Lake Eyre Basin Springs Assessment

Lake Eyre Basin (South Australia): mapping and conceptual models of shallow groundwater dependent ecosystems

DEWNR Technical note 2015/22

Government of South Australia
Department of Environment, Water and Natural Resources

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Catherine Miles[1] and Justin F. Costelloe[2]
Department of Environment, Water and Natural Resources

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[1]Miles Environmental Consulting

[2]Department of Infrastructure Engineering, University of Melbourne

Department of Environment, Water and Natural Resources

GPO Box 1047, Adelaide SA 5001

Telephone	National (08) 8463 6946
	International +61 8 8463 6946
Fax	National (08) 8463 6999
	International +61 8 8463 6999
Website	www.environment.sa.gov.au

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Foreword

The Department of Environment, Water and Natural Resources (DEWNR) is responsible for the management of the State's natural resources, ranging from policy leadership to on-ground delivery in consultation with government, industry and communities.

High-quality science and effective monitoring provides the foundation for the successful management of our environment and natural resources. This is achieved through undertaking appropriate research, investigations, assessments, monitoring and evaluation.

DEWNR's strong partnerships with educational and research institutions, industries, government agencies, Natural Resources Management Boards and the community ensures that there is continual capacity building across the sector, and that the best skills and expertise are used to inform decision making.

Sandy Pitcher
CHIEF EXECUTIVE
DEPARTMENT OF ENVIRONMENT, WATER AND NATURAL RESOURCES

Acknowledgements

The Lake Eyre Basin Springs Assessment (LEBSA) project received valuable guidance from the project Technical Reference Committee members made up of members from various offices, departments and groups and of diverse backgrounds, including the Department of Environment (DE), Bureau of Meteorology (BoM), Geoscience Australia (GA), Queensland Department of Science, Information Technology, Innovation, and the Arts (DSITIA), the SAAL NRM Board and the South Australian Department of Environment, Water and Natural Resources (DEWNR).

The LEBSA project has been delivered concurrently and in-conjunction with an equivalent project run by DSITIA, of which Keryn Oude-egberink (DSITIA LEBSA PM) has been instrumental in providing feedback to the TRC and SA LEBSA project, and guidance to the many DSITIA staff working on the project.

Overarching program guidance and coordination of SA and Qld LEBSA projects was provided by the Executive Steering Committee members: Peter Baker (DE), Edwina Johnson (DE), Anisa Coric (DE), Kriton Glenn (GA), Tim Evans (GA), Phil Deamer (BoM), Sarah van Rooyen (BoM), Brendan Moran (BoM), Tom Carrangis (DEWNR), Tim Ryan (DSITIA) and Keryn Oude-egberink (DSITIA).

The DEWNR LEBSA project team comprised: Andy Harrison (Project Manager), sub-Project Manager (Danny Brock), Travis Gotch, Ronald Bonifacio, Mel White, Dan Wohling, Mark Keppel, Dave Armstrong, Glen Scholz, Matt Miles, (DEWNR), with Catherine Miles (Miles Environmental Consulting) and Katie Fels (Jacobs).

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Summary

This project focusses on two preliminary assessment extents (PAE) (DEWNR 2014) of the Lake Eyre Basin in South Australia, the Arckaringa and the Cooper. The project aims were to

1. Capture the state of knowledge about ecosystems dependent on shallow groundwater through conceptual models and mapping, and

2. Trial the use of the Queensland groundwater dependent ecosystems (GDEs) mapping approach in South Australia.

Mapping of GDEs in the Arckaringa PAE was largely undertaken as part of a previous project (Miles and Miles 2015) that built on South Australia's Water Asset Database (WAD) for the South Australian Arid Lands region (Denny and Berens 2014). Research into water sources accessed by trees and surface water–groundwater interactions in the Neales River catchment has enabled the development of a relatively detailed conceptual model of GDEs for the Arckaringa PAE. Conceptual models for the Cooper PAE are more general, with less supporting evidence.

The Cooper GDE mapping aimed, in so far as possible, to apply the Queensland GDE mapping approach, whilst building on prior aquatic ecosystem mapping and classification. The Queensland mapping approach was used with the intent to achieve cross border consistency in mapping, however, application of the Queensland GDE mapping approach to the SA portion of the Cooper PAE was hampered by:

1. Lack of definitive spatial geometries to represent aquatic ecosystems

2. Lack of complementary spatial datasets of other features (such as vegetation, soils, depth to groundwater) necessary to apply the mapping rules approach

3. Very little knowledge about shallow groundwater resources and water sources accessed by vegetation in the Cooper PAE.

Therefore the results are considered preliminary. Despite the limitations, this work has demonstrated application of the mapping-rule sets approach used in Queensland with consistent GDE classification applied in the South Australian portion of the Cooper PAE (albeit with low confidence and limited extent). The mapping rule sets approach was found to be a useful method but reliant on supporting spatial data that was not available in that area. Two key recommendations from the draft report are that there needs to be improvement in the spatial data sets required to map GDEs, and on-ground investigations to determine different groundwater dependent ecosystems and their degree of reliance on groundwater.

1 Introduction

1.1 Overview of the Lake Eyre Basin Springs Assessment Project

This report is part of a series of studies forming part of the Lake Eyre Basin Springs Assessment (LEBSA) project. The LEBSA project is one of three water knowledge projects undertaken by the South Australian Department of Water, Environment and Natural Resources (DEWNR) to inform the Bioregional Assessment Programme in the Lake Eyre Basin (LEB). The three projects are:

- Lake Eyre Basin Rivers Monitoring (LEBRM)
- Arckaringa Basin and Pedirka Basin Groundwater Assessment
- Lake Eyre Basin Springs Assessment (LEBSA)

The Bioregional Assessment Programme is a transparent and accessible programme of baseline assessments that increase the available science for decision making associated with potential water-related impacts of coal seam gas (CSG) and large coal mining (LCM) developments. The coal-bearing Arckaringa, Pedirka, Cooper and Galilee basins (Figure 1.1) have been identified as regions where CSG and LCM developments are likely to occur or increase in the future. Bioregional assessments are being prepared in the LEB for the four coal regions to strengthen the science underpinning future decisions about CSG and LCM activities and their impacts on groundwater quality, surface water resources and aquatic ecosystems.

The objective of the LEBSA project was to address knowledge gaps relating to the potential impacts of mining developments on groundwater resources and assets across the LEB. In particular, the project aimed to characterise and attribute springs and other GDEs that are critical for the maintenance of those assets (e.g. ecological, hydrogeological, hydrochemical), in a way that is consistent across South Australia and Queensland.

The LEBSA project is being delivered by DEWNR for the South Australian areas of the LEB, with a similar project being run in parallel by the Queensland Government Department of Science, Information Technology, Innovation and the Arts (DSITIA) for Queensland areas of the LEB. The LEBSA project background, purpose, approach and links to the bioregional assessment are described in more detail in DEWNR (2015a).

1.2 Scope

The South Australian LEBSA project is predominantly focused on improving the state of knowledge about springs dependent on the deep groundwater of the Great Artesian Basin (GAB) (DEWNR 2015a). The project aims were to

1. Capture the state of knowledge about ecosystems dependent on shallow groundwater through conceptual models and mapping, and
2. Trial the use of the Queensland groundwater dependent ecosystems (GDEs) mapping approach in South Australia.

This project focusses on two Preliminary Assessment Extents (PAEs) of the LEB in South Australia, the Arckaringa and the Cooper, with the Cooper PAE included in order to extend mapping of groundwater dependent ecosystems being undertaken in Queensland (DSITIA).

