are strongly associated with irregular flooding in the surface drainage network and the ponding of water in swamps and flood-out areas. Little is known about groundwater discharge from the shallow aquifers, though it is probable that these systems sustain semi-permanent waterholes on the lower Finke River between intermittent surface water flows. Groundwater levels in the aquifers are typically shallow (less than 10 m) and discharge will also occur in the form of evapotranspiration from riparian vegetation.

1.1.4.3.3 Great Artesian Basin

A time composite density corrected potentiometric surface for the J aquifer is presented in Figure 25. The regional groundwater flow direction is to the east and south-east away from the margin of the basin and towards Dalhousie Springs and Kati Thanda – Lake Eyre. Regional groundwater gradients are very low, being in the order of 1:3300. Existing water level data are concentrated in a relatively small area along the western and north-western margin of the GAB. Groundwater flow directions and patterns away from this area should be viewed with a low level of confidence. A groundwater mound is present under the Finke River where it crosses outcropping Algebuckina Sandstone along the western edge of the basin. Local reduced groundwater levels are elevated 10 m to 15 m and local gradients 2-3 times higher than the regional aquifer, clearly indicating a zone of enhanced recharge around the Finke River. Similar features are present along the Hale and Plenty rivers and Illogwa Creek on the northern margin of the GAB.

Recharge processes to the J aquifer along the western margin of the GAB are investigated in detail in Love et al., (2013b). This study concluded that present day recharge rates are much lower than recharge rates in the past, and water stored within the western GAB aquifers represent a legacy of higher recharge rates that occurred during wetter periods in the Pleistocene. The current volume of recharge is considered to be significantly less than current natural discharge; however, contemporary recharge has local significance for the persistence of some GAB springs. Three key recharge mechanisms were identified: diffuse recharge, focused ephemeral river recharge and mountain system recharge. Diffuse recharge rates estimated through groundwater and unsaturated CMB techniques ranged from <0.1 to 1.5 mm/year and indicate that presently there is negligible diffuse recharge entering the GAB aquifer along the western margin. Active ephemeral river recharge was identified along the Finke River and Plenty River. Recharge rates along the Finke River were estimated at between 380 – 850 mm/year, occurring across a recharge zone of approximately 16 km^2. Rates along the Plenty River were estimated at 17 to 92 mm/year. This represents a total flux of 13 GL/year, which is minimal in comparison to the magnitude of groundwater flow and storage within the J aquifer. Mountain system recharge was identified around Marla and Denison and Davenport Ranges, it was considered an important source of water for the Proterozoic fractured rock aquifer and dependant 'recharge springs', however, its contribution to the J aquifer system is considered negligible.

The J aquifer provides the principal water source for the western margin GAB springs, of which Dalhousie Springs is the most significant to the Pedirka subregion, being located immediately south of the subregion margin. Love et al., 2013b identified mantle derived CO_2 in spring discharge water, suggesting that there are potential pathways for fluid migration from deeper systems through to the J aquifer and GAB springs. Groundwater discharge also occurs from the J aquifer to both the overlying K and Cenozoic aquifers via the slow upward leakage of groundwater through massive sections of the Rolling Downs Group aquitard and preferentially through fracture and fault zones. Love et al., (2013a) found the permeability of the shale was so low as to make the rate of diffuse movement effectively zero. Rates of preferential leakage were found to be three orders of magnitude greater but still only equated to a flux of approximately 0.1 mm/year.

1.1.4.3.4 Amadeus Basin and Warburton Basin

No information exists regarding the flow systems, hydrostratigraphic units, or recharge and discharge processes in either the Amadeus Basin or Warburton Basin sequences where they are relevant to the Pedirka subregion.

1.1.4.3.5 Aquifer connectivity

Little is known about the prevalence and nature of intra-basinal aquifer connectivity within the Pedirka Basin. Current hypotheses concerning intra-basinal aquifer connectivity is based upon recently re-processed and interpreted seismic data presented in Wohling et al. (2013).

Both the Purni and Crown Point formations contain coarser grained sediments interbedded with finer grained siltstone shale and mudstone. Therefore, both formations have the capacity to act as either regional aquifers or contain a number of intra-formational aquifers that may be at least partially connected either via fault displacement or hydrogeological similar sediments in contact across unconformities.

Re-interpretation of seismic data presented in Wohling et al. (2013) inferred that Permian sediments are significantly faulted and folded, resulting in vertical displacement or the removal of sediments by erosion. In some instances, the displacement appears to have caused at least localised discontinuity within the Permian sequence; this being particularly evident in the vicinity of the Dalhousie-McDills Ridge. This feature may have led to the formation of partially disconnected hydrogeological sub-basins within the Permian sediments.

1.1.4.3.6 Current stresses

Beyond the minor water abstraction from Permian aquifers near the north-western and western margin of the Pedirka subregion, there is no known major abstraction and therefore no known major stress on groundwater resources within the Pedirka Basin.

1.1.4.4 Groundwater planning and use

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 is the only currently operational regional groundwater monitoring network within the Pedirka subregion (Figure 15). Additionally, there is periodic monitoring of water quality and flow of four springs within the Dalhousie complex approximately every six months undertaken by the South Australian Government (Sibenaler, 2010).

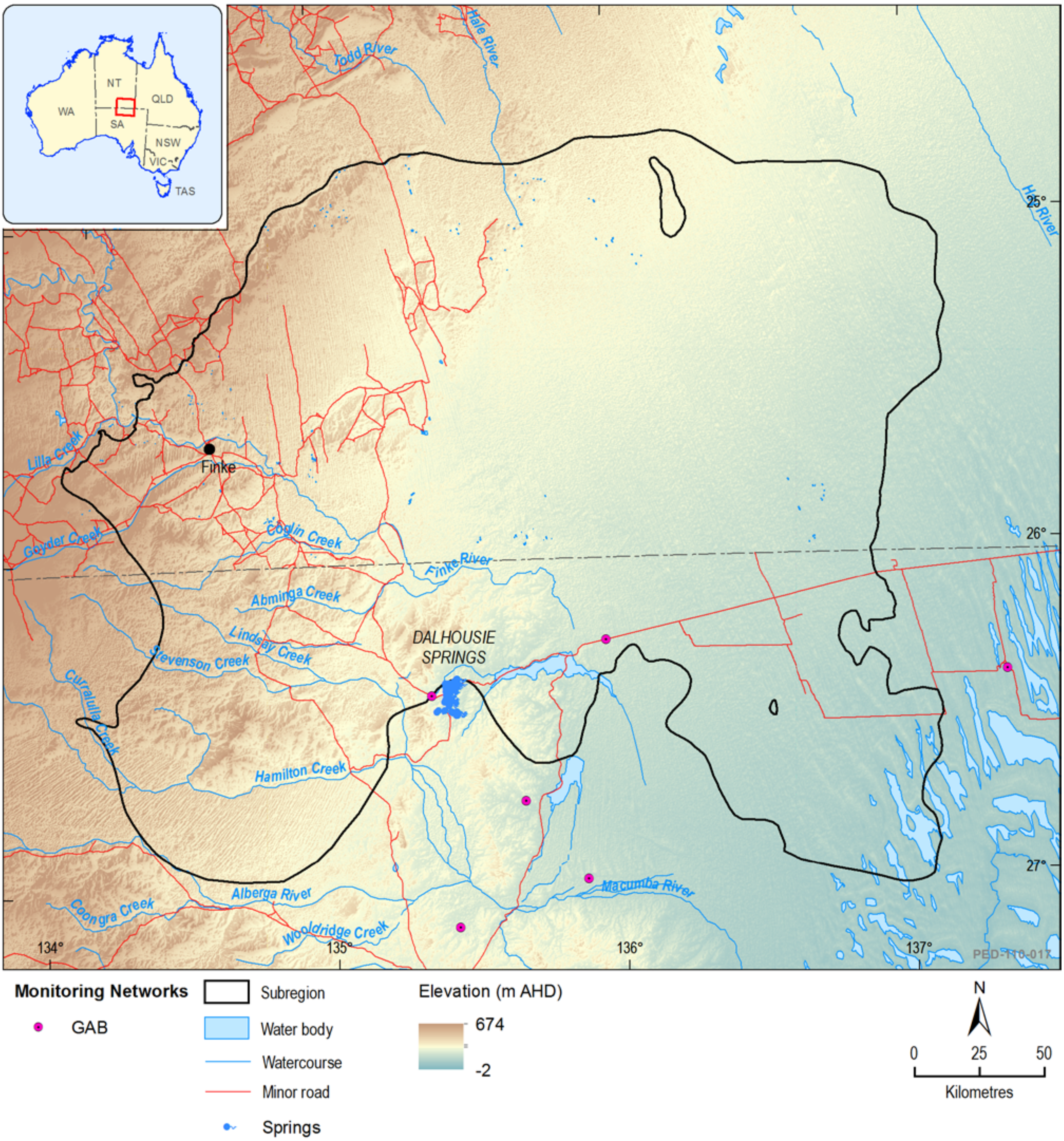

Figure 29 Groundwater monitoring networks within the Pedirka subregion

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1.1.5 Surface water hydrology and surface water quality

Summary

The Pedirka subregion of the Lake Eyre Basin is situated around the boundary of the NT and SA, and contains the most downstream part of the Finke catchment in the west of the subregion and intersects the Macumba catchment in the southern portion of the subregion. The extreme north of the Pedirka subregion also contains the lower floodout of the Hale River. The majority of the subregion is sandy desert, with the Simpson Desert covering more than half of the subregion to the east and the Pedirka Desert covering the south-western extents (Figure 30).

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 regimes in particular rivers. The site with the highest quality quantitative data in the Pedirka subregion is Eringa Waterhole, located on Lindsay River in the Macumba catchment, where only 17 months of measurements have been recorded. The data collected indicate the presence of shallow, high quality groundwater and suggest that the local flow regime is similar to that of the Neales-Peake (Arckaringa subregion) and flow events may occur around once a year. Observational evidence of the lower reaches of the Finke River catchment and the Finke Floodout indicate that large flow events, with annual recurrence intervals of around 10 years or more, are necessary to fully inundate the floodout. In addition, these large flows have been determined to be of importance for Great Artesian Basin (GAB) recharge as an area near Finke Community, immediately upstream of the Finke Floodout, has been identified as a key GAB recharge zone.

Smaller flow events in the lower reaches can fill waterholes, and may contribute to the persistence of the interdunal wetlands of the Finke Floodout subsequent to initial inundation created by a large river flow. Local flows from tributaries that feed directly into the floodout area may make a similar contribution to surface aquatic ecosystems. No data concerning the Hale River Floodout have been collected.

1.1.5.1 Surface water systems

1.1.5.1.1 Finke catchment

The headwaters of the 85,894 km^2 Finke catchment develop in the MacDonnell Ranges at an average elevation of 750 m. The typically well-defined and sandy main channel runs generally south-east for approximately 500 km before it reaches the edges of the dunefields of the Simpson Desert and breaks up into minor channels and interdunal lakes and floodways in the area known as the ‘Finke Floodout’ (Duguid, 2013) approximately 120 m above sea level. Flood events commencing in the upper reaches of the Finke catchment that are large enough to reach the terminal floodouts are uncommon, with an annual recurrence interval estimated as one in ten years (Ride, 2001). Hydraulic connectivity of the Finke catchment with Kati Thanda – Lake Eyre North was hypothesised as early as 1896 (Spencer, 1896), but no recorded evidence of such an event exists (Duguid, 2011). The best recorded large flood event since European settlement, occurring in 1967 was not large enough to connect the Finke with the Macumba catchment (Williams, 1970). Other large events in 2000 and 2010 have not been documented as causing connectivity, however there is very little information regarding these events.

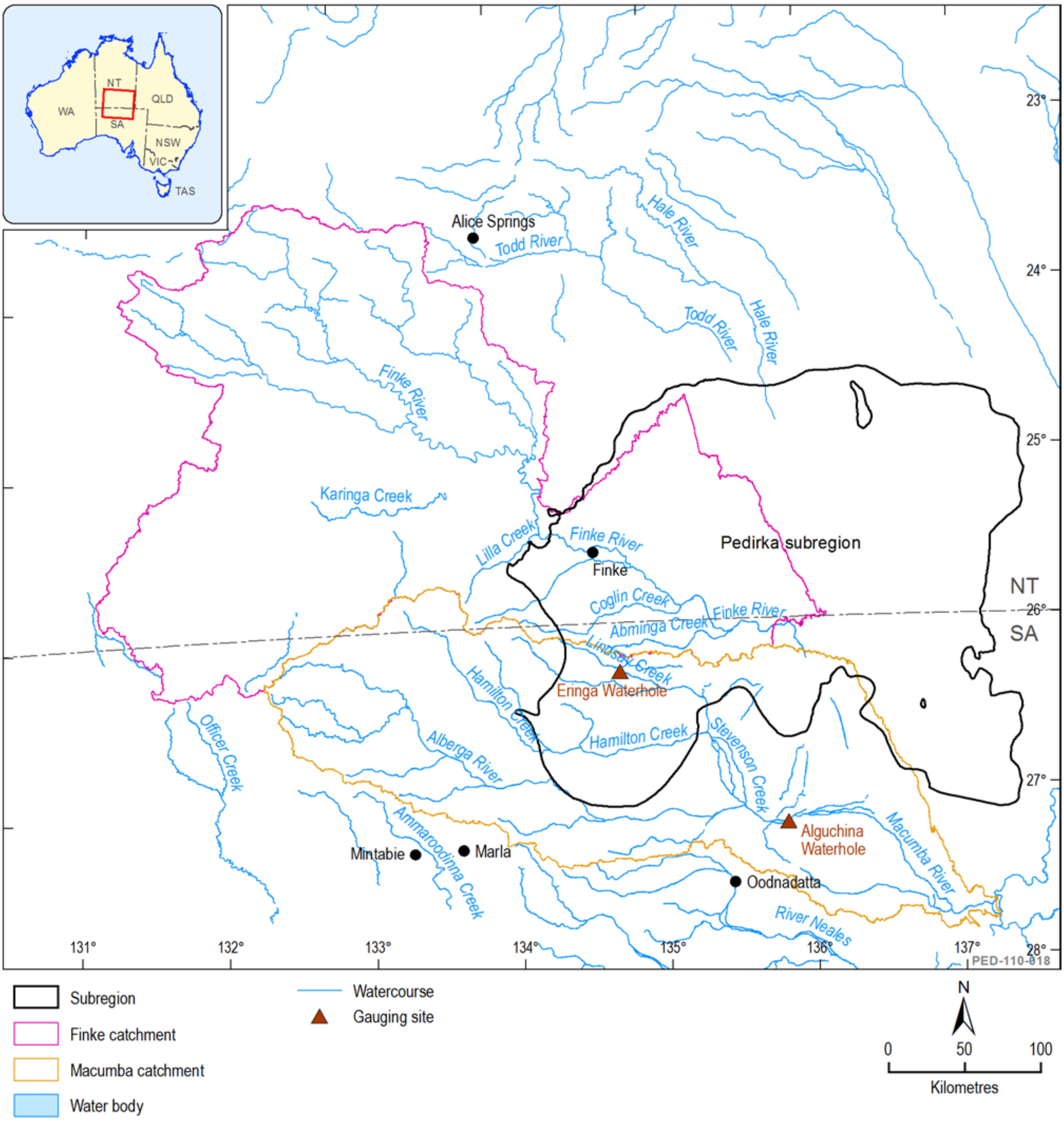

Figure 30 The Pedirka subregion with Finke and Macumba catchments shown

The Pedirka subregion intersects the Finke catchment adjacent to the confluence of Lilla Creek and the main channel of the Finke River, approximately 80 km downstream of the confluence of the main channel and Karinga Creek. The confluence with Karinga Creek has been defined as the potential differentiating confluence in defining the separation of the mid-Finke with the lower Finke (Duguid, 2013), although the 40 km prior to confluence is a floodway as opposed to a well-defined channel. Hydraulic connectivity between Karinga Creek and the main channel occurs perhaps as seldom as less than once every ten years (Duguid, 2013). The lower Finke has relatively few persistent waterholes and probably no permanent ones (Duguid, 2013). Observational evidence suggests that there are no permanent waterholes in the floodout (A Duguid, pers. comm., 2013).