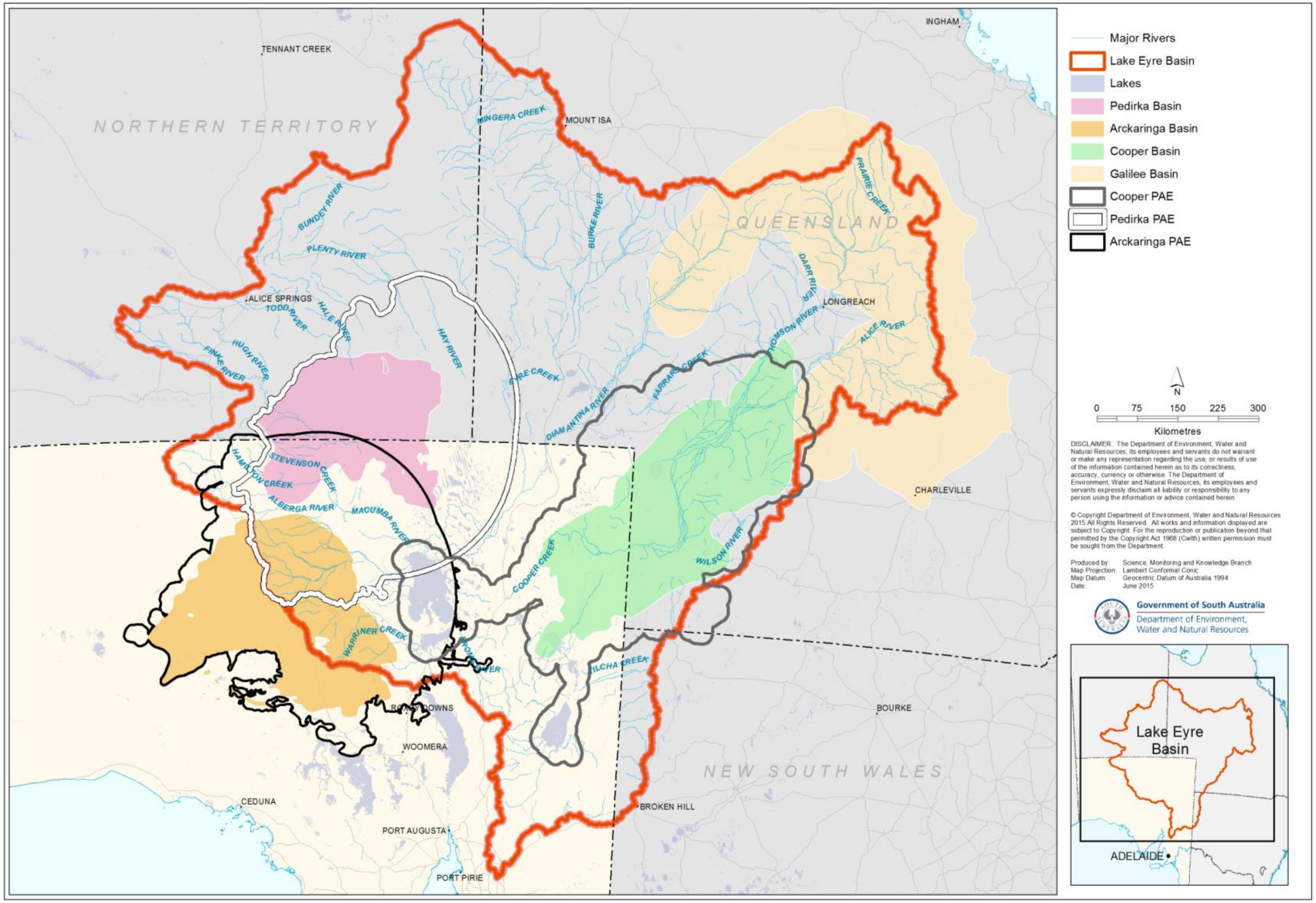

Figure 1.1 Location of the LEB, coal basins and preliminary assessment extents (PAEs) in South Australia

1.3 Classification and definition of groundwater dependent ecosystems

Understanding what water sources support aquatic ecosystems is a critical step to assessing potential risks to ecosystems from CSG and coal mining developments. Water source is an attribute of the interim Australian National Aquatic Ecosystems (ANAE) Classification Framework (AETG 2012a), but the classification of groundwater dependency is further refined in the Australian GDE assessment framework (Richardson et al. 2011). Groundwater dependent ecosystems are defined as 'ecosystems that require access to groundwater on a permanent or intermittent basis to meet all or some of their water requirements so as to maintain their communities of plants and animals, ecological processes and ecosystem services (Richardson et al. 2011 p. 1).' Three types of GDEs are recognised in the national GDE assessment framework:

1. Aquifers and cave systems (subterranean)
2. Ecosystems dependent on the surface expression of groundwater
3. Ecosystems dependent on subsurface presence of groundwater (Richardson et al. 2011)

This project has focused on the second and third types of GDEs as there is insufficient knowledge about subterranean GDEs in this region.

1.4 Overview of aquatic ecosystem mapping, classification and groundwater dependency attribution in the Lake Eyre Basin, South Australia

There have been a number of efforts to map, attribute and classify non-GAB spring aquatic ecosystems in the LEB in South Australia including as part of the LEB Rivers Assessment (e.g. Tunn and Cameron 2008), a trial of the guidelines for identifying High Ecological Value Aquatic Ecosystems (AETG 2012b) and for the national GDE Atlas (BoM 2015). A first project undertaken in preparation for the Bioregional Assessment Program was the collation of existing data-sets for the development of a Water Asset Database (WAD) (Denny and Berens 2014). The WAD was further developed into a geodatabse as part of the LEBRM project, with refinement of the spatial mapping of aquatic ecosystems in the Arckaringa PAE and application of the ANAE classification (Miles and Miles 2015). This project has built on the LEBRM work to apply groundwater dependency attributes aligned with the GDE Atlas to enable updating of the GDE Atlas and consistency with GDE mapping work being undertaken in Queensland a part of the LEBSA project there. The LEBRM geodatabase was used as the main data source for this project, with other data sources incorporated to refine the attribution (Table 1.1).

Table 1.1 Aquatic ecosystem mapping and classification undertaken for the Bioregional Assessment Programme

Program	Project	Sub-project (product)	Main data source geometry	Additional datasets incorporated (geometry and attribution)	Spatial format	Geographical focus
National Partnership Agreement	Vulnerability Assessment (2013)	SAAL Water Asset Database (Denny & Berens 2014)	Statewide wetlands, rivers and springs Other non-aquatic ecosystem water assets (e.g bores)	GDE Atlas Local and expert knowledge	Points Lines Polygons Relational database	Statewide
Water Knowledge Program	LEBRM (2014)	Aquatic Ecosystem Classification and Mapping (Miles & Miles 2015)	Water Asset database	Statewide and national datasets (vegetation structure, soil, landform energy, IBRA) Technical reports Expert opinion	Polygon shapefiles (geo-database)	Arckaringa PAE (Neales & Macumba catchments)
Water Knowledge Program	LEBSA (2015)	Cooper PAE GDEs (Miles & Costelloe 2015)	Aquatic Ecosystem Classification and Mapping (LEBRM)	Statewide data sets (vegetation structure, surface geology) Technical reports Expert opinion	Polygons shapefile (geo-database)	Cooper PAE (Cooper creek catchment)

2 Arckaringa alluvial groundwater dependent ecosystems

The mapping and description of conceptual models of groundwater dependent ecosystems in the Arckaringa PAE builds on the work of Miles and Miles (2015). Another project, the 'shallow groundwater project' (DEWNR 2015b), scheduled for completion in early 2016 is focused on improving the understanding of ecosystems dependent on shallow groundwater in the western rivers of the LEB. The shallow groundwater project will refine the conceptual model outlined below as well as mapping the distribution of GDEs in the Arckaringa region.

2.1 Conceptual model

Conceptual models of non-GAB GDEs in the western rivers of the Lake Eyre Basin were based on literature and expert opinion (Figure 2.3). There is very little data in the South Australian LEB on which to determine what ecosystems are groundwater dependent (other than GAB springs), their attributes and the hydrogeological processes contributing to their existence.

The major factors determining the likelihood of GDEs forming are:

- Geology and soil type
- Geomorphology
- Depth to groundwater
- Groundwater quality
- Recharge dynamics

2.1.1 Geology and soils

The surface geology of the region is predominantly composed of subcropping or outcropping, highly weathered Bulldog Shale. Consequently, the regolith profile of the region is interpreted to be predominantly highly weathered residual bedrock, with more recent transported alluvial sediments restricted to drainage channels. Outcropping and subcropping basement and JK aquifer rocks are found within and in the vicinity of the Peake and Denison Inlier, which forms a chain of ranges within the eastern portion of the area of investigation. These ranges are cut by the Neales River/ Peake creek river system (Figure 2.1).

The different geologies the rivers intersect are sediment sources for the alluvium and contribute to variable alluvium properties (Wakelin-King, 2011, 2014). The Neales and Macumba Rivers show a general pattern, typical of most rivers, of the alluvial sediments becoming finer grained along a downstream gradient. In addition, limited drilling also indicates that the alluvial sediments become coarser with depth. For instance, the alluvial soils in middle (and potentially lower) reaches of the Neales catchment consist of interlayered clays and silts overlying higher permeability sands and gravels (Costelloe et al., 2005b). In some reaches the upper alluvium is more silty sand (e.g. Angle Pole to Cramps Camp) (Ryu et al., 2014), and coarse in the Arckaringa and Lora Creeks (Wakelin-King, 2014). Macumba River catchment alluvial sediments are predominantly sandy.

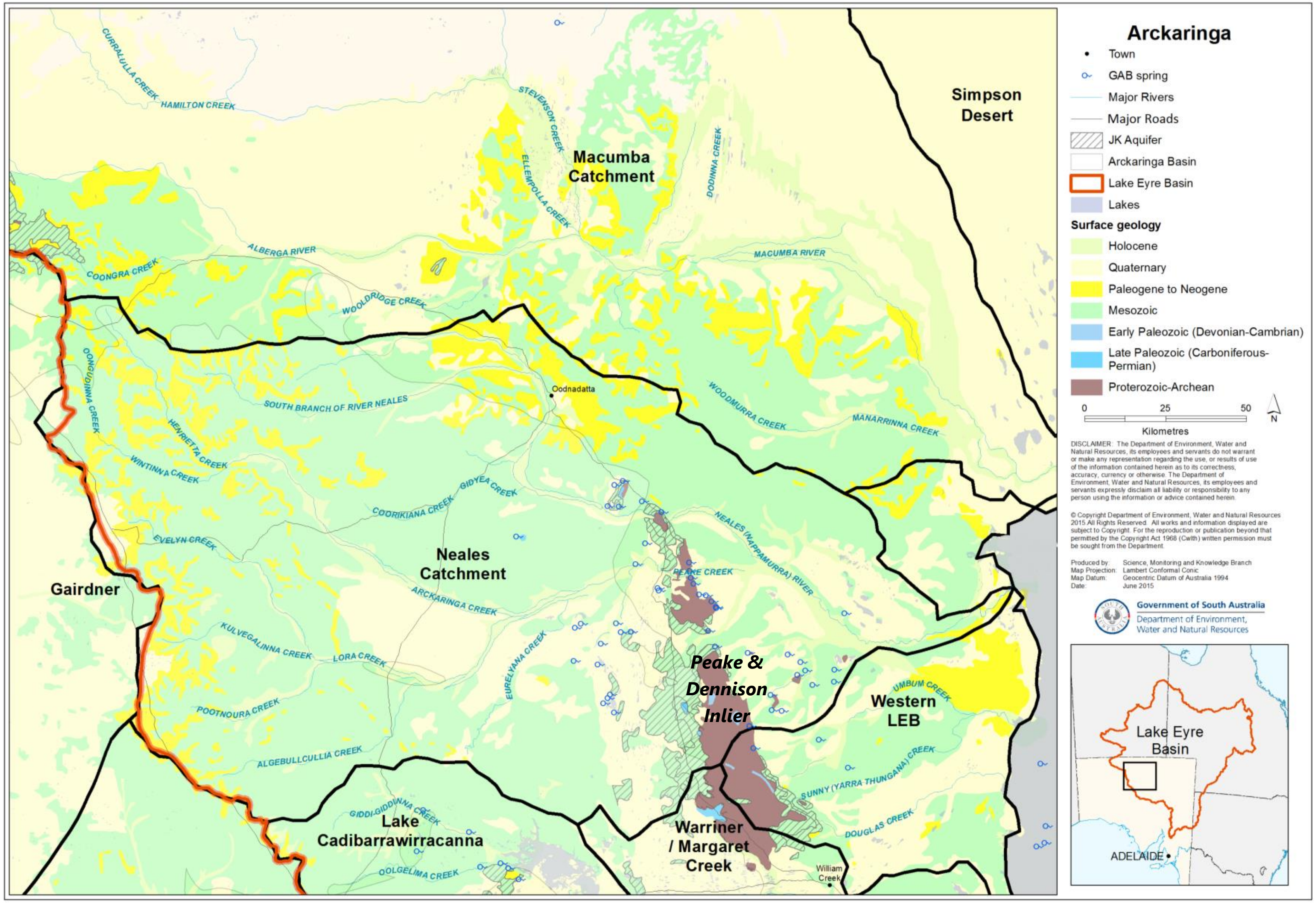

Figure 2.1 Surface geology of the Arckaringa PAE

2.1.1 Geomorphology

In the Neales catchment, in single channel reaches, deeper channel segments may cut down through the clays and silts to intersect layers of higher permeability sands and gravels. These higher permeability deposits can outcrop in the channel banks, but can also be concealed by a layer of clay lining the watercourse or waterhole (Costelloe et al., 2006). Multi-channel segments are shallower and do not penetrate through the clay-silt layer, but the micro-relief of shallow channels and slight rises create zones of differing soil water regimes (Costelloe et al., 2006). The channel morphology shows a general longitudinal, downstream pattern, moving from multiple channel forms in the upper to mid reaches to more single channel forms in the lower reaches (Wakelin-King, 2011, 2014). However, the channel forms also respond to particular changes in river slope and valley containment that overprint this general pattern (Wakelin-King, 2011, 2014).

2.1.2 Depth to groundwater

The regional unconfined groundwater level is mapped as being between 10 to 30 m below ground surfaces close to drainages over the Neales catchment, lower Peake sub-catchment and the Macumba catchment but this mapping is based on few data points (Figure 2.2) (Miles et al. 2015). Except at a few locations, groundwater in the upper Peake (including Arckaringa) catchment is deeper. However, the unconfined groundwater level mapping should be treated with caution as:

1. data are very sparse in the Neales-Peake and lower Macumba, particularly close to drainages (see Figure 2.2)
2. as noted below, the connectivity between regional and alluvial groundwaters is unknown.

In general, the depth to groundwater also follows a longitudinal downstream pattern, being deeper in the upper reaches and shallower in the lower reaches as the rivers approach the regional low point of Kati Thanda-Lake Eyre North (). Complicating this longitudinal pattern are the occurrences of probable perched aquifers at relatively shallow levels in the upper reaches.

Unpublished groundwater depth observations (see Figure 2.2 for locations) recorded in alluvial systems are:

- 0.7 m below the surface of the dry Ethawarra waterhole, a shallow waterhole on Hamilton Creek in the Macumba catchment (Ryu et al., 2014); this is possibly a perched alluvial aquifer.
- Approximately 5–6 m below stream base at Wintinna Homestead on Wintinna Creek, an upper tributary of Arckaringa Creek. Other data from Figure 2.2 indicates that the water table is typically much deeper in these upper reaches. Controls on the existence of perched alluvial aquifers are not well understood but may be facilitated by the existence of coarser grained alluvial sediments underlain by relatively impervious basement (non-alluvial) sediments/rocks at shallow depths.
- Three to seven metres below the floodplain surface at sites in the mid-Neales River and mid-Peake Creek (Costelloe et al., 2006). This groundwater is known to interact with waterholes and deeper primary channel section in these reaches.
- In the lower reaches of the Neales River (i.e. by Tardetakarinna Waterhole at the junction of the Neales and Peake), deeper pools in the river are groundwater fed and indicate that the depth to the watertable is only 2–3 m deep.

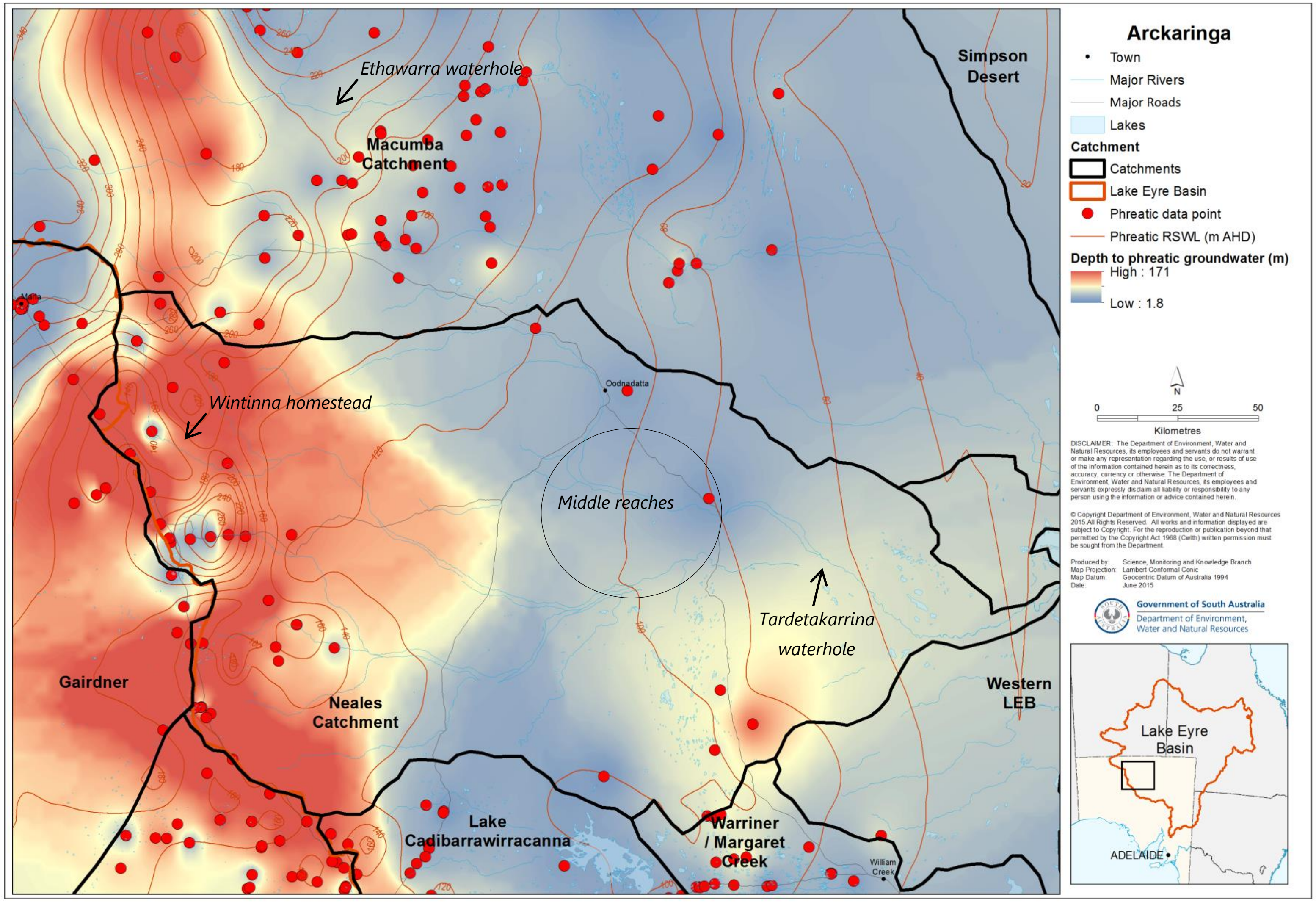

Figure 2.2 Interpreted phreatic groundwater contours for the Arckaringa PAE

Note: although phreatic groundwater is ubiquitous across the landscape and is commonly represented by groundwater in Cenozoic forrmations, this surface does not necessarily imply continuous groundwater movement between formations, nor is it completely restricted to Cenozoic formations. Source: Miles et al. 2015, figure 24