The lower Finke is characterised by broad, well-defined sandy channels in both the main channel and tributaries. Lilla Creek and Goyder Creek are minor tributaries of the Finke River, starting in southern NT and connect with the main channel above the floodout in periods of flow. Coglin Creek is a more substantial tributary, forming on the uplands on the south side of the Beddome Range, both in the NT and SA and flooding out near Charlotte Waters Telegraph Station before merging with the Finke Floodout.

The Finke Floodout consists of distributory channels, longitudinal swamps between dunes, and areas of woodland. Some parts of the extensive woodlands are relatively dense and have been called ‘The Finke Floodout Forest’ (Duguid et al., 2005). Two major distributory channels form on the east and south sides of the floodout. To the east, Snake Creek runs into the Simpson Desert dunefield and forms a series of interdunal lakes and swamps. Below the Finke Floodout Forest, the other main distributory channel, renamed the Finke River, reforms and flows across the border into SA where it skirts the edge of the Simpson Desert dunefield and the rocky uplands east, before flooding out at the edge of the dunefields (Duguid, 2013). The last significant tributary of the Finke catchment, Abminga Creek, is wholly within South Australian borders and merges into the floodout around Mount Dare Homestead.

Annual rainfall totals vary greatly within the Finke catchment, with annual precipitation depths of around 300 mm found in Alice Springs, the most reliable nearby gauging station in the upper catchment, though it is likely that totals may be even higher in the headwaters of the catchment at the foot of the MacDonnell Ranges. This decreases to less than 170 mm at the Finke Floodout. Although rainfall events can occur at any time throughout the year, key rainfall events are the large summer transient depressions of tropical origin that dump large amounts of rain over the MacDonnell Ranges. It is these big rains that create enough flow for the floodout to be inundated (A Duguid, pers. comm., 2013). Nonetheless, local flows may play an important part in influencing the persistence of the interdunal wetlands of the Finke Floodout.

1.1.5.1.2 Macumba catchment

The Macumba catchment covers 57,015 km^2 and is an ephemeral, unregulated river system, consisting of four main watercourses: The Macumba River in the far south-east of the catchment, draining Stevenson Creek in the north of the catchment, Hamilton Creek in the mid-catchment and Alberga River in the south. The Macumba River begins at the confluence of Alberga River and Stevenson Creek, with the confluence of Hamilton Creek and Stevenson Creek 50 km upstream from that point.

Stevenson Creek has its headwaters in the Beddome Range at an elevation of around 370 m, running around 240 km, generally south-east, before it joins with Alberga River and becomes the Macumba River. Hamilton Creek also begins in the Beddome Range, but at a higher elevation than that of Stevenson Creek of around 500 m. It runs 250 km east south-east before merging with Stevenson Creek. The Alberga River has its headwaters at the foot of the much higher Mann-

Musgrave Ranges, at an elevation of around 700 m. It runs in a generally south-easterly direction for around 350 km before joining Stevenson Creek. The Macumba River runs generally to the south-east for around 160 km before flooding out in a large area of swampland that also contains the floodout of Kallakoopah Creek before merging with the floodout of Warburton Creek and draining into Kati Thanda – Lake Eyre. The hydraulic connection formed between the Macumba River and Warburton Creek during high flow events has been suggested to be of great significance to local fish species (D McNeil, pers. comm., 2013). By linking the arid rivers of northern SA to the immense Georgina-Diamantina system that spans 600,000 km^2 and contains many more permanent refugia, this connection provides the best means of repopulation of fish species after extended periods of drought. Recent research has indicated that fish species are consistent through the Macumba – Georgina-Diamantina system and different to those that were found in the Neales-Peake and Finke catchments (D McNeil, pers. comm., 2013). This provides evidence that the Macumba catchment has been hydraulically connected with Warburton Creek.

All major watercourses are characterised by sandy bed sediments and typically have quite good channel definition and several instream waterholes, except for Stevenson Creek between the Hamilton Creek and Alberga River confluences and the Macumba Floodout, both of which are poorly channelised, sandy floodplains. The Pedirka desert makes up much of the floodplains of the Alberga River and southern bank of Hamilton Creek, with the rocky gibber plains making up the floodplain for much of the middle reaches of Stevenson and Hamilton Creeks.

Annual rainfall in the catchment varies from approximately 300 mm at the feet of the Mann-Musgrave Ranges to around 140 mm at floodout. Although the majority of rainfall occurs in the summer months, significant winter rains are not uncommon (Costelloe et al., 2005). Key rainfall events in the Macumba catchment 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.

1.1.5.1.3 Hale Floodout

The Hale River has its headwaters north of Alice Springs, in the north-east MacDonnell Ranges, around 800 m above sea level and runs approximately 300 km before flooding out into the dunefields on the edge of the Simpson Desert, 180 m above sea level. The channel prior to floodout is well-defined and sandy (Duguid, 2011). Examination of remotely sensed imagery and observations from aerial survey suggests that the Hale River Floodout forms an area of very dense woodland, similar to the Finke Floodout Forest (Duguid, 2011). There is no available information regarding the regularity, volume, or quality of flow events in this area.

1.1.5.2 Surface water quality

1.1.5.2.1 Finke catchment

Extremely limited water quality data exists for the lower Finke and Finke Floodout. Observational evidence of one waterhole on Lilla Creek, Paddy's Well, indicates that it is fresh, though no measurements of conductivity were taken (A Duguid, pers. comm., 2013).

1.1.5.2.2 Macumba catchment

As mentioned previously, less than one and one-half years of water quality data for the Macumba catchment exists at two locations in the catchment. The most complete data are that collected at Eringa Waterhole on Lindsay River. Figure 31 indicates that the waterhole is predominately fresh, except when flushed with saline inflow from a flood event. During the flood event of March 2012, the initial floodwaters dropped conductivity from 170 to 105 µs/cm before rising to a maximum value of 1597 µs/cm one week after peak stage and receding to 145 µs/cm 32 days after peak salinity. It can be seen from Figure 31, that the small local flow in January 2012 was not significant enough to affect conductivity.

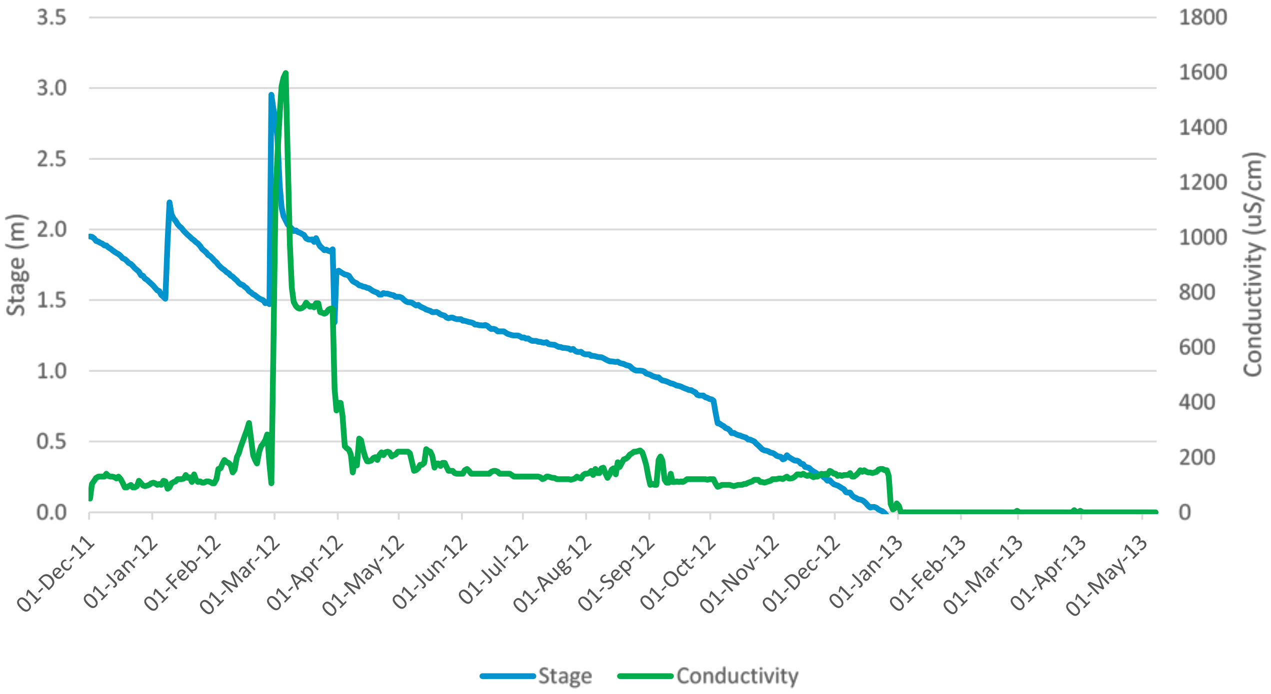

Figure 31 Stage and conductivity for Eringa Waterhole, December 2011 – May 2013

1.1.5.3 Surface water flow

1.1.5.3.1 Finke catchment

As previously mentioned, there is no dedicated monitoring of the lower Finke and Finke Floodout at this time, though Williams (1970) mentions that the 1967 floods were gauged at Finke Community without providing any quantitative information. The NT Government (A Duguid, pers. comm., 2013) has confirmed that there was a gauge in operation between 1960 and 1978 at Finke Community, likely by the old Ghan railway line, and can confirm that at least three flood events occurred during this time. It cannot be stated with any confidence that this is the definitive list of flood events during that time, nor is there any quantitative information regarding those flow events.

It has been suggested that the floodout will receive some water around one in five years (Love et al., 2013), though large flows originating in the upper Finke catchment that completely inundate the floodout have been suggested as occurring around once a decade or less (Duguid, 2013). There are no data to confirm this suggestion. Flows large enough to reach the floodout are of importance for recharge of the Great Artesian Basin aquifers as a key recharge area has been located upstream of the floodout, near Finke Community (Love et al., 2013).

Key flood events recorded in the upper reaches of the Finke catchment that at least partially inundated the Finke Floodout are known for 2010, 2000, (possibly) 1988, 1974, 1972, 1967, and (likely) 1921.

Contrasting the 2000 and 2010 floods, water was known to persist in the floodout for nearly three years following the 2000 event (Duguid, 2005) whereas the wetting caused by the 2010 flood dried out much more quickly. This could be due to more small and/or local flow events in the years following the 2000 flood than the 2010 flood. These flows tend not to be of sufficient magnitude to inundate the floodout without prior establishment of hydraulic connectivity by the larger, main channel floods. However, when connected, they enable the wetlands to persist far longer than would otherwise be the case (A Duguid, pers. comm., 2013) and therefore could be of great ecological significance. At this time, no data have been collected to confirm these observations and much of the initial flooding has been unobserved. Currently, work is being undertaken to improve monitoring of the floodout and better liaise with local pastoralists.

1.1.5.3.2 Macumba catchment

There is very little information regarding flow events in the Macumba catchment. The best documented flow event was the 1967 flood, detailed by Williams (1970). Caused by the southward intrusion of monsoonal storms, that event was enough to cause inundation of several kilometres of floodplain, the flooding of Stevenson Creek shown in Figure 32. Stage heights were estimated at between 5 to 7 m in Stevenson and Hamilton Creeks and Alberga River (Williams, 1970). The Macumba Floodout was extensive and is shown in Figure 33. No information is provided as to how long the floodwaters persisted. Similarly to the Neales-Peake catchment, described in Section 1.1.5 of the companion product 1.1 for the Arckaringa subregion (Miles et al., 2015), subcatchment and local flows in response to the more localised thunderstorm-derived rainfall are more common than whole-of-catchment events. These lower flow events are of critical importance to local biota, though no information exists at this time to describe the mechanics of the long term flow cycle in the catchment.

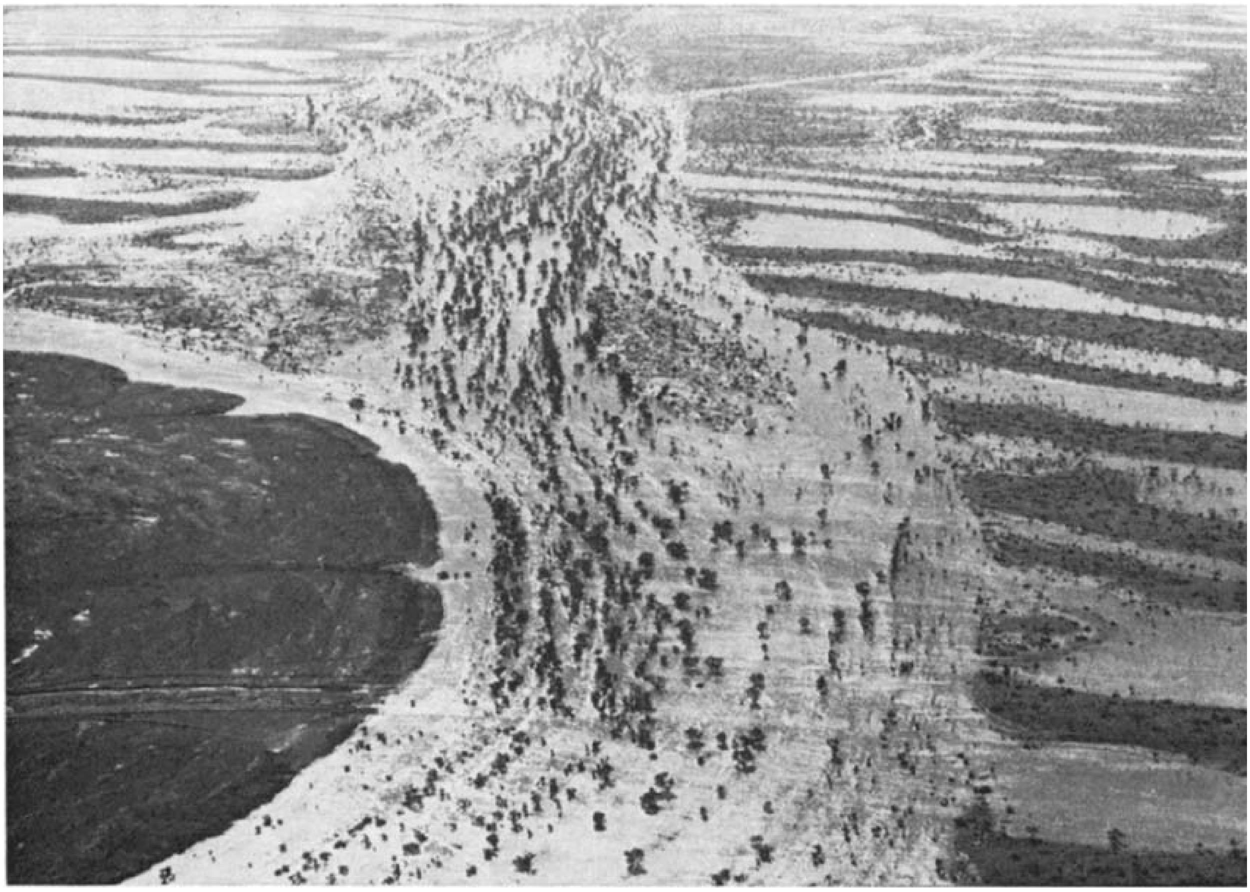

Figure 32 Flood of Stevenson Creek in 1967

Source: Williams (1970). This figure is not covered by a Creative Commons Attribution licence. It has been reproduced with permission from Elsevier.

Figure 33 Macumba Floodout during the 1967 floods

Source: Williams (1970). This figure is not covered by a Creative Commons Attribution licence. It has been reproduced with permission from Elsevier.

At this time, the hydrological data collected in the catchment consists of stage and water quality data at both Eringa Waterhole on the Lindsay River, a tributary of the upper Stevenson, and at the Macumba River near Alguchina Waterhole towards the downstream end of the catchment for the period December 2011 to present. Figure 34 demonstrates that in this period two flow events were captured at both sites, with the March 2012 flow observed at both locations indicating a subcatchment flow. The other flow events were local flow events, with the local event of December 2012 observed at Alguchina and Algebuckina Waterhole in the Neales-Peake catchment (see Section 1.5.1 of the companion product 1.1 for the Arckaringa subregion (Miles et al., 2015)). Alguchina Waterhole is 30 km closer to Algebuckina than to Eringa, and the fact that a flow event that was observed in Eringa was not seen Alguchina and a flow event large enough to register in both Alguchina and Algebuckina but not Eringa highlights the local nature of rainfall events and the difficulties inherent in modelling the catchment response thereof.

The nature of these flow events suggests that the Macumba catchment behaves similarly to the Neales-Peake, where flow events can be expected most years. Analysis of the Eringa stage data (Figure 34) indicates observed losses are approximately equal to those that would be expected from evaporation of a closed (i.e. non-leaky) waterbody. No information regarding the frequency of the Macumba River flooding into Warburton Creek is available.

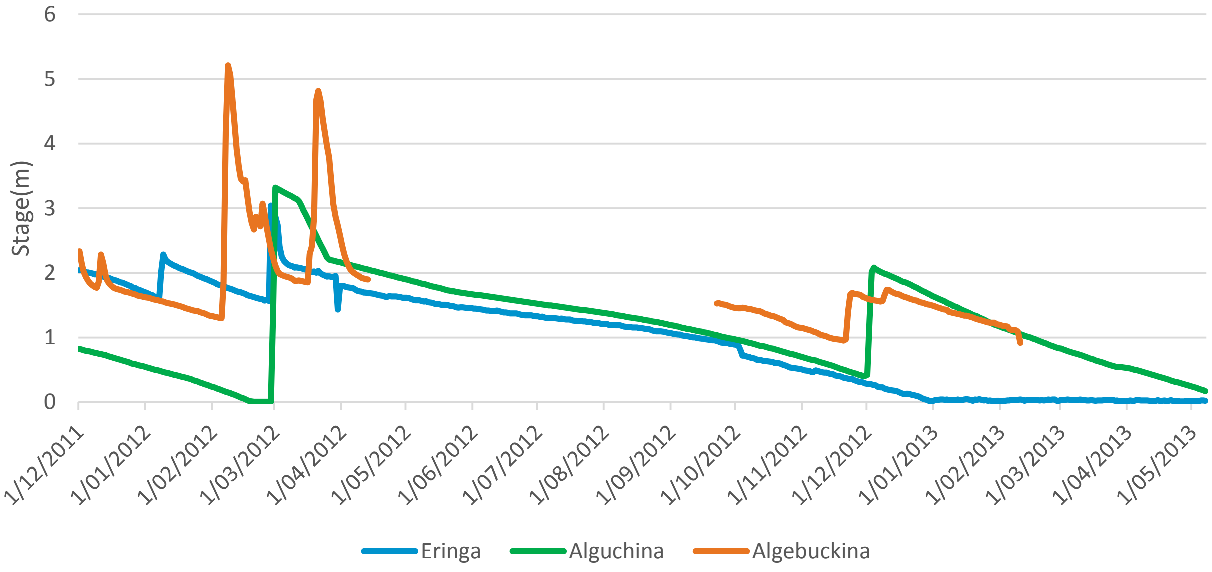

Figure 34 Stage data for Eringa, Alguchina and Algebuckina Waterholes for the period December 2011 – May 2013

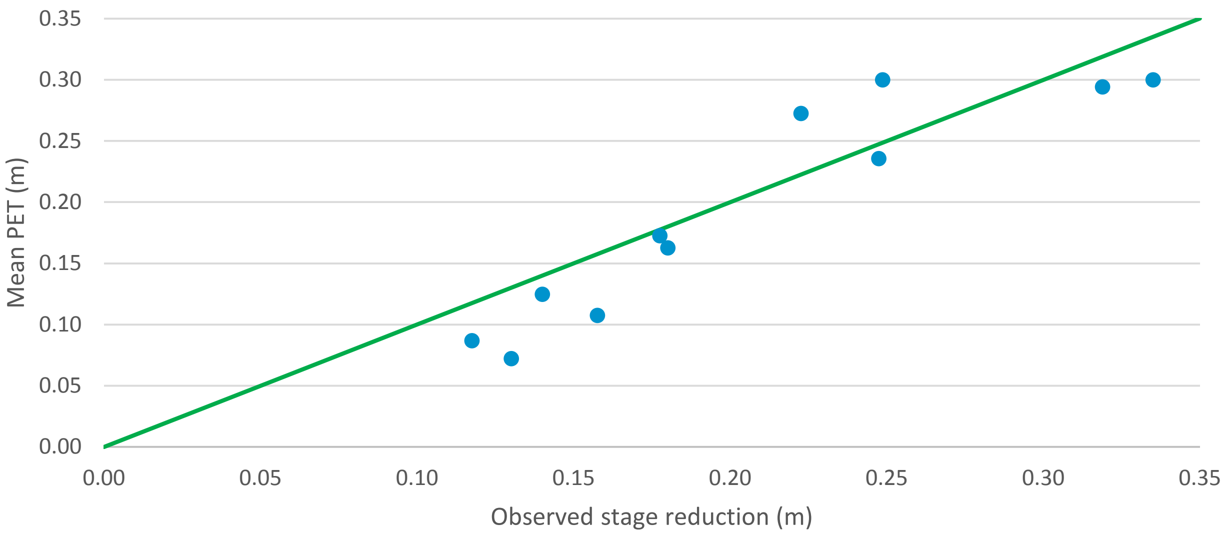

Figure 35 Observed stage reduction against estimated potential evapotranspirative loss for Eringa Waterhole, December 2011 – May 2013, with 1:1 line shown in orange

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1.1.6 Surface water – groundwater interactions

Summary

Surface water – groundwater interactions in the Pedirka subregion are largely confined to ephemeral river recharge (ERR). ERR refers to recharge occurring 'in channel' through the base of the river bed and does not encompass any localised recharge that results from overbank flooding (Love et al., 2013). Although flow events in arid-zone rivers are often anecdotally referred to as 'floods', overbank flooding along the recharge reach of the rivers is relatively rare due to the significant width and defined channel structure of the rivers.

Recent assessments of surface water – groundwater connectivity in the Pedirka subregion have identified the lower Finke as an important recharge zone for the GAB. The same research determined that key watercourses in the Macumba catchment, namely Alberga River and Stevenson Creek have limited recharge potential, with either the presence of an aquitard or a shallow unconfined aquifer restricting direct recharge.

1.1.6.1 Finke River recharge

The Finke River recharge zone (Figure 36) has been recognised as commencing approximately 6 km west of the Finke Community and terminating 36 km downstream near the margin of the confining beds, covering an area of approximately 13 km^2 (Love et al., 2013). The decadal floods originating in the MacDonnell Ranges that inundate the Finke Floodout and are described in Section 1.1.5.1.1 have been identified as the key events for recharge to the GAB, with hydraulic and environmental tracer data indicating that the recharge from smaller, local flows is negligible in comparison to the bigger floods. This is illustrated by considering that although annual recharge rates through the Finke River are estimated at between 380 and 850 mm/year, the measured recharge from a single flood event in 2010 was 1275 mm. In addition to the infiltration in the Finke River recharge zone, observational evidence suggests that the floodwaters reaching the Finke Floodout recharge a shallow aquifer, which helps sustain vegetative communities between intermittent flow events (D Wohling, pers. comm., 2013). In addition to recharge to the GAB, current research indicates that the Finke River may have potential for recharge to the deeper Pedirka Basin sediments (Wohling et al., 2013).

Observational evidence indicates that further connectivity between surface water and alluvial groundwater resources may occur throughout the length of the Finke River downstream of the recharge zone (Duguid, 2011).

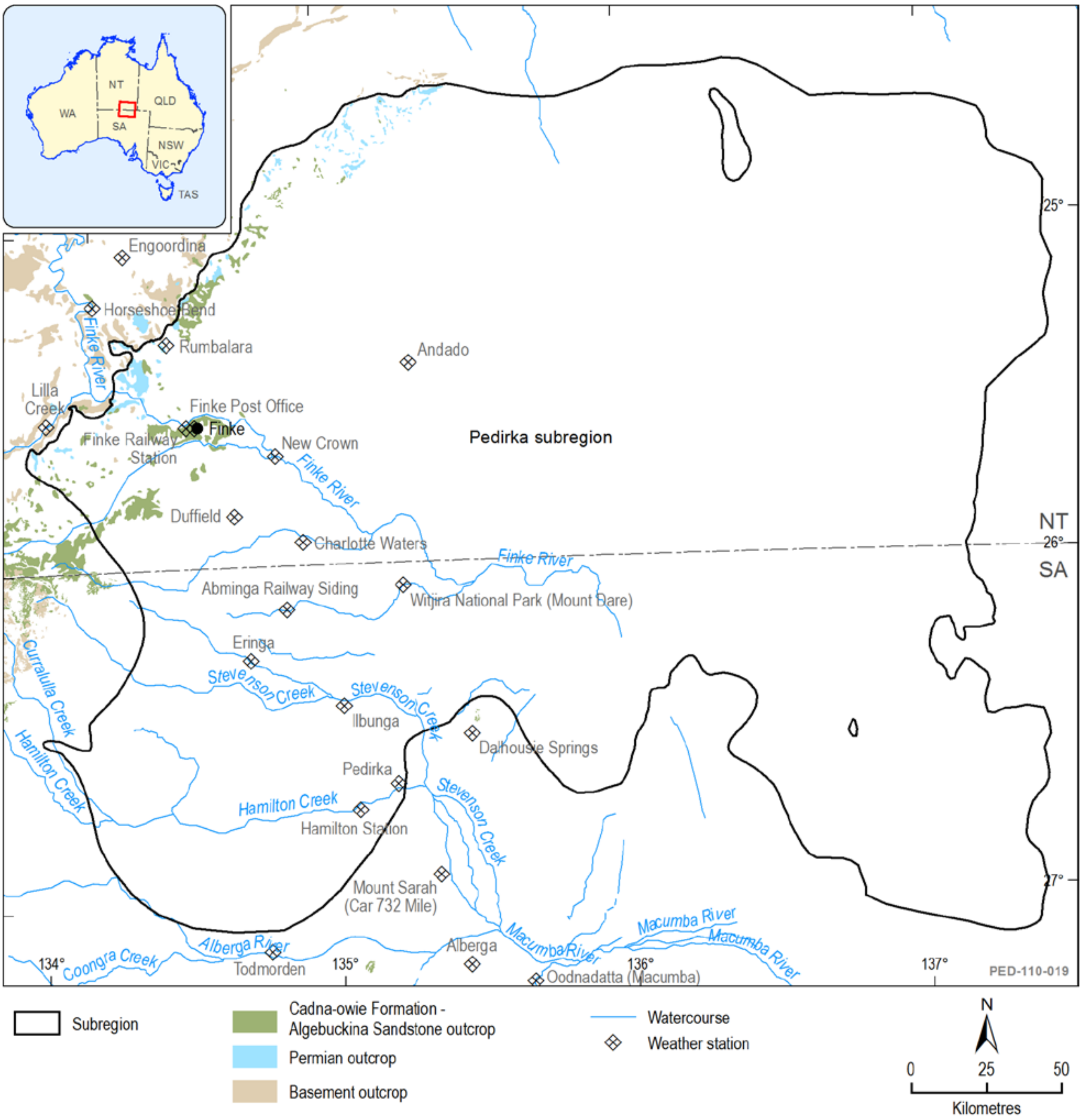

Figure 36 Finke recharge zone

1.1.6.2 Macumba catchment recharge

There is very little information regarding surface water – groundwater interactions in the Macumba catchment. Recent work has demonstrated that the Alberga River and Stevenson Creek have limited recharge potential (Love at al., 2013). Observational evidence suggests that the upper Macumba catchment has shallow groundwater, which impacts the persistence of key waterholes in the catchment (cf Section 1.1.5.2.1), though further work is necessary to confirm these observations.

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1.1.7 Ecology

Summary

The Pedirka 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 region has become increasingly arid over past millennia, leading to the isolation of aquatic ecosystems. Great Artesian Basin (GAB) springs of the Dalhousie supergroup are found near the southern boundary of the Pedirka subregion. These springs have flowed continuously for between one and two million 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. Five species of fish, three crustaceans, and three molluscs are found only at Dalhousie Springs. 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.

There are two major surface catchments occurring within the Pedirka subregion: the Macumba and Finke catchments. Both catchments are highly ephemeral and exhibit the ‘boom and bust’ ecology of the Lake Eyre Basin. Large floods occur infrequently, but drive spectacular booms in biotic production. Clusters of smaller floods prolong waterbody persistence and connectivity between waterbodies and produce cumulative responses from aquatic biota. During extended droughts, the entire Macumba catchment dries out, while permanent waterholes in the upstream reaches of the Finke provide refuge for obligate aquatic species in that catchment.

The Macumba catchment drains into Kati Thanda – Lake Eyre via the lower Georgina-Diamantina catchment. With no known permanent waterholes in the Macumba catchment, the nine native fish species found in the Macumba catchment can become locally extinct during extended droughts and are most likely to be reliant on populations in the Georgina-Diamantina catchment to repopulate during flood events.

The Finke River catchment floods out between the dunes of the Simpson Desert in the Pedirka subregion. This catchment is believed to have flowed to Kati Thanda – Lake Eyre between 1,000 and 20,000 years ago. Fish have been observed in the Finke floodout, but there have been no surveys in this reach. These wetlands support a diversity of waterbirds and wetland vegetation types and are of national significance.

Other wetlands occur in the Pedirka subregion, including endoreic drainages, swamps and interdune lakes. Some are known to be of conservation significance regionally, but many are very poorly studied.

1.1.7.1 Ecological systems

The Pedirka 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 Pedirka subregion contains three IBRA bioregions: Finke, Stony Plains and Simpson Strzelecki Desert (Table 5; Figure 37). The Simpson Strzelecki Desert is the predominant land system; it mainly comprises vast dunefields.

The Pedirka subregion has not been cleared of native vegetation, however, the natural biodiversity and condition has been altered through changes in burning regimes, introduction of pastoral grazing, pest plants and animals, additional watering points and free flowing bores, changes in water pressure to GAB springs and changes to surface water flow through construction of infrastructure (DEH & SAAL NRMB 2009).