2.1.3 Groundwater quality

Alluvial groundwater in the mid-Neales is saline to hyper-saline except close to the banks of channelized sections (Costelloe et al., 2005b). Close (<10–15 m) to the banks, the groundwater is flushed during flow events (Costelloe et al., 2008). Waterholes in the mid-Neales which are known to receive groundwater (see below) become hypersaline soon after flow events cease and can reach hypersaline levels (e.g. >70,000 mg/L TDS – twice seawater salinity) within 6-18 months. It is likely that all waterholes downstream of Tardetakarinna receive groundwater and are hypersaline for most of the time (Costelloe, 2011; Ryu et al., 2014). Groundwater in the lower Macumba catchment is shallow and may be saline, as seen in the lower Neales (Ryu et al., 2014). In general, the groundwater salinity will show a similar downstream longitudinal pattern as the depth to groundwater, i.e. the shallower the depth to groundwater the higher is its salinity. This is considered to be driven by evapo-concentration processes where the groundwater is exposed to the surface, or near-surface environment, particularly in deeper ephemeral channels (Costelloe et al., 2007). This process may also be facilitated by the presence of finer grained alluvial sediments that limit infiltration and surface flushing but allow more capillary rise to the near-surface, compared to coarser grained alluvial sediments.

Fresh groundwater was recorded below the surface of Ethawarra Waterhole (on the Hamilton Creek, Macumba catchment) when it was dry in May 2013 (Ryu et al., 2014). Potable unconfined groundwater occurs around Wintinna Homestead and is most likely alluvial perched groundwater recharged by the nearby Wintinna Creek (tributary of Arckaringa Creek). These limited observations indicate that upper tributaries with coarse grained alluvial sediments, and the sand-dominant reaches of the upper to mid Macumba catchment, can contain low salinity, alluvial groundwater. Otherwise, in the mid to lower reaches of the Neales, the available data indicate that the unconfined groundwater is saline to hypersaline. For example, at Algebuckina Waterhole, the groundwater within 100 m of the channel had a salinity of 13 000 mg/L TDS but a salinity of 32 000 mg/L TDS approximately 200 m from the primary channel. The piezometric gradient of the groundwater was generally sloping away from the waterhole except at very low surface water levels.

2.1.4 Recharge

2.1.4.1 Regional recharge

The direction of regional groundwater flow is from the margins of the LEB towards Kati Thanda-Lake Eyre (Keppel et al., 2013) There are insufficient data to determine the degree of exchange between alluvial aquifers and regional groundwater but they are likely to be well-connected, with the exception of probable perched alluvial aquifers in the upper reaches.

Sources of recharge to the regional groundwater are likely to be a combination of diffuse rainfall and streamflow recharge. Love et al. (2013) found that diffuse recharge to GAB formations in the region is effectively zero under current climatic conditions. In the Diamantina River catchment, Tweed et al. (2011) found that the stable isotope data from groundwater outside of the Diamantina floodplain were consistent with diffuse recharge from large rainfall events (>100 mm/month) to the unconfined regional groundwater. Fluvial recharge to unconfined groundwater has been observed by a number of studies. For example, piezometric monitoring, groundwater–surface water modelling and hydrogeochemistry in the Neales catchment show that fluvial recharge is occurring in the middle reaches (Costelloe et al., 2006; 2007). Fluvial recharge has also been observed in the Finke River (Fulton et al., 2013) and Cooper Creek (Cendon et al., 2010). The contribution of the GAB to regional unconfined groundwater is minimal, but there are zones of preferential discharge to the upper aquifer around springs and via fractures and faults (Harrington et al., 2013).

2.1.4.2 Middle and lower reaches

The alluvium has been shown to be laterally recharged in some channelized reaches through the banks during flow events (Figure 2.3). Where higher permeability layers outcrop in the banks, recharge occurs via these, but where waterholes are clay lined then recharge may be limited or occur via macropores (cracks and tree roots) (Costelloe et al., 2006). The degree of discharge and recharge in these reaches is likely to be controlled by the depth of the channel incision through the uppermost, finer grained alluvial sediments.

Costelloe et al. (2006) found recharge to groundwater did not occur in unchannelised reaches, instead perennial floodplain vegetation used all the water that entered the soil before it reached the groundwater. Additionally, floodplain Coolabahs (*Eucalyptus coolabah*) have been shown to use all soil water recharged during floods and rainfall events (Costelloe et al., 2008), and therefore recharge is also likely to be limited on floodplains. For example, a study on the middle reaches of Cooper Creek found recharge below floodplain clay soils to be <1 mm y^{-1} (Larsen, 2011).

2.1.4.3 Sandy reaches

In the sandier reaches (e.g Angle Pole to Cramps Camp near Oodnadatta) and gravelly reaches (e.g. upper Arckaringa near Wintinna homestead) of the Neales and in the Macumba catchment there may be higher rates of recharge from river flows (Costelloe et al., 2005b; Ryu et al., 2014). This is inferred by the presence of Red Gums (*Eucalyptus camaldulensis* var. *obtusa*) in the Angle Pole to Cramps Camp reach of the Neales and through much of the Macumba, and by the observation of fresh groundwater at Ethawarra Waterhole, and the presence of shallow stock bores, on Hamilton Creek of the Macumba catchment. There are few direct observations of recharge behaviour in this region except for the mid-lower Neales (Costelloe et al., 2006) and Finke River (Fulton et al., 2013).

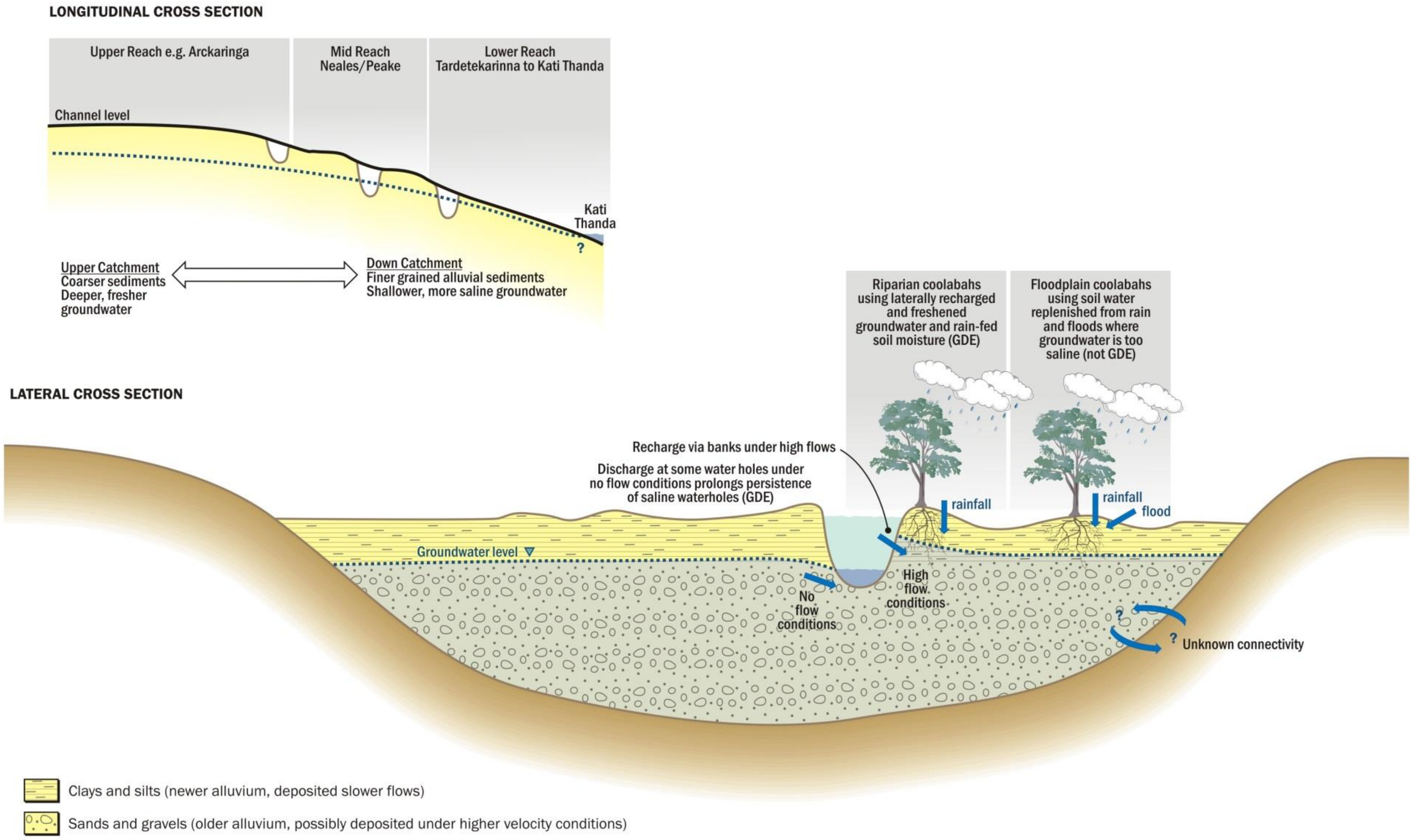

Figure 2.3 Conceptual model of groundwater–surface water relationships in the Arckaringa sub-region

Where GDEs exist in the upper reaches, the alluvial water table level is likely to be above the regional water table (perched or losing); in the lower reaches the alluvial water table may be level with or below the regional water table (gaining), however the alluvial groundwater is prevented from discharging into some waterholes by a thick clay layer lining the channel. Diagram not meant to imply a relationship between groundwater level and alluvium soil type.