The region has undergone gradual desertification over past millennia (Cohen et al., 2011; Magee et al., 2004) leading to the isolation of aquatic ecosystems (Gotch, 2013b). Aquatic ecosystems, including floodplains, floodouts, springs and ephemeral watercourses provide critical refuge and vital habitats for many species, including aquatic and terrestrial species (McNeil et al., 2011). Ecological processes are influenced by high levels of disturbance and variability driven by the variable arid climate. Large floods occur infrequently but drive spectacular booms in biotic production in the Lake Eyre Basin (LEB) (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. Within the Pedirka subregion there are no known permanent aquatic ecosystems, however the Great Artesian Basin (GAB) springs at Dalhousie just beyond the southern boundary of the subregion (and dependent on recharge zones within the subregion (Fulton et al., 2013)) include permanent pools and are estimated to have been active for between one and two million years (Kreig 1989). 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; Noack 2005; 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 criteria in the LEB, Kati Thanda – Lake Eyre, into which the Macumba catchment drains, and Dalhousie Springs were the only two aquatic ecosystems in the entire LEB to score very high in three HEVAE criteria (Hale et al., 2010).

Table 5 IBRA bio regions and IBRA subregions with a significant portion occurring in the Pedirka subregion

IBRA bioregion	IBRA subregion code	IBRA subregion	Description
Stony Plains	STP06	Witjira	Extensive undulating silcrete gibber tablelands with entrenched drainage, escarpments and undulating stony plains. Includes small areas of sandplains, dunes, claypans and GAB springs.
Simpson Strzelecki Desert	SSD02	Simpson Desert	An extensive field of parallel dunes separated by flat interdune corridors. There is a cover of hummock grassland (*Zygochloa paradoxa, Triodia basedowii)* and other grasses (e.g. *Aristida contorta* and *A. holathera* var. *holathera*), low open woodland (*Acacia aneura*) and chenopod shrubland (*Halosarcia* spp. *Sclerostegia tenuis* and *Frankenia* spp.).
Finke	FIN04	Pedirka	A gently undulating plain with parallel dunes. The plains support a low open woodland of *Hakea* spp., *Grevillea* spp., *Acacia aneura* and *A. cibaria* on red earthy sands, while a tall shrubland of *Hakea* spp., *Grevillea* spp., *Acacia ligulata, Aristida holathera* var. *holathera* and *A. contorta* is found on the red siliceous sands of the dunes.
	FIN02	Finke River	Description not available

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

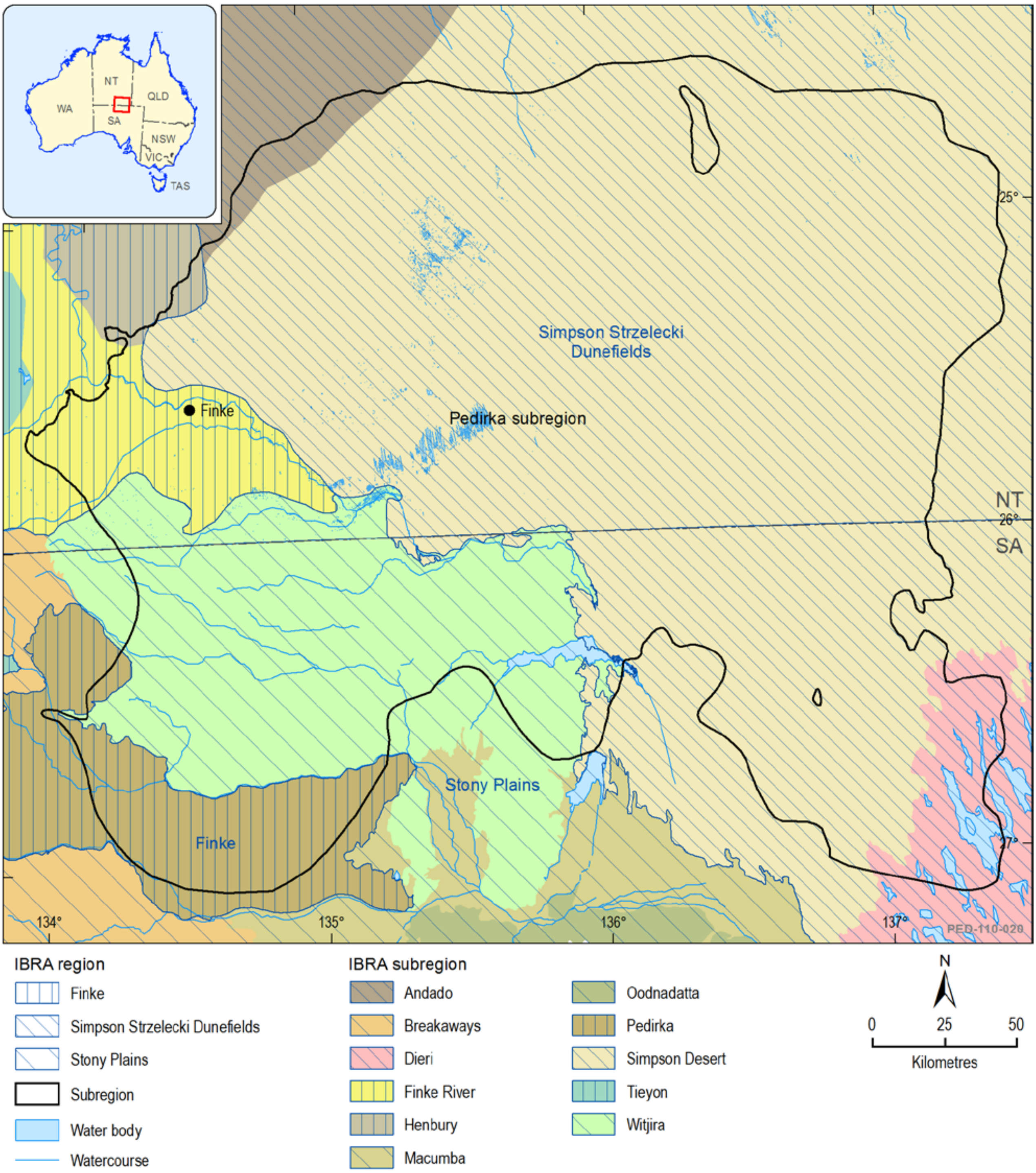

Figure 37 Interim Biogeographic Regionalisation of Australia regions and subregions

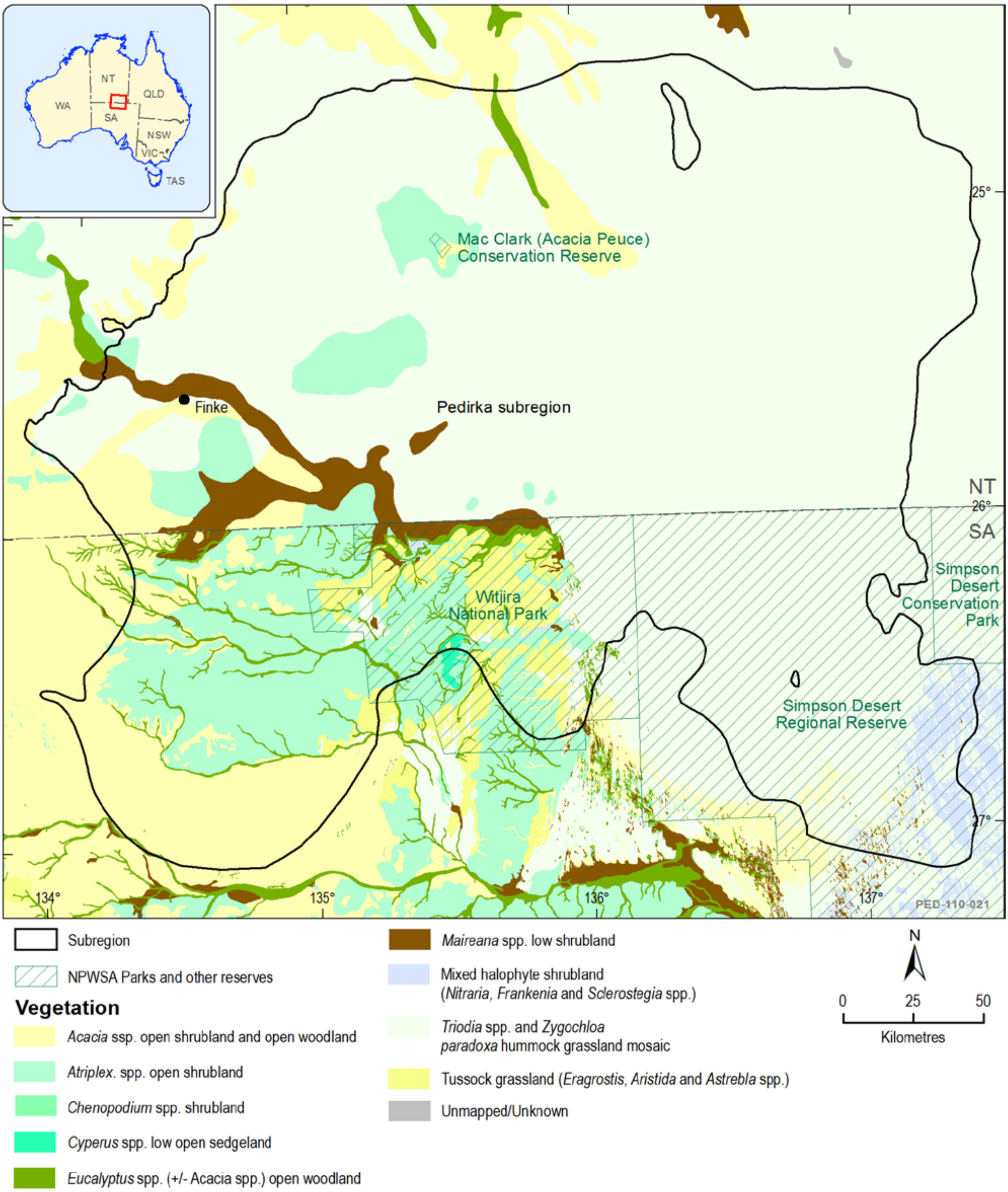

Figure 38 Mapped vegetation associations for the Pedirka subregion

1.1.7.2 *Terrestrial species and communities*

Northern SA and southern NT, 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 soil maps of 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 Department for Environment 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 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) 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 Lake Eyre Region* (Badman et al., 1991) is written as a visitor's guide to the region (see also three volume set *Lake Eyre South* published by Royal Geographical Society).

1.1.7.2.1 Threatened species

Using data sourced from the Biological Database of SA and *Atlas of living Australia*, the distribution of threatened flora and fauna for the Pedirka subregion is shown in Figure 39 to Figure 42. It should be noted that these databases do not include all data collected in the region, particularly aquatic species monitoring records (e.g. Cockayne et al., 2012, 2013). All records from sites within a 5 km 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: Environmental Protection and Biodiversity Conservation (EPBC) Act 1999
- State: South Australian National Parks and Wildlife Act 1972 or Territory Parks and Wildlife Conservation Act 2000
- Regional: Outback region status (Gillam and Urban, 2013), note: there is no equivalent regional rating for the NT.

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, and on one or more occasion.

Conservation rankings are provided in Table 6.

Table 6 Conservation ratings and abbreviations under the National (EPBC Act 1999), South Australian (SA NPW Act 1972), Northern Territory (TPWC Act 2000) or regional level (Outback Region, Gillam and Urban 2013)

Abbreviation	Rating	Relevant Rating system
CR	Critically endangered	EPBC Act, Regional, TPWC Act
DD	Data deficient	Regional, TPWC Act
E	Endangered	SA NPW Act
EN	Endangered	EPBC Act, Regional, TPWC Act
EX	Extinct	EPBC Act, SA NPW Act, TPWC 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, TPWC Act
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

Within the Pedirka subregion, 116 taxa from 10 families have been recorded. 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. There are four taxa rated Rare at the state level and one Vulnerable. Regionally, the Short-tailed Pygmy Monitor and Bronzeback Legless Lizard are rated Rare and Vulnerable respectively (Table 7). 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.

Table 7 List of reptiles with conservation status ratings at the National (EPBC Act), South Australian (SA NPWS Act), Northern Territory (TPWCA 2007) or regional level (Outback NRM Region) recorded within the Pedirka subregion

Species	Common Name	EPBC ACT	SA NPWS ACT	Regional Status	TPWCA 2007
Acanthophis pyrrhus	Desert Death Adder		V		
Aspidites ramsayi	Woma		R	NT	
Notoscincus ornatus	Desert Glossy Skink		R	LC	
Ophidiocephalus taeniatus[a]	Bronzeback Legless Lizard	VU	R	VU	DD
Varanus brevicauda	Short-tailed Pygmy Monitor		R	RA	

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

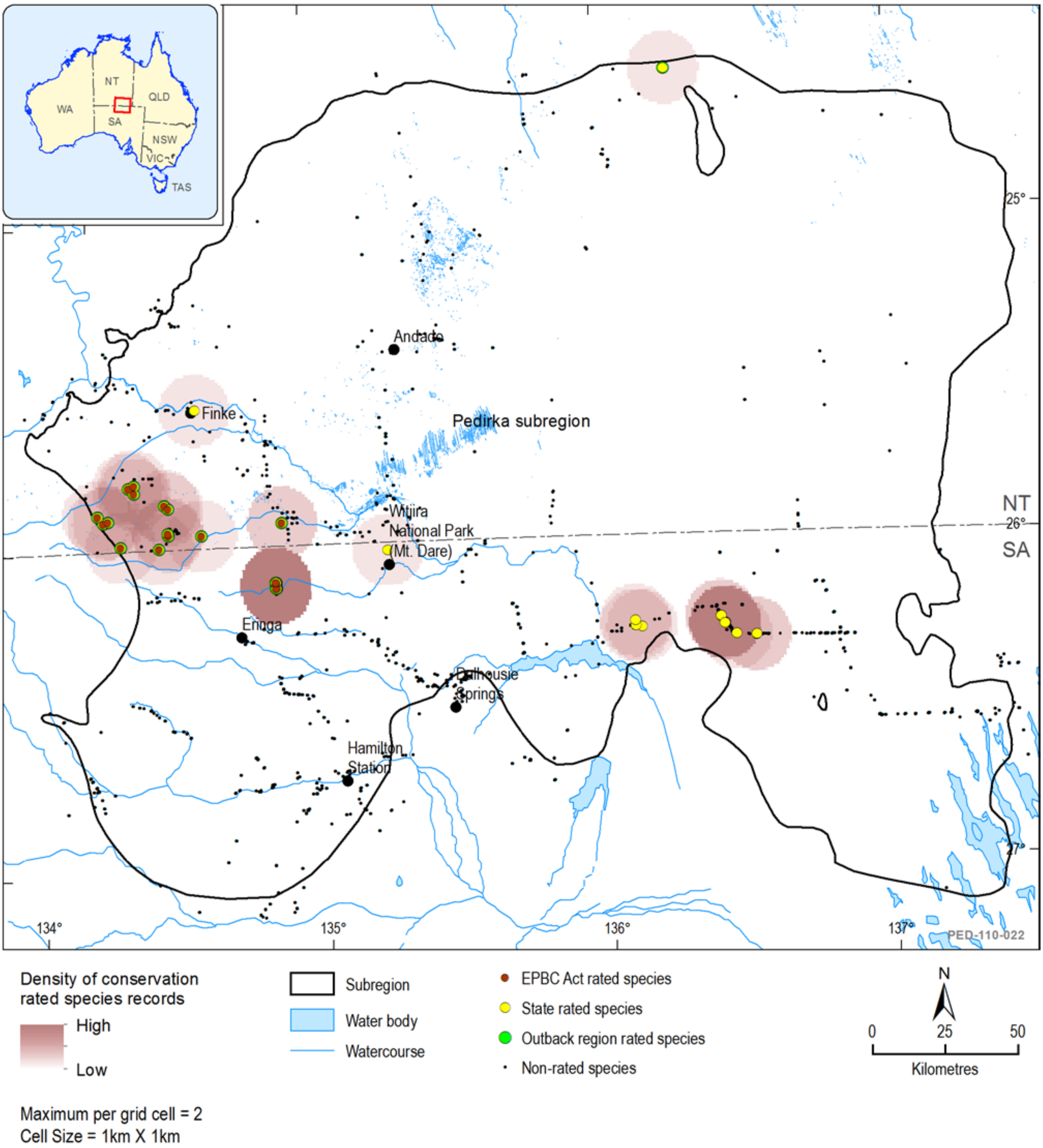

Figure 39 Significant reptile sites within and near the Pedirka subregion

Birds

Within the Pedirka subregion, approximately 200 taxa from 61 bird families have been recorded. Of these, 80 taxa from 39 families have a National (EPBC – 4 taxa), State (SANPW Act – 42 taxa), NT (15 taxa, including 5 extinct) or Regional (Outback NRM Region (71 taxa) conservation status rating (Table 8). Figure 40 shows the distribution of rated species records within each rating category and the density of rated species records within 1 km^2 grid cells. There are a number of locations predominantly on the western half of the subregion where up to 74 records of rated bird taxa per 1 km^2 grid cell are recorded, with many centred on drainage lines.