2.2 Mapping

The Arckaringa PAE (particularly the Neales and Macumba catchments) was the focus of a LEBRM project (Miles and Miles 2015) that aimed to improve the spatial mapping and attribution of aquatic ecosystems, building on the work undertaken for the WAD project (Denny & Berens 2014) and aligning with the Interim Australian National Aquatic Ecosystems (ANAE) classification framework (AETG 2012a) and South Australian Aquatic Ecosystem (SAAE) classification (Fee and Scholz 2010). A component of the ANAE classification is the attribution of water source as surface water, groundwater or a combination (Figure 2.4). Miles and Miles (2015) expanded on the groundwater source attribution to provide more detail about the groundwater source. This project has further broken down the groundwater classification to align with the Queensland GDE classification (DSITIA 2015) and separate attributes for aquifer geology and confinement (see Appendix A)

For each aquatic ecosystem, a confidence rating was applied and the method or information source documented. Whilst there is little knowledge about groundwater dependence for most of the Arckaringa aquatic ecosystems, the hydrology and hydrogeology of some sites in the Neales catchment have been studied, enabling water source to be attributed with medium and high levels of confidence for select areas (Figure 2.5). However the confidence in the water source of aquatic ecosystems over the rest of the region was rated as low. The GDE Atlas (BoM 2015) was considered unreliable in this region, due to mapping many highly ephemeral streams that only hold water during a flow event as being reliant on the surface expression of groundwater (moderate potential) and all woodland vegetation as being reliant on the subsurface expression of groundwater (high potential). Remote sensing image analysis is commonly used as a method to map groundwater dependent ecosystems over large areas (E.g. BoM 2015; White et al. 2014; Kellett et al. 2012); studies to date (White et al. 2014; BoM 2015; Kellett et al. 2012) have produced conflicting results in the Arckaringa PAE. Since the water source of aquatic ecosystems was attributed in Miles & Miles (2015), additional analysis of MODIS imagery by White et al. (2014) has become available that indicates areas of vegetation on the Arckaringa Creek floodplain that have a high likelihood of groundwater dependence. The results of White et al. (2014) concur with and may refine the BoM (2015) GDE mapping but are in contrast to MODIS analysis presented in Kellett et al. (2012) and on-ground results (Ryu et al. 2014). Combining remotely sensed image analysis with on-ground groundwater investigation will be a priority for the shallow groundwater project (DEWNR 2015b) and will contribute to improved confidence in GDE mapping the Arckaringa PAE.

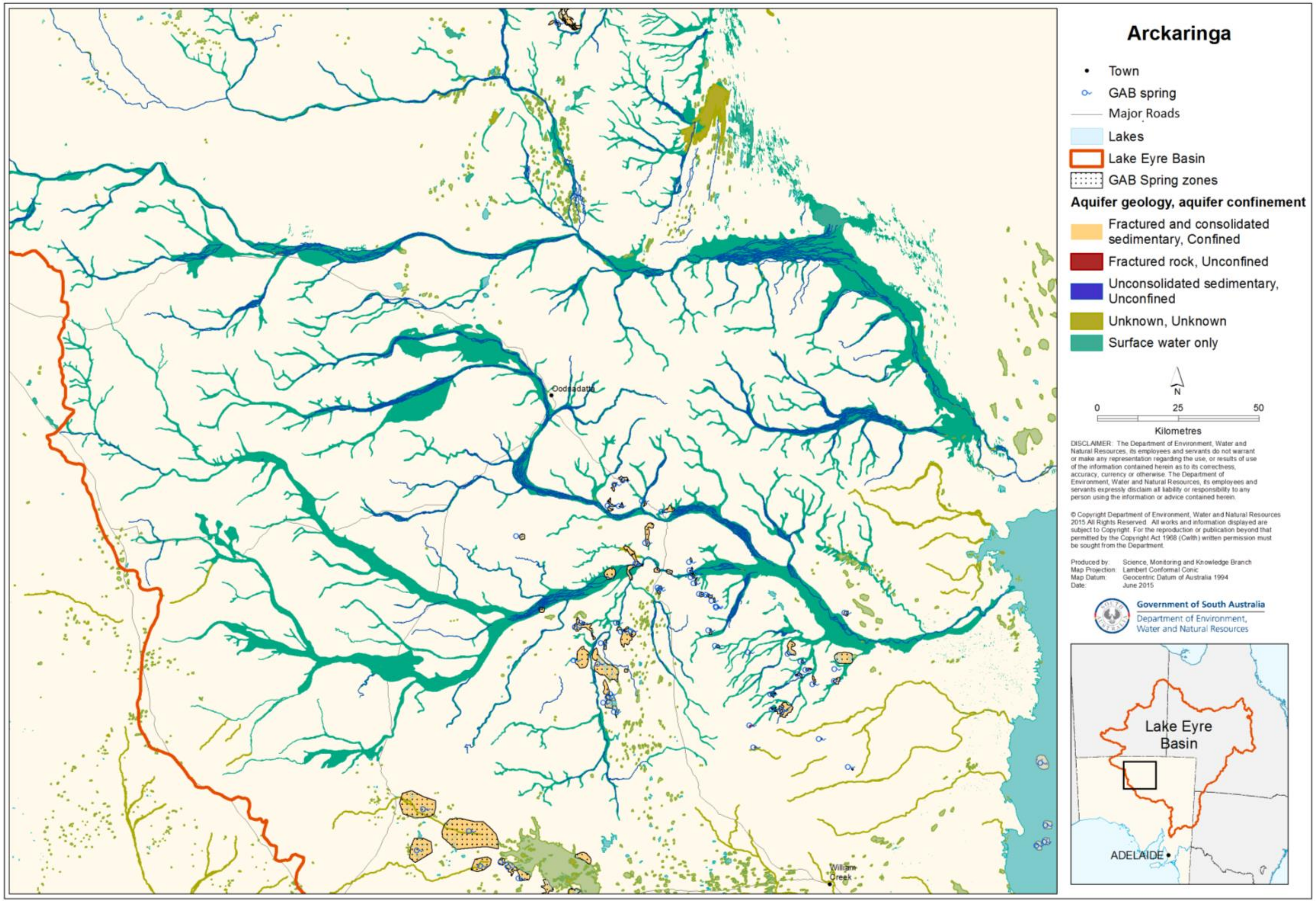

Figure 2.4 Map of aquifer geology and aquifer confinement for potential GDEs in the Arckaringa PAE

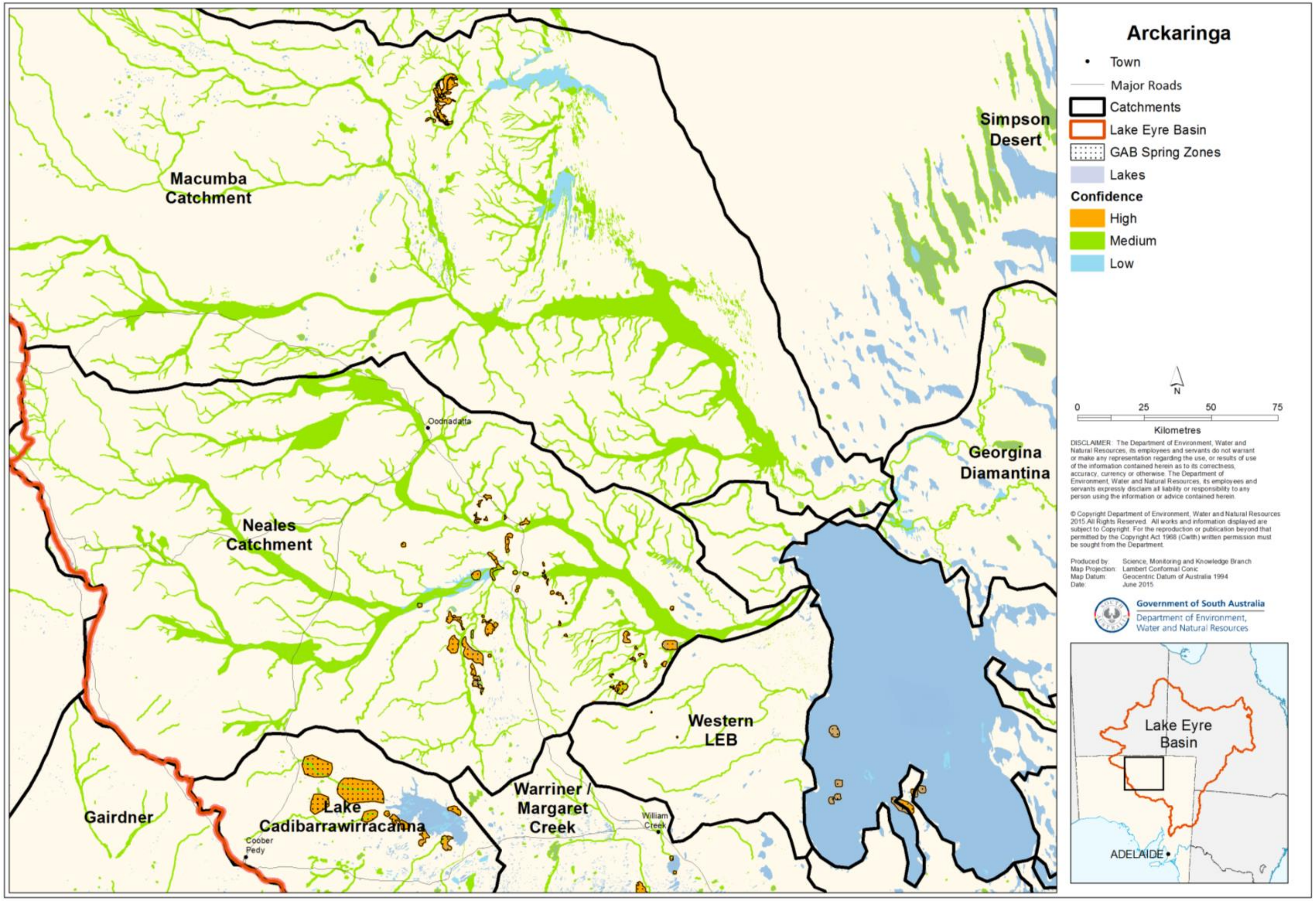

Figure 2.5 Map of confidence in water source attribution for aquatic ecosystems in the Arckaringa PAE

2.3 Groundwater dependent ecosystems

2.3.1 Waterhole groundwater dependent ecosystems

In the Neales catchment, four out of 22 studied waterholes are considered to receive significant groundwater inputs, these are Baltacoodna, Warrawaroona, Peake Crossing and Tardetakarinna (Ryu et al., 2014). Of these, only the latter is permanently maintained by groundwater while the others have prolonged persistence but will dry out after long (1–2 years) periods without flow (Ryu et al., 2014). Saline, semi-permanent and potentially permanent waterholes exist downstream of Tardetakarinna (McNeil et al., 2011; Ryu et al., 2014). A small trickle of moderate salinity (<6 400 mg/L TDS) groundwater inflow was observed in the upstream end of Algebuckina Waterhole during severe drought conditions of October 2013. It is unlikely that the observed flow would make a significant difference to the persistence of the main waterhole but would maintain small pools in the rocky upstream end of the waterhole.

These hyper-saline waterholes are unique environments that for periods of time can support abundant, low diversity assemblages of salt-tolerant fish [Lake Eyre Hardyheads (*Craterocephalus eyresii*) and Desert Gobies (*Chlamydogobius eremius*) (McNeil et al., 2011)], invertebrates (Shiel et al., 2006) and algae (Costelloe et al., 2005a). McNeil et al. (2011) refer to these waterholes as Polo-club refuges for fish as they are only suitable for a select few species. However, the salinities of these waterholes can exceed conductivities of 96 000 mg/L TDS within 6–9 months of a flow event (Costelloe and Russell, 2014) and these salinities exceed the tolerance of Lake Eyre Hardyheads and all but a few algal species. Riparian vegetation consists of sparse salt-tolerant shrubs and groundcovers but Coolabah can occur on bank-top positions.

Waterholes in the Macumba catchment are not considered to be GDEs (see below).

2.3.2 Riparian woodlands

Red Gums (*Eucalyptus camaldulensis* ssp. obtusa) are known to occur in the Neales catchment from Angle Pole to Cramps Camp (Ryu et al., 2014), in the upper Arckaringa Creek (Wakelin-King, 2014) and throughout the middle and upper Macumba catchment. As a general hypothesis, the distribution of different riparian tree assemblages can indicate the groundwater dependency of the riparian tree community but this is still to be confirmed by field observations. The following assemblages are considered to indicate characteristic GDE conditions:

1. Red Gum woodland – accessible (i.e. shallow) groundwater of low to moderate salinity (e.g. <6 400-9 600 mg/L TDS). Red Gum dominant riparian zones indicate particularly fresh groundwater

2. Coolabah dominant woodland – accessible (i.e. shallow) groundwater of moderate to high salinity (e.g. 6 400–32 000 mg/L). In mixed Red Gum–Coolabah assemblages, the Red Gums will only be in bank or bank top positions (accessing fresh bank storage) while Coolabahs occupy bank top and floodplain positions (accessing more saline alluvial groundwater). Reaches with sparse Coolabahs as the dominant tree type will typically have the Coolabahs around the primary channels and they may be utilising only soil moisture supplied by streamflow and rainfall events.

3. *Acacia* spp. dominant woodland – deeper groundwater, possibly below the root zone (hence not a GDE). The occasional Coolabah is common in Acacia dominant woodland but they occupy primary channel positions that have higher availability of soil moisture.

In the Neales catchment, in reaches with hypersaline groundwater (close (<4 m) to the floodlplain surface, riparian Coolabah woodlands are able to grow in channelized sections by using a mixture of soil water and groundwater, growing close to the banks where lateral recharge freshens the groundwater (Costelloe et al., 2008). Riparian Coolabah woodlands on the lower Macumba may also be supported by bank flushing, but this has not been investigated.

Red Gums in the sandy reaches of the Macumba, upper Neales and Arckaringa may be accessing fresher groundwater (Ryu et al., 2014), or may indicate zones of high run-off from surrounding catchments frequently filling relatively small volume of alluviums (G. Wakelin-King (Wakelin Associates) 2014, pers. comm. 24 September). There has not been any research into water sources accessed by Red Gums in the western LEB. One location where Red Gums occur in the Arckaringa (Figure 44 in Wakelin-King (2014)) is approximately 500 m from a bore located above the floodplain where the depth to groundwater level has been measured at 11 m. There are two other locations in these upper catchments where shallow groundwater is recorded, but there are no records of vegetation at these sites.

3 Cooper (South Australia) groundwater dependent ecosystems

3.1 Overview

The Cooper GDE mapping aimed to apply the Queensland GDE mapping approach (DSITIA 2015) to the South Australian (SA) portion of the Cooper PAE whilst building on the existing work of Miles and Miles (2015) and Denny and Berens (2014). The Queensland GDE mapping methodology includes a structured workshop phase to capture local and expert knowledge termed "walking the landscape." Much of the consultation phase of "walking the landscape" was undertaken prior to this project as part of consultation for the Water Allocation Plan (WAP) processes and NRM Water Asset Database project (Denny and Berens 2014). The Queensland GDE mapping approach uses the information gathered in the "walking the landscape" phase to develop mapping rules that are applied using existing spatial data sets to determine likely GDEs.

The spatial geometry of the WAD (Denny and Berens 2014) was used and additional polygons were only added for the riparian woodland GDEs (Section 3.2). Additional fields were added to the Miles and Miles (2015) geodatabase to create attributes consistent with the Queensland GDE mapping (DSITIA) and the Queensland definitions were used in these fields (see Appendix B). The values for water source and other attributes applied by Miles and Miles (2015) were not altered as part of this work unless specific evidence was found in journal articles that increased confidence to high.

The Queensland mapping approach was used with the intent to achieve cross border consistency in mapping GDEs, however, application of the Queensland GDE mapping approach to the SA portion of the Cooper PAE was hampered by:

1. very little knowledge about shallow groundwater resources and water sources accessed by vegetation in the Cooper PAE
2. a lack of relevant and accurate data sets with which to apply GIS rules
3. multiple and overlapping spatial geometries of aquatic ecosystems.

Therefore the Cooper component of this project has focused on presenting conceptual models of GDEs that are likely to occur in the region and then mapping them in so far as is reasonably practical with the available datasets. The results are considered preliminary and require on-ground validation.

Shallow groundwater well data in the Cooper PAE are sparse and very high salinities (26 000 to 95 000 mg/L TDS) have been recorded (Costelloe et al. 2009). Groundwater dependency has been the subject of very little research in the Cooper in SA and is recommended as a priority for future investigations (Costelloe 2013).

As there is limited knowledge to identify what ecosystems are groundwater dependent with confidence, there is also limited knowledge to determine what aquatic ecosystems are not groundwater dependent. Therefore all aquatic ecosystems other than those identified through the mapping approach outlined below were assigned "Unknown" GDE Type.

Private industries operating in the Cooper PAE in South Australia have also been undertaking work in mapping GDEs but this information was not available to be included in this work.

3.2 Riparian woodland groundwater dependent ecosystems

3.2.1 Conceptual model

The Riparian Woodland GDE conceptual model is consistent with the Queensland "Alluvia – lower catchment" conceptual model (DSITIA 2015) and the riparian woodland component of the Arckaringa conceptual model presented in Section 2.1. A key difference with the Arckaringa conceptual model is that groundwater close to the channel banks is sufficiently fresh to support riparian Red Gum woodlands in the upper reaches (upstream of the Coongie Lakes (on the North West Branch) and Munjoorooanie Waterhole, north of Cuttapirie Corner, on the Main Branch (Gillen and Reid 2013)).