Forty-two species are waterbirds (including migratory birds) or birds dependent on wetlands or riparian systems for breeding or roosting (Table 8).

Table 8 List of birds with conservation status ratings at the National (EPBC Act), South Australian (SA NPWS Act), Northern Territory (TPWCA 2007) or regional level (Outback NRM Region) recorded within the Pedirka subregion

Species	Common Name	EPBC ACT	SA NPWS ACT	Regional Status	TPWCA 2007
Acanthiza robustirostris	Slaty-backed Thornbill			RA	
Acrocephalus australis[a]	Australian Reed Warbler			RA	
Actitis hypoleucos[a]	Common Sandpiper		R		
Amytornis textilis	Thick-billed Grasswren	VU		RA	
Anhinga novaehollandiae[a]	Australasian Darter		R	RA	
Aphelocephala pectoralis	Chestnut-breasted Whiteface		R	RA	
Aprosmictus erythropterus	Red-winged Parrot		R	VU	
Ardea alba[a]	Great Egret			RA	
Ardea pacifica[a]	White-necked Heron			RA	
Ardeotis australis	Australian Bustard		V	VU	VU
Burhinus grallarius	Bush Stone-curlew		R	CR	
Cacatua leadbeateri	Major Mitchell's Cockatoo		R	EN	
Calidris acuminata[a]	Sharp-tailed Sandpiper			RA	
Calidris ruficollis[a]	Red-necked Stint			RA	
Calyptorhynchus banksia	Red-tailed Black Cockatoo	ssp	ssp	EN	
Chalcites osculans	Black-eared Cuckoo			RA	
Charadrius leschenaultii[a]	Great Sand Plover		R		VU
Charadrius ruficapillus[a]	Red-capped Plover			RA	
Chlidonias hybrida[a]	Whiskered Tern			RA	
Cinclosoma castanotum	Chestnut Quailthrush		ssp	RA	
Circus approximans[a]	Swamp Harrier			RA	
Cladorhynchus leucocephalus[a]	Banded Stilt		V	RA	
Climacteris affinis	White-browed Treecreeper		R		
Conopophila whitei	Grey Honeyeater		R	EN	
Coturnix ypsilophora	Brown Quail		VU	RA	
Cygnus atratus[a]	Black Swan			RA	
Daphoenositta chrysoptera	Varied Sittella			RA	
Dromaius novaehollandiae	Emu				VU
Elanus scriptus	Letter-winged Kite		R	VU	

Species	Common Name	EPBC ACT	SA NPWS ACT	Regional Status	TPWCA 2007
Emblema pictum	Painted Finch		R	RA	
Epthianura crocea	Yellow Chat		E	EN	
Eremiornis carteri	Spinifexbird		E	EN	
Falco hypoleucos	Grey Falcon		R	EN	VU
Falco peregrinus	Peregrine Falcon		R	VU	
Falco subniger	Black Falcon			RA	
Gallinula tenebrosa[a]	Dusky Moorhen			RA	
Gallirallus philippensis[a]	Buff-banded Rail			RA	
Gelochelidon nilotica[a]	Gull-billed Tern			RA	
Geophaps plumifera[a]	Spinifex Pigeon		R	VU	
Gerygone fusca	Western Gerygone		R	RA	
Grus rubicunda[a]	Brolga		V	VU	
Hamirostra melanosternon	Black-breasted Buzzard		R	RA	
Himantopus leucocephalus[a]	Black-winged Stilt			RA	
Hydroprogne caspia[a]	Caspian Tern			RA	
Lichmera indistincta	Brown Honeyeater		R	RA	
Lophoictinia isura	Square-tailed Kite			EN	
Melanodryas cucullata	Hooded Robin		ssp		
Melanodryas cucullata	Hooded Robin		ssp		
Microcarbo melanoleucos[a]	Little Pied Cormorant			RA	
Microeca fascinans	Jacky Winter		ssp	RA	
Myiagra inquieta	Restless Flycatcher		R	RA	
Neophema splendida	Scarlet-chested Parrot		R	EN	
Northiella haematogaster	Bluebonnet		ssp		
Nycticorax caledonicus[a]	Nankeen Night Heron			RA	
Pedionomus torquatus	Plains Wanderer	VU	E	EN	DD
Pelecanus conspicillatusv	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	

Species	Common Name	EPBC ACT	SA NPWS ACT	Regional Status	TPWCA 2007
Plegadis falcinellus[a]	Glossy Ibis		R	RA	
Podiceps cristatus[a]	Great Crested Grebe		R	RA	
Polytelis alexandrae	Princess Parrot	VU	V	EN	VU
Pomatostomus temporalis	Grey-crowned Babbler		ssp	EN	
Porphyrio porphyrio[a]	Purple Swamphen			RA	
Porzana fluminea[a]	Australian Spotted Crake			RA	
Porzana tabuensis[a]	Spotless Crake		R	RA	
Ptilonorhynchus guttatus	Western Bowerbird		R	RA	
Recurvirostra novaehollandiae[a]	Red-necked Avocet			RA	
Rhipidura albiscapa	Grey Fantail			RA	
Rostratula australis[a]	Australian Painted Snipe				VU
Stictonetta naevosa[a]	Freckled Duck		V	RA	
Stipiturus ruficeps	Rufous-crowned Emuwren		R	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		
Tringa nebularia[a]	Common Greenshank			RA	

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

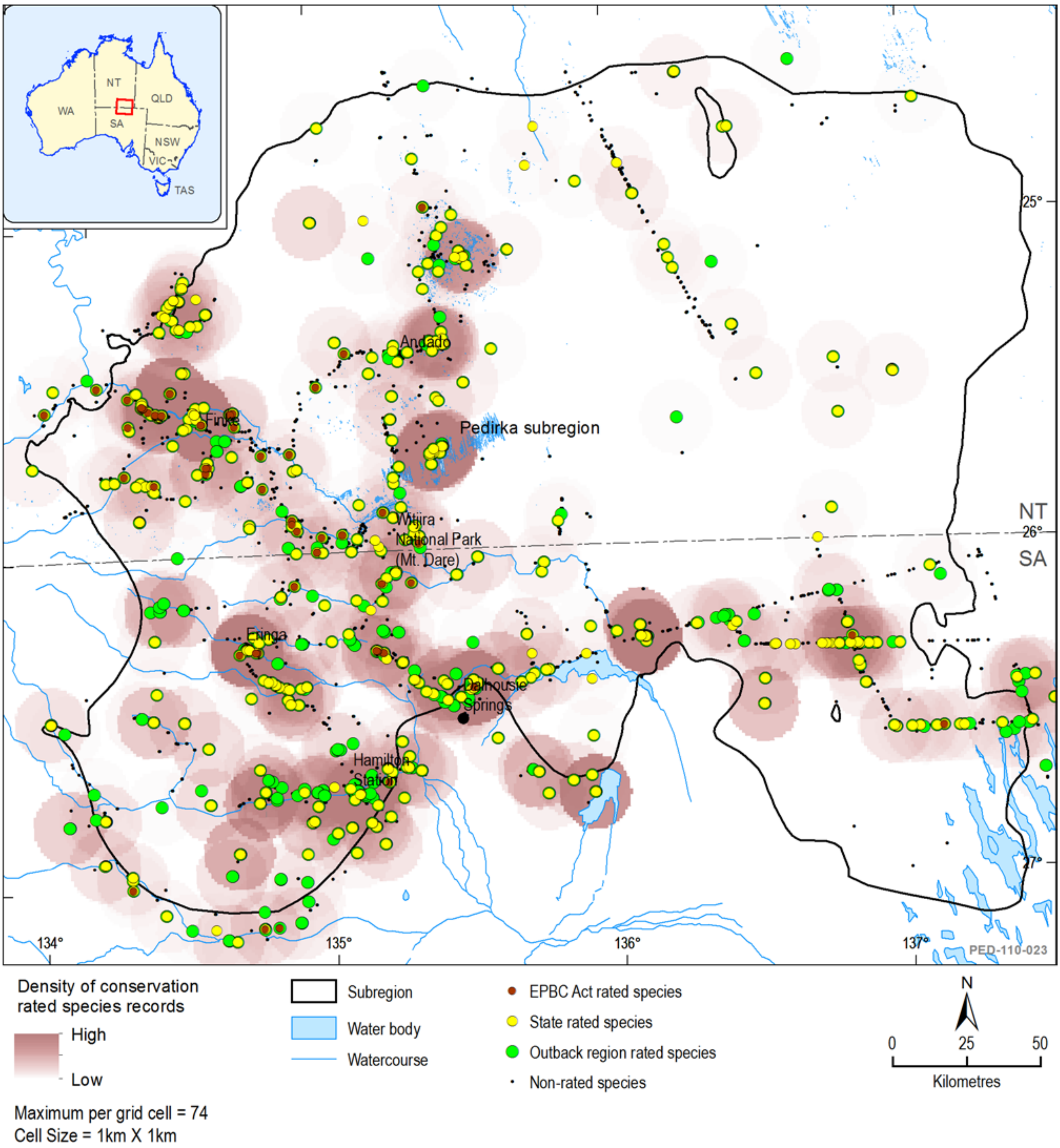

Figure 40 Significant bird sites within and near the Pedirka subregion

Mammals

Within the Pedirka subregion, 44 native taxa have been recorded from 13 families. Of these, 18 taxa from 8 families have a National (EPBC - 13 taxa- 4 extinct), State (SANPWS - 17 taxa (including 6 extinct in SA), NT (TPWCA 15 taxa) or Regional (Outback NRM Region-14 taxa (including 8 regionally extinct) conservation status rating (Table 9 and Figure 41). Figure 43 shows the distribution of rated species records within each rating category and the density of rated species records within 1 km^2 grid cells. There are a number of locations predominantly on the western half of the subregion where up to 20 records of rated mammal species per 1 km^2 grid cell are recorded.

Three taxa (Hairy-nosed Freetail-bat, Plains mouse and Common Brushtail Possum) are reliant on riparian or floodplain systems as a major part of their habitat or for breeding or roosting (Table 9).

Table 9 List of mammals with conservation status ratings at the National (EPBC Act), South Australian (SA NPWS Act), Northern Territory (TPWCA 2007) or regional level (Outback NRM Region) recorded within the Pedirka subregion

Species	Common Name	EPBC ACT	SA NPWS ACT	Regional Status	TPWCA 2007
Chaeropus ecaudatus	Pig-footed Bandicoot	EX	EX	RE	EX
Dasycercus blythi	Brush-tailed Mulgara	VU	E	RE	VU
Dasycercus cristicauda	Crest-tailed Mulgara	EN		LC	VU
Dasyuroides byrnei	Kowari	VU	V	VU	DD
Dasyurus geoffroii	Western Quoll	VU	E	RE	EX
Isoodon auratus	Golden Bandicoot	VU	EX	RE	EN
Macrotis lagotis	Bilby	VU	V	VU	VU
Macrotis leucura	Lesser Bilby	EX	EX	RE	EX
Mormopterus eleryi[a]	Hairy-nosed Freetail-bat		V	RA	
Notomys amplus[b]	Short-tailed Hopping-mouse	EX	EX	RE	EX
Notomys cervinus	Fawn Hopping-mouse		V	VU	EN
Notomys fuscus	Dusky Hopping-mouse	VU	V	LC	EN
Notoryctes typhlops	Central Marsupial Mole	EN	V	DD	EN
Perameles eremiana	Desert Bandicoot	EX	EX		EX
Pseudomys australis[a]	Plains Rat	VU	V	RA	EN
Rattus tunneyi	Pale Field-rat		EX	RE	VU
Sminthopsis youngsoni	Lesser Hairy-footed Dunnart		R	RA	
Trichosurus vulpecula[a]	Common Brushtail Possum		R	RE	EN

[a]Wetland, drainage-line or floodplain dependant taxa are indicated. [b]Taxa known from sub-fossil only

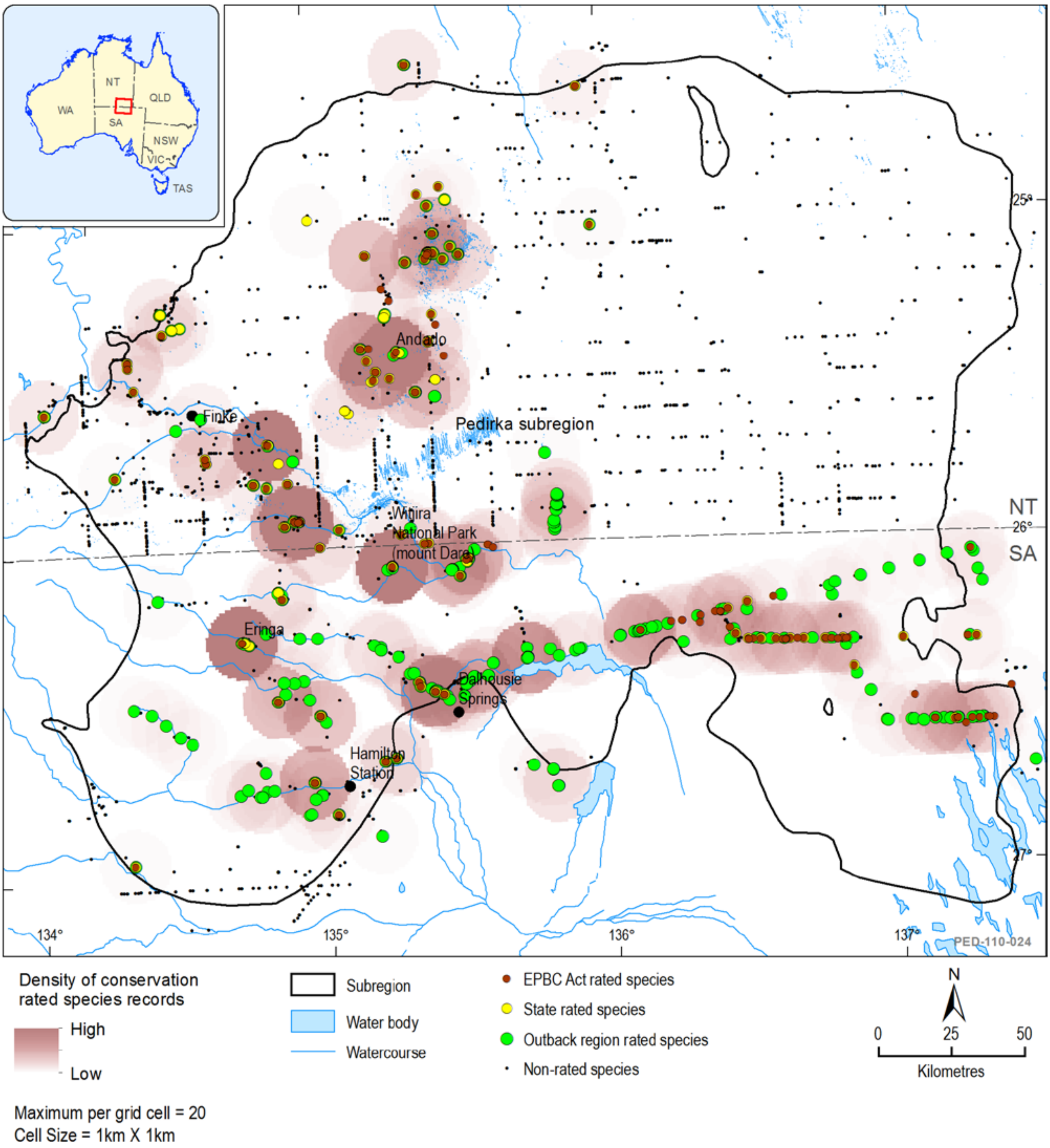

Figure 41 Significant mammal sites within and near the Pedirka subregion

Flora

Within the Pedirka subregion, approximately 1250 taxa from 88 vascular plant families have been recorded. Of these, 113 taxa from 39 families have a National (EPBC – 2 taxa), State (SANPWS – 30 taxa) NT (4 taxa) or Regional (Outback NRM Region (101 taxa)) conservation status rating (Table 10). Figure 42 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 plant taxa records (20 records in a 1 km^2 grid cell) is in a band south-west of Finke across the SA border, with other locations around Andado.

More than 40 taxa from 20 families occur in wetland, drainage-line and or halophytic habitats, including the one of the EPBC rated taxa, *Frankenia plicata* (Endangered) (Table 10).

Table 10 List of vascular plants with conservation status ratings at the National (EPBC Act), South Australian (SA NPWS Act), Northern Territory (TPWCA 2007) or regional level (Outback NRM Region) recorded within the Pedirka subregion

Species	Common Name	EPBC ACT	SA NPWS ACT	Regional Status	TPWCA Rating
Acacia georginae	Georgina Gidgee		R	RA	
Acacia latzii	Latz's Wattle	VU	R	RA	VU
Acacia peuce	Birdsville Wattle				EN
Acacia pickardii	Birds Nest Wattle	VU	R	RA	EN
Acacia sericophylla	Wirewood			RA	
Amaranthus interruptus	Native Amaranth			RA	
Amyema hilliana				RA	
Aristida arida			R	RA	
Aristida inaequiglumis	Feathertop Three-awn			RA	
Aristida jerichoensis var. subspinulifera	Jericho Three-awn			RA	
Atriplex acutibractea ssp.				RA	
Atriplex acutiloba				RA	
Atriplex incrassata	Oodnadatta Saltbush			RA	
Atriplex turbinata				RA	
Baumea arthrophylla[a]	Swamp Twig-rush			VU	EN
Bergia occultipetala[a]			V	NT	
Bergia pedicellaris[a]			V	NT	
Bolboschoenus caldwellii[a]	Salt Club-rush			NT	EN
Brachyscome eriogona			R	LC	
Brachyscome tesquorum	Shrubby Desert Daisy			RA	
Callitriche sonderi[a]	Matted Water Starwort		R	NT	
Calocephalus knappii	Knapp's Beauty-heads			RA	
Calocephalus sonderi	Pale Beauty Heads		R		
Calotis kempei	Kemp's Burr-daisy			RA	
Carinavalva glauca				RA	
Centipeda minima	Spreading Sneeze Weed			RA	
Centipeda minima ssp. minima	Spreading Sneezeweed			RA	
Cheilanthes sieberi ssp. pseudovellea				RA	
Corynotheca micrantha var. divaricata	Small-flower Sand Lily			RA	

Species	Common Name	EPBC ACT	SA NPWS ACT	Regional Status	TPWCA Rating
Cyperus bifax[a]	Downs Flat-sedge		R	RA	
Cyperus dactylotes[a]			V	VU	
Digitaria ctenantha	Comb Finger-grass			VU	
Dipteracanthus australasicus ssp. australasicus				RA	
Drosera indica[a]	Indian Sundew			RA	
Eclipta alatocarpa				RA	
Elatine gratioloides[a]	Waterwort		R	RA	
Eleocharis geniculata[a]	Spike-rush		R	EN	
Eleocharis papillosa[a]	Dwarf Desert Spike-rush				EN
Eleocharis pusilla[a]	Small Spike-rush			RA	
Eragrostis lacunaria	Purple Love-grass		R	RA	
Eragrostis sp. Limestone (P.K.Latz 5921)				RA	
Eragrostis speciose	Handsome Love-grass			RA	
Eremophila battii				RA	
Eremophila pentaptera			R	VU	
Eucalyptus intertexta[a]	Gum-barked Coolibah			RA	
Euphorbia mitchelliana				RA	
Fimbristylis sieberiana[a]	Sieber's Fringe-rush			VU	
Frankenia plicata[a]		EN	V	DD	
Glinus oppositifolius[a]	Slender Carpet-weed			RA	
Glinus orygioides[a]	Desert Carpet-weed			RA	
Glossostigma cleistanthum[a]	Spoon Mud-mat			RA	
Goodenia anfracta			R	RA	
Goodenia heteromera	Spreading Goodenia		R	RA	
Goodenia modesta				RA	
Haloragis glauca f. glauca[a]	Bluish Raspwort			RA	
Haloragis glauca f. sclopetifera[a]	Grey Raspwort			RA	
Haloragis gossei[a]	Gosse's Raspwort			RA	
Hydrocotyle verticillata[a]	Shield Pennywort			VU	
Imperata cylindrical	Blady Grass			EN	
Isolepis australiensis[a]	Southern Club-rush			RA	
Isolepis cernua[a]	Nodding Club-rush			RA	

Species	Common Name	EPBC ACT	SA NPWS ACT	Regional Status	TPWCA Rating
Ixiochlamys integerrima				RA	
Josephinia eugeniae[a]	Josephina Burr			RA	
Lemna disperma[a]	Common Duckweed			RA	
Lepidium papillosum	Warty Peppercress			RA	
Lepidosperma avium[a]	Central Australian Rapier-sedge		R	RA	
Leptochloa fusca ssp. fusca	Brown Beetle-grass			RA	
Lobelia heterophylla ssp. centralis			R	RA	
Lomandra leucocephala ssp. robusta	Woolly Mat-rush			RA	
Maireana carnosa	Cottony Bluebush			RA	
Maireana luehmannii	Luehman's Bluebush			VU	
Maireana melanocarpa	Black-fruit Bluebush		R	RA	
Marsilea costulifera[a]	Narrow-leaf Nardoo			RA	
Melaleuca glomerata[a]	Inland Paper-bark			RA	
Momordica balsamina	Balsam Apple			RA	
Myriocephalus rhizocephalus	Woolly-heads			RA	
Nicotiana burbidgeae			V	VU	
Nicotiana rosulata ssp. rosulata				RA	
Ophioglossum polyphyllum[a]	Large Adder's-tongue		R	RA	
Phragmites australis	Common Reed			RA	
Phyllanthus maderaspatensis var. angustifolius				RA	
Pimelea penicillaris	Sandhill Riceflower		R	VU	
Plantago multiscapa[a]	Many-stem Plantain		V	RA	
Potamogeton pectinatus[a]	Fennel Pondweed			RA	
Psydrax ammophila[a]				RA	
Ptilotus aristatus ssp. Aristatus			R	RA	
Ptilotus parvifolius	Small-leaf Mulla Mulla			RA	
Radyera farragei	Desert Rose Mallow			RA	
Rostellularia adscendens var. clementii	Pink Tongues			VU	
Santalum acuminatum	Quandong			NT	VU
Schoenoplectus dissachanthus[a]	Inland Club-rush			RA	
Sclerolaena articulata	Jointed Bindyi			RA	
Sclerolaena bicuspis	Two-spine Bindyi			RA	

Species	Common Name	EPBC ACT	SA NPWS ACT	Regional Status	TPWCA Rating
Sclerolaena blackiana	Black's Bindyi		R	NT	
Sclerolaena clelandii	Cleland's Bindyi			RA	
Sclerolaena fontinalis[a]	Mound Spring Bindyi		R	VU	
Senecio runcinifolius	Thistle-leaf Groundsel			RA	
Senna glutinosa ssp. glutinosa	Sticky Senna			RA	
Sonchus hydrophilus	Native Sow-thistle			RA	
Stackhousia clementii	Limestone Candles			RA	
Swainsona oligophylla			R	NT	
Tecticornia fontinalis[a]	Mound Spring Samphire			VU	
Tecticornia halocnemoides ssp. halocnemoides[a]	Grey Samphire			RA	
Tecticornia halocnemoides ssp. tenuis[a]				RA	
Tecticornia pergranulata ssp. elongata[a]	Black-seed Samphire			RA	
Tecticornia undulata[a]				VU	
Thysanotus exiliflorus	Inland Fringe-lily			RA	
Triodia schinzii				RA	
Typha domingensis[a]	Narrow-leaf Bulrush			RA	
Vigna lanceolata var. latifolia	Maloga Bean			RA	
Wahlenbergia aridicola	Dryland Bluebell			RA	
Wahlenbergia gracilenta	Annual Bluebell			RA	
Zygophyllum crassissimum	Thick Twinleaf		R	RA	

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

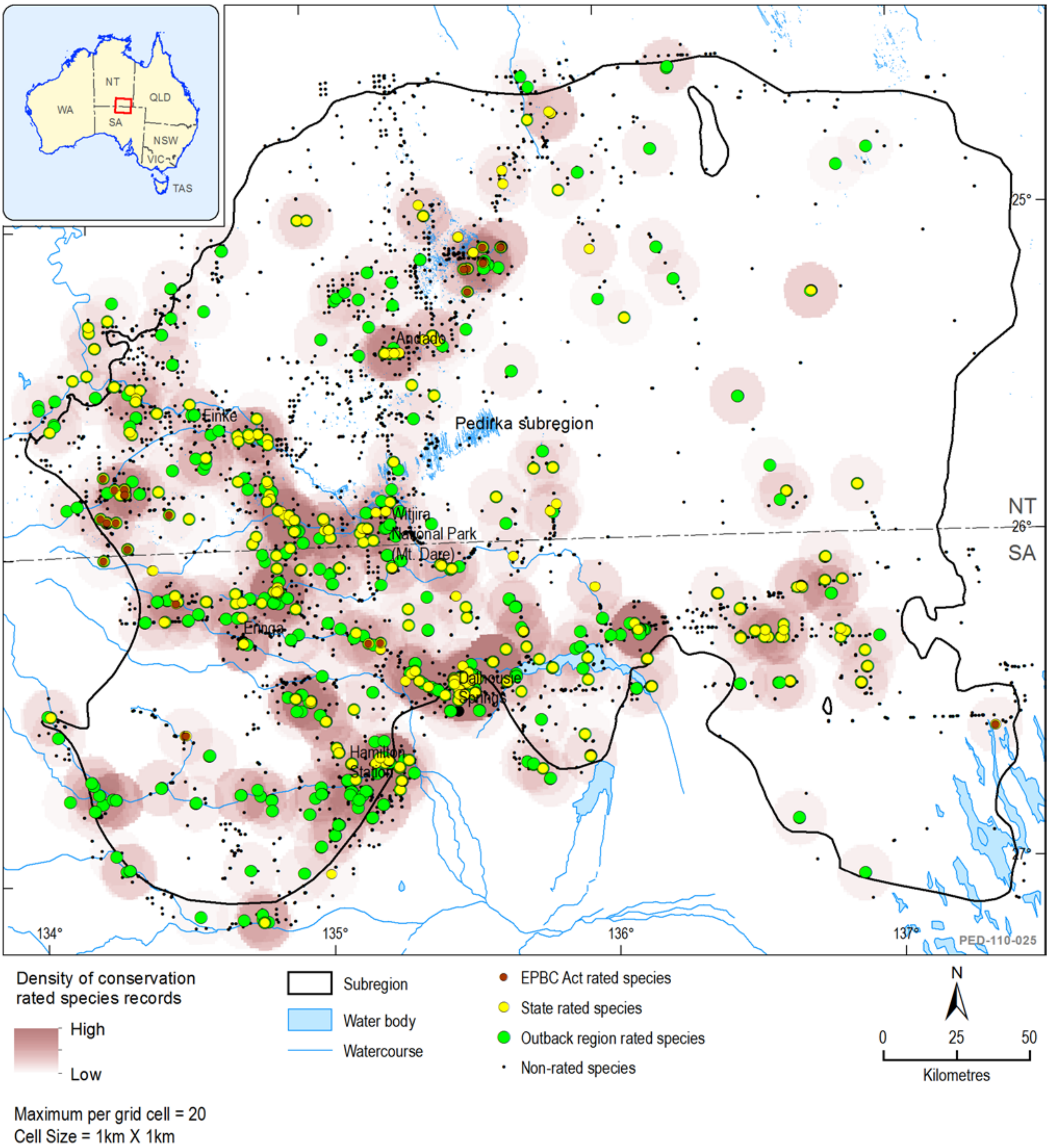

Figure 42 Significant flora sites within and near the Pedirka subregion

1.1.7.3 *Aquatic species and communities*

The aquatic ecosystems of the Pedirka subregion can be broadly grouped into the groundwater-dependent Great Artesian Basin (GAB) springs and the surface water-dependent ecosystems which lie within the LEB (Figure 43). 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 dune lake systems are very poorly understood and in the Pedirka 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 their biota cannot repopulate 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 Pedirka subregion there are no known perennial waterholes; in the Finke catchment perennial waterholes exist upstream of the Pedirka subregion while the Macumba catchment is most likely to be reliant on refuge waterholes in the lower Georgina-Diamantina catchment. 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 Pedirka 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 Pedirka subregion are shown in Figure 39. 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.