There is little specific data to support the application of this conceptual model in the South Australian Cooper catchment as data on shallow groundwater and water sources accessed by riparian trees are scarce. However MODIS Enhanced Vegetation Index analysis for the drought period of 2000–08 indicates riparian vegetation along the Cooper Creek from upstream of the SA–Qld border down to the junction of the North West and Main branches as having a high likelihood of being groundwater dependent (Figure 6.25 in Kellett et al. 2012).

Studies in more upstream reaches of the Cooper Channel Country (Cendon et al 2010; Larsen 2011) indicate the main mechanism for recharge of the alluvial groundwater occurs when clay sediments lining channel banks are scoured during high flows, resulting in zones of fresher groundwater immediately adjacent to channels and waterholes. Riparian trees may access groundwater freshened by this recharge mechanism, as has been documented in the Neales and Diamantina catchments (Costelloe et al. 2008). The occurrence of Red Gums lining the channels and waterholes of the more permanent upper reaches may also be indicative of alluvial groundwater of sufficiently low salinity (i.e. below 40 000 μS/cm; Mensforth et al. 1994) due to more frequent flow events.

3.2.2 Mapping

A mapping rule was adopted from the Queensland “Alluvia – lower catchment” conceptual model (DSITIA 2015) Mapping Rule-Set 01M: Quaternary alluvial aquifers with brackish, ephemeral groundwater connectivity regime and Mapping Rule-Set 01R: Quaternary alluvial aquifers with saline, ephemeral groundwater connectivity regime. The key difference between 01R and 01M is that the former has saline groundwater and was applied in the Georgina catchment, while 01M has brackish groundwater and was applied in the Cooper catchment. It is likely that the 01M (brackish) rule would apply in the upper reaches in the Cooper catchment in South Australia but that this should grade to 01R (saline) at some point moving downstream, possibly at a point coinciding with the downstream extent of River Red Gums (Costelloe 2013; Gillen and Reid 2013).

Due to the limited extent of vegetation structure mapping in SA, this rule could effectively only be applied in discrete areas of the Cooper PAE (Figure 3.1).

The vegetation structure attribution given in Miles and Miles (2015) was re-calculated for aquatic ecosystems in the Cooper PAE using ESRI ® ArcToolbox Union to identify the parts of aquatic ecosystems that are mapped woodland and the adjacent mapped woodland areas. The vegetation method field was attributed ‘Union SA_VEG_STRUCTURE GENFORMDESC’ and confidence assigned ‘medium.’ All new woodland polygons not intersecting the alluvial geology were deleted. All woodlands and woodland aquatic ecosystems intersecting alluvial geology were then assigned riparian woodland GDE attributes (as per Table 3.1)

The results of this mapping (Figure 3.1) are similar to the mapping of sub-surface GDEs for the same region in the GDE atlas (BoM 2015).

Table 3.1 Attribution of Cooper riparian woodland GDEs

GDE attribute	Value
GDE type	Sub-surface GW GDE
Rule name	Qld LEB Alluvia
Rule part	Qld LEB RS 01M – upper* Cooper Qld LEB RS 01R – lower* Cooper, Macumba, Neales, Diamantina catchments Qld LEB RS 01X – other
Confidence	Low
Evidence	EXTRAPOLATED FROM RULE
Data source (for spatial geometry)	LEBRM AECM SA woodland veg – LEBRM AECM for those polygons delineated by being woodland alone
Conceptual model	Riparian woodland
Aquifer geology	Unconsolidated sedimentary

GDE attribute	Value
Aquifer confinement	Unconfined
Aquifer porosity	Primary
Groundwater flow system*	Shallow alluvial
Groundwater salinity	Qld LEB RS 01M: Brackish Qld LEB RS 01R: Saline Qld LEB RS 01X: Unknown
Groundwater pH	Unknown
Aquifer recharge source	Unknown
Groundwater connectivity regime (temporal)	Unknown
Groundwater connectivity regime (spatial)	Unknown

* The distinction between upper and lower Cooper catchment was defined as Coongie Lake on the North West Branch and Munjoorooanie Waterhole on the Main Branch

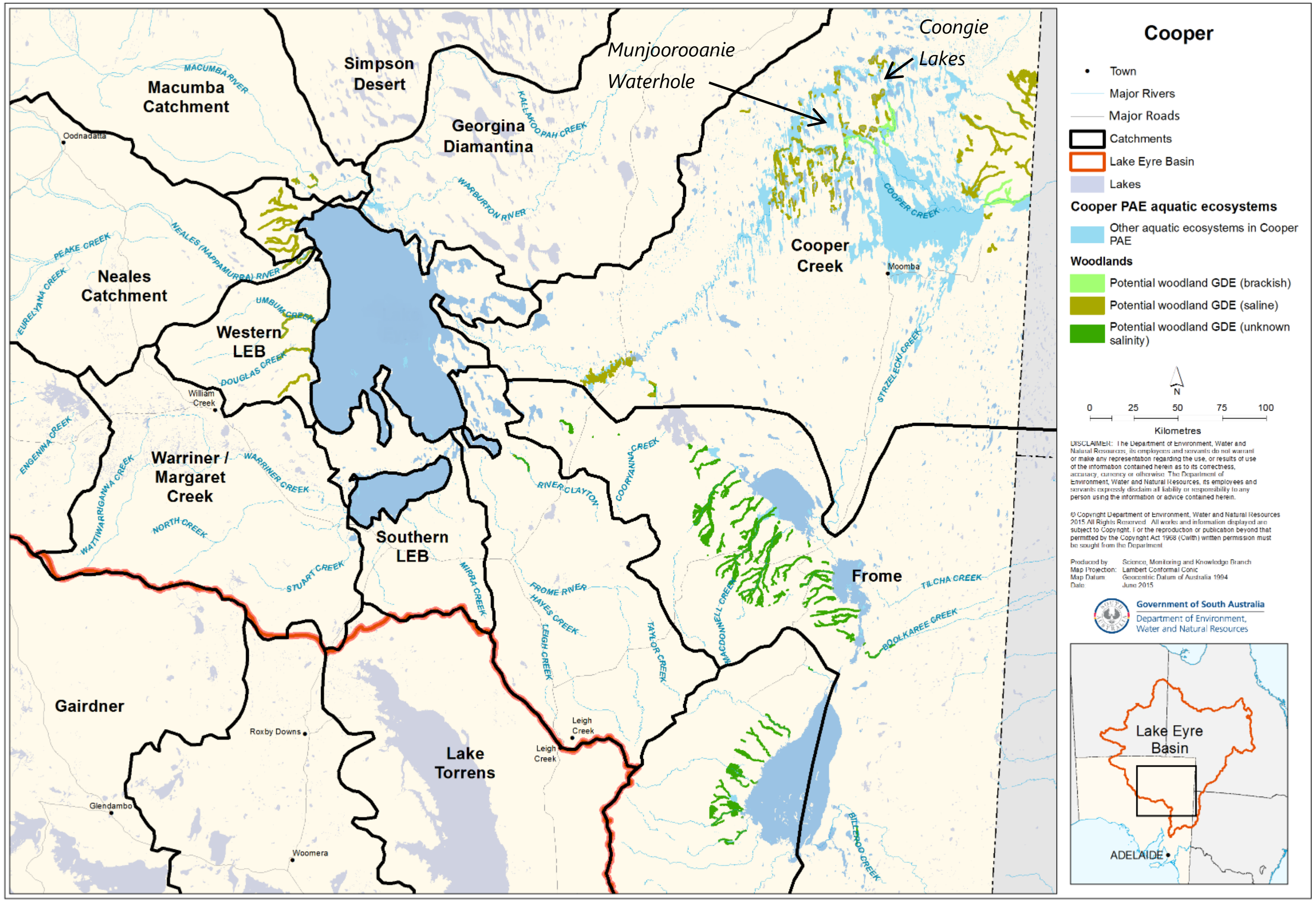

Figure 3.1 Potential woodland GDEs in the Cooper PAE

Note: size of the woodland GDEs has been exaggerated to be visible at this mapping scale

3.3 Waterhole groundwater dependent ecosystems

3.3.1 Conceptual model

Research in the Cooper Channel Country has found that waterholes are lined with clay sediments that prevent interaction with alluvial groundwater for the majority of the time, except during high flow events, during which the clays are scoured and alluvial groundwater is recharged (Hamilton et al. 2005; Cendon et al. 2010; Larsen 2011). While Cendon et al. (2010) and Larsen (2011) found the alluvial groundwater table was below the depth of the studied waterholes, the watertable becomes increasingly shallow approaching Kati Thanda-Lake Eyre (Kellett et al. 2012) and therefore in SA the deeper waterholes may intersect the watertable, particularly Cullyamurra waterhole, which is over 25 m deep (Costelloe 2013). Monitoring of surface water levels at five sites on the Cooper in SA indicated that there is unlikely to be significant groundwater inputs but there could be some groundwater connection (Costelloe et al. 2007; Costelloe 2013). However it is likely that the deeper waterholes on the Cooper upstream of the junction of the Main and North West branches may receive some groundwater inputs, of which fresh bank storage is likely to be a significant factor. Well data available on WaterConnect (Government of South Australia 2015) indicates shallow (15-40 m below ground level) brackish to saline groundwater occurs near to the Cooper Creek near Innamincka, and a 10 m deep well[2] adjacent to Cullyamurra waterhole which recorded groundwater with EC 242 µS/cm, implying groundwater was encountered at less than 10 m.