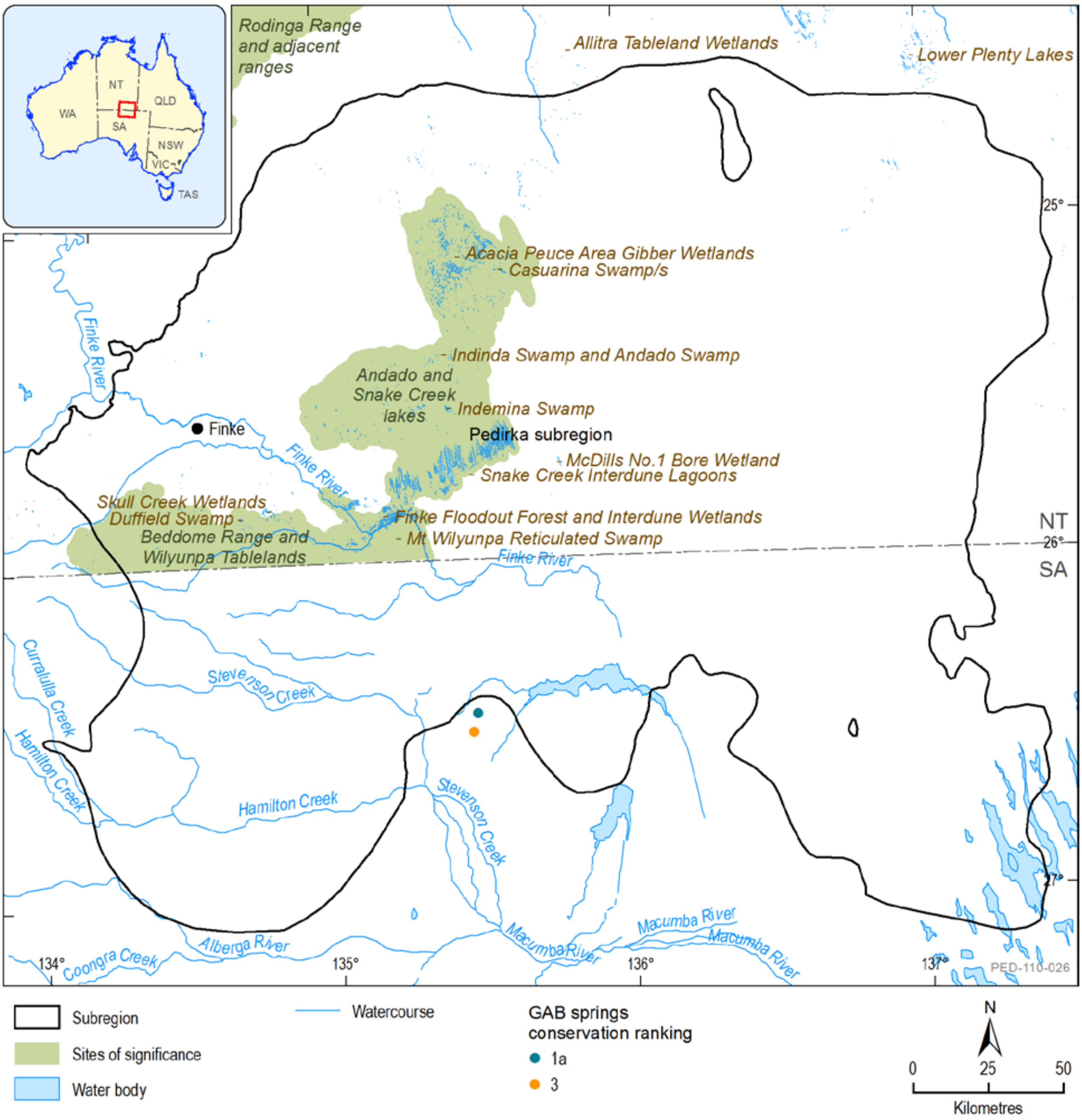

Figure 43 Dalhousie GAB Springs and Northern Territory significant wetland sites (see Table 18) within and near the Pedirka subregion

Source: Dalhousie GAB Springs (Fensham et al. 2005) and Northern Territory significant wetland sites (Duguid 2011)

1.1.7.3.1 Fish

Twelve taxa from 8 families are recorded for the area. None have an EPBC or SA NPWS Act rating, however, regionally 6 are considered rare and 5 vulnerable (Table 11). Figure 44 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 is at Dalhousie Springs and in the Macumba catchment in Hamilton Creek and Lindsay Creek (Figure 44).

Table 11 List of fish with conservation status ratings at the National (EPBC Act), South Australian (SA NPWS Act), or regional level (Outback NRM Region) recorded within the Pedirka subregion

Species	Common Name	EPBC ACT	SA NPWS ACT	Regional Status
Amniataba percoides	Bared Grunter			RA
Chlamydogobius eremius	Desert Goby			RA
Chlamydogobius gloveri	Dalhousie Goby			VU
Craterocephalus dalhousiensis	Dalhousie Hardyhead			VU
Craterocephalus eyresii	Lake Eyre Hardyhead			RA
Craterocephalus gloveri	Glover's Hardyhead			VU
Leiopotherapon unicolor	Spangled Perch			NT
Melanotaenia splendida tatei	Desert Rainbow Fish			RA
Mogurnda thermophila	Dalhousie Purple-spotted Gudgeon			VU
Nematalosa erebi	Bony Bream			RA
Neosilurus gloveri	Glover's Catfish			VU

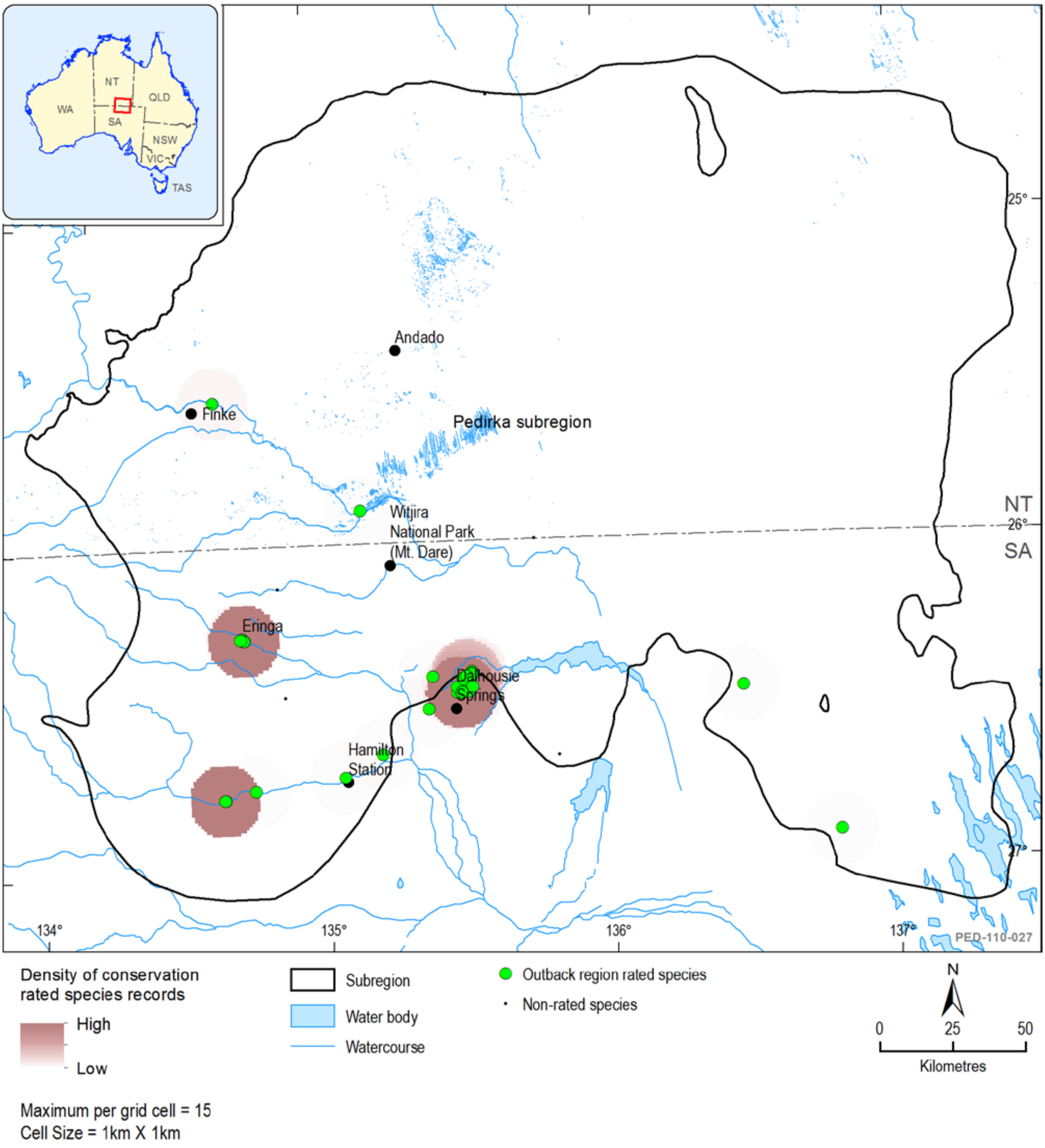

Figure 44 Significant fish species within and near the Pedirka subregion

1.1.7.3.2 Amphibians

Seven taxa from two families have been recorded from the Pedirka subregion (Table 12). The Shoemaker Frog (*Neobatrachus sutor*) has a state conservation status rating of Vulnerable, with a single record from within the subregion. All the frog taxa have close affinities with drainage lines and floodplains.

Table 12 List of amphibians recorded within the Pedirka subregion

Species	Common Name
Cyclorana platycephala[a]	Water-holding Frog
Cyclorana maini[a]	Main's Frog
Litoria rubella[a]	Desert Tree Frog
Neobatrachus sudelli[a]	Sudell's Frog
Limnodynastes tasmaniensis[a]	Spotted Marsh Frog
Platyplectrum spenceri[a]	Spencer's Burrowing Frog
Neobatrachus sutor[a]	Shoemaker 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 *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The Dalhousie GAB springs occur near the southern boundary of the Pedirka subregion (Figure 43); the hydrogeology in relation to these springs is discussed in Section 1.1.4. The Dalhousie Springs are listed in the Directory of Important Wetlands in Australia, and scored very high in three out of four HEVEA criteria for the LEB, these being distinctiveness, diversity and evolutionary history (Hale 2010). To the north of Pedirka subregion, the GAB flows in an easterly direction towards the Mulligan River supergroup of springs in Queensland (Rousseau-Gueutin et al., 2013).

Gotch (2013a) has developed a spring nomenclature to provide a common language to describe GAB springs in SA (Table 13) 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. The Dalhousie Springs comprise 148 spring vents from 12 spring groups (Gotch, 2013b). The Fensham et al. (2005) dataset separates the springs at Dalhousie into two complexes while Gotch (2013a) identifies all springs as belonging to a single complex. The Dalhousie Springs have the largest outflow of any GAB springs in the arid zone (Habermehl, 1982), with the most recent estimates being between 54 ML/day (Sibenaler, 1996) and 60 ML/day (Gotch, 2013c) using the tool developed by White and Lewis (2011).

The term ‘mound spring’ has historically been used to describe GAB springs, however, not all GAB 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 14) (Green et al., 2013). The Dalhousie Springs include carbonate mounds, sand and silt mounds and carbonate terraces (Habermehl, 1982; White et al., 2013b).

Table 13 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)

Table 14 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. Elevation of the spring vent is a vent 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 pressure above spring surface 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). 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 JK 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 in response to rainfall variation (White et al., 2013a). Some vents within a spring group may be permanently connected, by discharging to the same pool, by overland flow, or by saturated soil conditions. Because of intra- and inter annual variation (White et al., 2013a), 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). Because the conductivity of each spring vent varies, the rate of flow for any given spring vent cannot be determined from pressure above spring surface alone (Green and Berens, 2013). Spring flow rates are difficult to measure on-ground, however wetland area can be monitored by remote sensing methods as a surrogate for monitoring spring flow rate (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 SA 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.

Dalhousie Springs

The Dalhousie Springs are estimated to have been active for between one and two million years (Krieg, 1989); none have ceased flowing in recent history (Fensham et al., 2010). The Dalhousie

Springs are surrounded by extremely arid environments, effectively existing as aquatic islands within a sea of desert. The isolation of springs and their persistence over millions of years of increasingly arid climate change has contributed to high levels 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 and condition of the wetland environment (Table 15); the highest rank for an individual spring within a complex is applied to the complex (Fensham et al., 2010). Within Dalhousie supergroup, Dalhousie Springs complex is ranked 1a and Dalhousie Ruins ranked 3 (Fensham et al., 2005). Five species of fish, three crustaceans and three molluscs were identified that are found only at Dalhousie Springs (Fensham et al., 2010) (Table 16). There are, however, limitations to 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. Additionally, the Fensham et al. (2010) ranking is based on data collated in 2005 (Fensham et al., 2005) and additional research (both in field survey and taxonomy) has since been undertaken. Gotch et al. (2008) found very high levels of short-range endemism to area amongst wolf (lycosid) spiders at Dalhousie compared with other GAB springs in SA. A recent survey and genetic analysis of invertebrate fauna of Lake Eyre supergroup springs identified 42 new 'evolutionarily significant units[1]', 16 of which were restricted to only one spring group (Guzik and Murphy, 2013). This research indicates it is likely that the diversity of short-range endemic species has probably been vastly under estimated.

Table 15 Conservation ranking criteria for Great Artesian Basin spring complexes

Ranking	Criteria	Number of spring complexes in Dalhousie 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	
2	Provides habitat for isolated populations of plant and/or animal species; populations of species not known from habitat other than spring wetlands within 250 km	
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	1
4	All springs are highly degraded	
5	All springs are inactive	

Source: Fensham et al. (2010)

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[1] Potentially new species

Table 16 Species endemic to Dalhousie Springs

Group	Species
Fish	*Chlamydogobious gloveri* *Craterocephalus dalhousiensis* *Craterocephalus gloveri* *Mogunrda themophila* *Neosilurus gloveri*
Crustaceans	*Austrochiltonia* sp. AMS P68165 *Caradinia* sp. Mitchel (1985) *Cherax* sp. Sokol (1987)
Molluscs	*Austropyrgus centralia* *Caldicochlea globosa* *Caldicochlea harrisi*

Source: Fensham et al. (2010)

The Dalhousie Springs supports almost 1000 ha of wetlands, of which Common Reed (*Phragmites australis*) reedbeds are the main vegetation type, followed by White Tea Tree (*Melaleuca glomerata*) open forests and woodlands which occur mainly around the spring pools (White et al., 2013b). The flora species diversity is very high by comparison with other GAB springs (Gotch, 2013c), with 104 species recorded to date (Noack, 2005) in 44 plant communities (Mollemans, 1989). Many of these species are widespread in more temperate and tropical regions, but are highly restricted within central Australia (Mollemans, 1989; Noack, 2005). 155 bird species, including 56 waterbirds and several migratory species, have been recorded at Dalhousie Springs (Noack, 2005). The wetlands drain into Spring Creek, which runs for approximately 50 km before terminating in the Simpson Desert (Wolaver et al., 2013).

Despite its isolation, the ecology of Dalhousie Springs has been impacted by changes in land management practices. Date Palms (*Pheonix dactylifera*), which were planted at Dalhousie in the late 1800s for food, have become a major weed that significantly reduces natural flows due to their very high water requirements (Gotch, 2013c). Nearly 2,500 Date Palms were recently removed, but outlying and small plants remain (Gotch, 2013c). Changes in the fish composition of pools, including local extirpations, has been attributed to loss of open water habitat due to vegetation growth resulting from changes in burning and grazing regimes (Kodric-Brown et al., 2007).

Recent studies of aquatic invertebrate fauna in GAB springs in SA have found there is very little dispersal between spring groups and complexes (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). 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).

Bore drain wetlands

Bore drain wetland in the Pedirka subregion include McDills No.1 and Purni Bores. McDills No.1 Bore sources water from the GAB and has been rehabilitated to control the rate of flow so that a small area of wetland and associated wildlife are supported, as directed by the Traditional Owners (Duguid, 2011). 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). 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).

Other groundwater-dependent ecosystems

While it is considered likely that alluvial groundwater may prolong the persistence of some waterholes and support other aquatic ecosystems such as floodplain and floodout woodlands and forests (Duguid 2011), there have been no studies to determine the contribution of alluvial groundwaters in the Pedirka subregion.

1.1.7.3.4 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 Pedirka 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 is in contrast to other major drainage systems in Australia, (such as the Murray Darling Basin (MDBC, 2008)) and internationally, making the LEB unique nationally and internationally (LEBSAP, 2008). Therefore, it is the maintenance and protection of the components (such as refugia) and processes (such as flooding and connectivity) that enable the species within these systems to persist through the dry phases (resistance) and disperse and rebuild populations during wet periods (resilience) that are critical to ensuring the ongoing persistence of the ecosystems (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, become 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, 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. 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 key parameters: fish, water quality, and hydrology (DSEWPAC, 2011, 2012, 2013). LEBRA monitoring data are summarised in Cockayne et al., (2012, 2013) but has not been interpreted in terms of condition reporting.

Within the Pedirka subregion, the Macumba and Finke catchments have been monitored for the LEBRA since autumn 2011, however all LEBRA sites in the Finke catchment are located upstream of the Pedirka subregion (Cockayne, 2012, 2013) (Figure 45). Sites within the Macumba catchment have also been monitored by the SA EPA with monitoring including macroinvertebrates and water quality parameters (monitoring has been twice, ten years apart; Goonan et al., 2003; EPA, 2012). While there have been some additional one-off biological surveys (most notably the SA Arid Rivers biological survey 2005/2006, and surveys by Duguid 2011 and Eldridge and Reid 1998), the Pedirka subregion contains some of the least studied aquatic ecosystems in the LEB; in particular, the dune lakes in the south-eastern part of the subregion that have not been the subject of any studies (e.g. Lakes Peera Peera Poolana and Griselda).

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 SA 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.

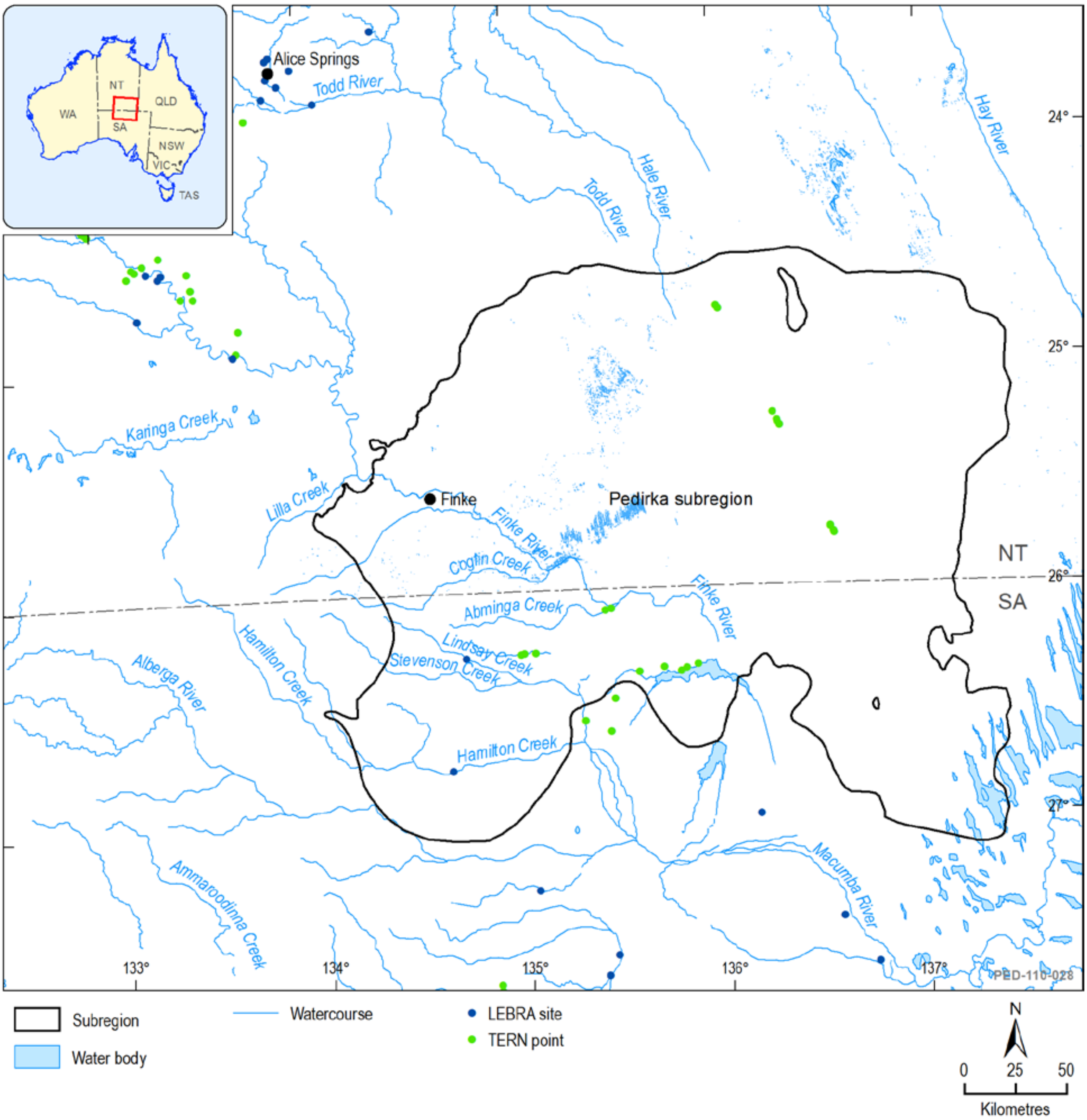

Figure 45 Location of aquatic ecosystem monitoring sites

Table 17 Riverine fish fauna found in the Macumba and Finke catchments

Species	Common Name	Finke catchment	Macumba catchment
Ambassis mulleri	Desert Glassfish^	●	●
Amniataba percoides	Barred Grunter	●	●
Bidyanus welchi	Welch's Grunter^		●
Chlamydogobius japalpa	Finke Goby^	●	
Craterocephalus centralis	Finke River Hardyhead^	●	
Craterocephalus eyresii	Lake Eyre Hardyhead^		●
Leiopotherapon unicolour	Spangled Perch	●	●
Macquaria sp. B	Lake Eyre golden perch^		●
Melanotaenia splendida tatei	Desert Rainbow Fish^	●	●
Mogurnda larapintae	Finke Mogurnda^	●	
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)
Note: *exotic/introduced, ^endemic to the LEB

Macumba catchment

The Macumba catchment, of which the Stevenson and Hamilton creek subcatchments lie within the Pedirka subregion, is the only surface drainage system within the Pedirka subregion to contribute flow to Kati Thanda – Lake Eyre under current climatic conditions. This it does via outflow into the Kallakoopah Creek, an anabranch of the Warburton Creek in the lower Georgina-Diamantina catchment (see Section 1.1.5). There are no known permanent waterholes in the Macumba catchment, however there are several waterholes that can hold water for over a year without flow. Nine native fish species have been recorded in the catchment, all of which are also found in the Georgina-Diamantina catchment (refer Table 12) (Cockayne et al., 2013). The fish assemblage differs from neighbouring Neales and Finke catchments, indicating the fish of the Macumba catchment are most likely to be sourced from the Georgina-Diamantina catchment rather than via Kati Thanda – Lake Eyre or connectivity with the Finke catchment. The nearest permanent waterhole to the Macumba River-Kalakoopah Creek confluence is Pandie Pandie waterhole, at least 300 to 400 km upstream in Goyders Lagoon.

This biological data supports the role of the Macumba River as a lowland tributary of the Warburton Creek (and therefore the Georgina-Diamantina catchment). However, as both tributary and main stream are highly ephemeral at the point of juncture, both catchments would have to have sufficient synchronous flow of sufficient magnitude and duration for hydrological connectivity to occur long enough for fish dispersal. The parameters of such an event are unknown.

The pattern of fish species dispersal observed in three years of LEBRA monitoring (Cockayne et al., 2012, 2013) is consistent with migration from refugia in the Georgina-Diamantina catchment. LEBRA fish monitoring has shown that species that possess rapid dispersal and colonisation traits (McNeil et al., 2011; Kerezsy et al., 2013) were found to rapidly recolonise the upper reaches of the Macumba catchment following extended connection with the Warburton Creek in 2010. Species with poorer dispersal traits were only recolonised in the lower reaches of the Macumba River, nearer to refuge sources in the Warburton. A similar pattern was observed in the neighbouring Eyre Creek catchment where fish dispersed from refuges in the Georgina-Diamantina catchment into the Mulligan River up to 300 km from the nearest permanent waterhole (Kerezsy et al., 2013). Similar trait-based dispersal patterns were observed with some species dispersing earlier and further while others dispersed later and did not move past deeper waterholes in the middle reaches, or move into the catchment at all (Kerezsy et al., 2013). A similar pattern has also been found in the Neales during recovery from drought (McNeil et al., 2008, 2009, 2011).

While the Macumba catchment is clearly reliant on source populations in the Georgina-Diamantina, it is likely that, if successive floods occur in both catchments before the Macumba catchment waterholes dry out, fish from the Macumba catchment will disperse back into the Georgina-Diamantina catchment. Thus the Macumba catchment may act as ‘nursery’ and feeding area for the ‘parent populations’, similar to the way in which floodplain ecosystems support fish populations during floods (Balcombe et al., 2007), and contribute to the genetic resistance and overall population resilience of the parent populations (McNeil pers. com., 2013). The patterns of hydrological connectivity and availability of emigrational pathways for fish through Kati Thanda – Lake Eyre during simultaneous high flow events in multiple catchments are unknown, however there is potential for connectivity across the Macumba, Warburton, Cooper and Neales catchments during periods of very high rainfall and flow. Current genetic programs being undertaken at Monash and Flinders Universities may provide insight into these patterns of Basin-scale connectivity.

Finke catchment

North of the Macumba catchment, the lower Finke River floods out in the Simpson Desert dunefields within the Pedirka subregion. It has not been known to flow to Kati Thanda – Lake Eyre under current climatic conditions, but is likely to have between 1,000 and 20,000 years ago (Unmack, 2001a) and possibly more recently during occasional mega floods (Pickup, 1991). The Finke catchment contains numerous permanent, seasonal and ephemeral waterholes (Duguid, 2013) however all known permanent waterholes are located upstream of the Pedirka subregion (Duguid, 2011). Within the lower Finke, some waterholes can last over a year without flow, but will dry out without any subsequent flow. Large interdune lakes and pans as well as wooded swamps also occur in the Finke floodout but only fill infrequently and are dry most of the time (Duguid, 2011).

Nine native fish species occur in the Finke, of which three are endemic to that catchment and the remainder are found in other parts of the LEB (Table 17). No surveys have been undertaken in the lower reaches, but fish and piscivorous waterbirds have been observed in the Finke floodout (Duguid, 2011). Nothing is known about the fate of fish in floodouts, but it is likely that they may feed and breed and, if consecutive floods occur, may migrate back upstream. Therefore, these lower reaches may provide an occasional nursery and feeding area for the Finke fish populations. However, the influence of these on populations further upstream may be small and infrequent.

Water-dependent ecosystems are poorly mapped within the Pedirka subregion. Barnetson and Duguid (2010a) undertook some mapping of the LEB within NT and further work was undertaken for the GAB Water Control District (Duguid, 2011), including aerial videography. However, much of the data from the latter is yet to be digitised. Duguid (2011) includes descriptions of selected wetlands and wetland aggregations and compiled survey and anecdotal waterbird data to identify floodout systems known to and likely to support waterbirds. An earlier study of the vegetation, birds and terrestrial vertebrates found the floodouts of the Finke catchment support a range of species of biological significance, including Plains Rat (*Pseudomys australis*), Thick-billed Grasswren (*Amytornis textilis*), both classified as Vulnerable to extinction nationally, and Mongolian Plover (*Charadrius mongolus*), which is rarely recorded inland (Eldridge and Reid 1998). The study found that the Finke floodout provides refuge for terrestrial biota through drought periods (Eldridge and Reid, 1998). There are significant areas of forests and woodlands (both *Eucalyptus camaldulensis* and *Eucalyptus coolabah* ssp. *arida*) along channels, rivers and swamps that are likely supported by perched watertables (Duguid, 2011; see Section 1.1.6). Duguid (2011) identified three wetlands that meet the criteria of national significance in the Directory of Important Wetlands in Australia, four regionally significant wetlands, and proposed an additional three sites of possible significance for further investigation for the NT part of the Pedirka subregion (Table 18; Figure 43). Andando and Snake Creek Lakes and Beddome Range and Wilyunpa Tablelands are also identified as regions of conservation significance for the NT (Harrison et al., 2009; Ward and Harrison, 2009). Most of the wetlands are isolated from the major river drainages, including many of the ‘significant’ ones. Temporary perched watertables are thought to sustain some wetlands in floodouts for longer periods than rainfall or river flow alone, notably in the Snake Creek interdune wetlands which are part of the Finke floodout (Duguid, 2011).

There are severe infestations of Athel Pine (*Tamarix aphylla*), a weed of national significance, as well as other moisture-loving weeds, in some aquatic ecosystems of the Finke catchment and other catchments (Duguid pers. com., 2013). These compromise the ‘naturalness’ of these systems, altering the habitats and resources for fauna and outcompeting other native plants. They may also impact the hydrology-geomorphology relationships and alter flow paths.

Isolated surface water systems

The Pedirka subregion also includes many wetlands in the claypans between dunes filled from local rainfall events and not river flow. In the south-east of the Pedirka subregion there are numerous interdune lakes, known as the Peera Peera Poorana and Poeppel Lakes systems, that are fed by direct local rainfall. Some of the more southerly lakes connect with the Kallakoopah Creek (Nanson, 2010 in Hale et al., 2010). Nanson (in Hale et al., 2010) notes that this is the largest complex of dry lakes and interdunes in Australia, but it has been subject to almost no research due to its remoteness and difficulty of access.

Table 18 Potential Directory of Significant Wetlands Sites for NT-GAB, occurring partly or wholly within the Pedirka subregion

Level of Significance	Wetland Name	Main Values / Character
National/ International	Snake Creek Interdune Floodout Lakes	Waterbird diversity, large long-lasting waterbodies when filled.
National	Casuarina Swamp	EPBC listed plant species (*Eleocharis papillosa*).
National	Finke Floodout Forest 3 (and wetlands within and adjacent to it)	Large unusual vegetation type with diverse wetland elements.
Regional	Duffield Swamp	Extensive Bluebush swamp with sometimes long-lasting inundation.
Regional	Indemina Swamp	Large swamp with diverse elements, moderate plant species diversity is recorded, suspected waterbird values.
Regional	Indinda Swamp	A large swamp including areas of Bluebush, Lignum and wooded (Coolabah) swamp; moderate plant species diversity is recorded.
Regional	Skull Creek Swamps	Collection of small pans and swamps with diverse vegetation types.
Possible significance	Mt Wilyunpa Reticulated Swamp	An unusual geomorphic feature and wetland type; potentially distinctive vegetation.
Possible significance	Lower Plenty Lakes	An aggregation of wetlands – including claypans and semi-saline lakes.
Possible significance	Central Andado Wetlands: aggregations of shallow stony pans in the central Andado Station area, including around Mac Clarke (*Acacia peuce*) Conservation Reserve, The Peebles Creek catchment, and areas in between.	A very large collection of mostly small, shallow pans with mostly short lasting inundation; the number, density and extent of surface waterbodies is unusual in the arid NT and within NT-GAB; there is a group of pans/swamps at the edge of the stony plain and adjacent to the dunefield, 5.5 km NE of Rieks Dam that had a somewhat different appearance during aerial survey.

Source: Duguid et al. (2005) as presented in Duguid, (2011 p. 26) and Duguid (2011 p. 27)

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