The occurrence of waterhole GDEs in the SA upper Cooper is supported by remote sensing analysis presented in Kellett et al. (2012), indicating the riparian vegetation is persistently healthy throughout drought periods. There no evidence supporting the existence of waterhole GDEs in the middle reaches (downstream of the Main and Northwest Branch junction) but some speculation that they may occur close to the western shores of Kati Thanda-Lake Eyre, as evidenced by the persistence of some waterbodies in the Water Observations from Space (WOFS; Geoscience Australia 2015).

The Queensland alluvia–lower catchment conceptual model includes baseflow to watercourses, however there is limited support to apply this model directly in the South Australian reach and the model presented for the Arckaringa PAE (Figure 2.3) is more likely to apply, particularly with respect to bank storage processes.

3.3.2 Mapping

Waterhole: Upper Cooper: All waterholes with a cease to flow depth >5 m on the Cooper upstream of the Main Branch and North West Branch junctions (as recorded in Costelloe (2013)) were manually selected by their asset name and assigned surface expression GDE's as per Table 3.2.

Waterhole: Kati Thanda 50 km buffer waterholes (KT 50 km WH): All waterholes within a 50 km radius of Kati Thanda-Lake Eyre North and South were selected and assigned surface expression GDE attributes as per Table 3.2. Those waterholes in the Cooper catchment were assigned a low confidence (compared with other catchments which were assigned medium) on the basis that there are no known long lasting waterholes in the lower Cooper and the WOFS (Geoscience Australia 2015) does not indicate the presence of persistent waterbodies.

Waterhole: Non-GDE: All other waterholes were assigned "Non GDE."

The application of the above mapping rules (Figure 3.2) was reliant on aquatic ecosystems being classified as waterholes; this was undertaken as part of previous mapping work that contributed to the WAD (Denny and Berens 2014). Miles and Miles (2015) directed some effort towards improving the classification of waterholes as an aquatic ecosystem type in the Neales and Macumba catchments, including manually classifying aquatic ecosystems. It was beyond the scope of this project to undertake such a detailed check and correction of waterhole classification in the Cooper PAE due to the size of the area and complexity of the spatial geometries. Therefore it is highly likely that the application of the "Waterhole" rules would have missed some aquatic ecosystems to which the rules should have applied.

[2] Obswell number 7042-14, drilled in 1957

Table 3.2 Attribution of waterhole GDEs

GDE attribute	Upper Cooper	Kati Thanda-Lake Eyre
GDE type	Surface expression GDE	Surface expression GDE
Rule name	Waterhole	Waterhole
Rule part	Upper Cooper	KT 50 km WH
Confidence	Low	Low (Cooper) Medium (other)
Evidence	Expert opinion	WOFS and expert opinion
Data source (for spatial geometry)	LEBRM AECM	LEBRM AECM
Conceptual model	Lower catchment alluvium waterhole	Kati Thanda GW mound
Aquifer geology	Unconsolidated sedimentary	Unconsolidated sedimentary
Aquifer confinement	Unconfined	Unconfined
Aquifer porosity	Primary	Primary
Groundwater flow system*	Shallow alluvial	Shallow regional
Groundwater salinity	Brackish	Hypersaline
Groundwater pH	Unknown	Unknown
Aquifer recharge source	Unknown	Unknown
Groundwater connectivity regime (temporal)	Unknown	Unknown
Groundwater connectivity regime (spatial)	Unknown	Unknown

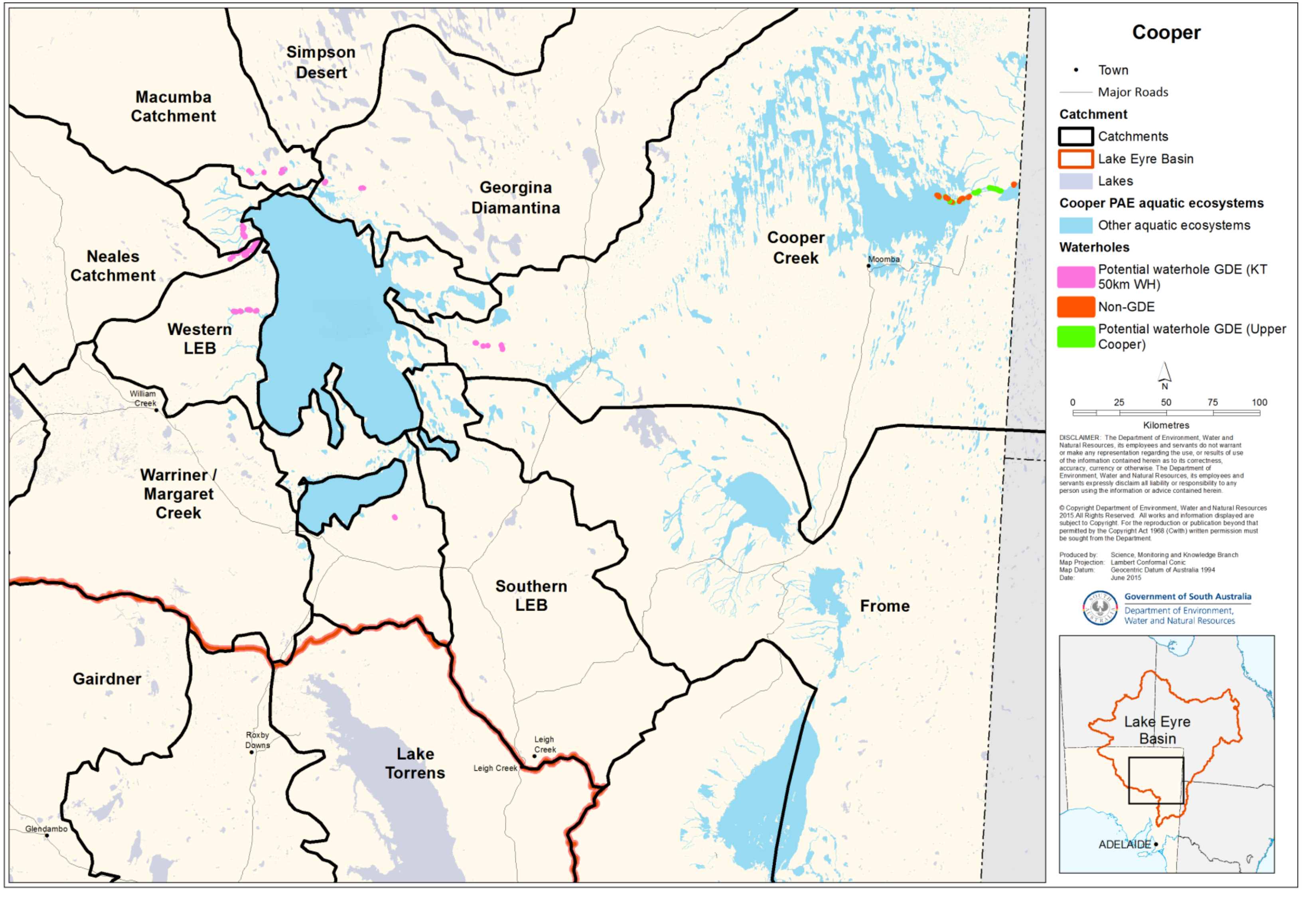

Figure 3.2 Potential waterhole GDEs in the Cooper PAE

Note: size of potential waterhole GDEs have been exaggerated to be visible at this scale

3.4 Evaporative influence groundwater dependent ecosystems

3.4.1 Conceptual model

Costelloe et al. (2009) presents evidence for a model of dynamic surface water–groundwater interaction occurring in some of the Coongie Lakes complex. Groundwater is recharged through the lake beds during flood events. The resulting shallow water tables result in the salinisation of the lake bed sediments due to capillary rise and evaporation during dry periods (Figure 3.3). Recharge occurs mainly via cracks (macropores) in the clay lake sediments and, as cracking tends to be more pronounced the longer the lake sediments are dry, recharge is also greater via this mechanism in less frequently inundated lakes and following extended dry periods. Recharge via the cracks bypasses most of the soil profile, so there is limited flushing of salts from the soil profile. However, if there are repeated wet events then recharge will occur via matrix flow and flush salt from the sediments to the groundwater. Therefore more ephemeral lake bed soils are more saline, while more permanent lakes have fresher shallow groundwater. The lakes are surrounded by more saline groundwater, and if significant recharge occurs, the subsequent rise in the surrounding groundwater levels may impact the health and distribution of surrounding vegetation; it is unknown how far the rise in the watertable extends away from the lake.

While this model does not indicate groundwater contributing water to the lakes or supporting surrounding vegetation as is traditionally thought of a GDE, the contribution of evaporative discharge during dry phases contributes to the water quality of these lakes and a gradation in salinity down catchment. These patterns are likely to influence the distribution of riparian and surrounding floodplain vegetation, in addition to the algal seed-banks and zooplankton egg-banks that occurs in the lake bed sediments (Costelloe et al. 2009). Therefore this model is presented as a surface expression GDE type, however further work may be required to determine to what extent this process of evaporative discharge supports the ecological character of the aquatic ecosystem.

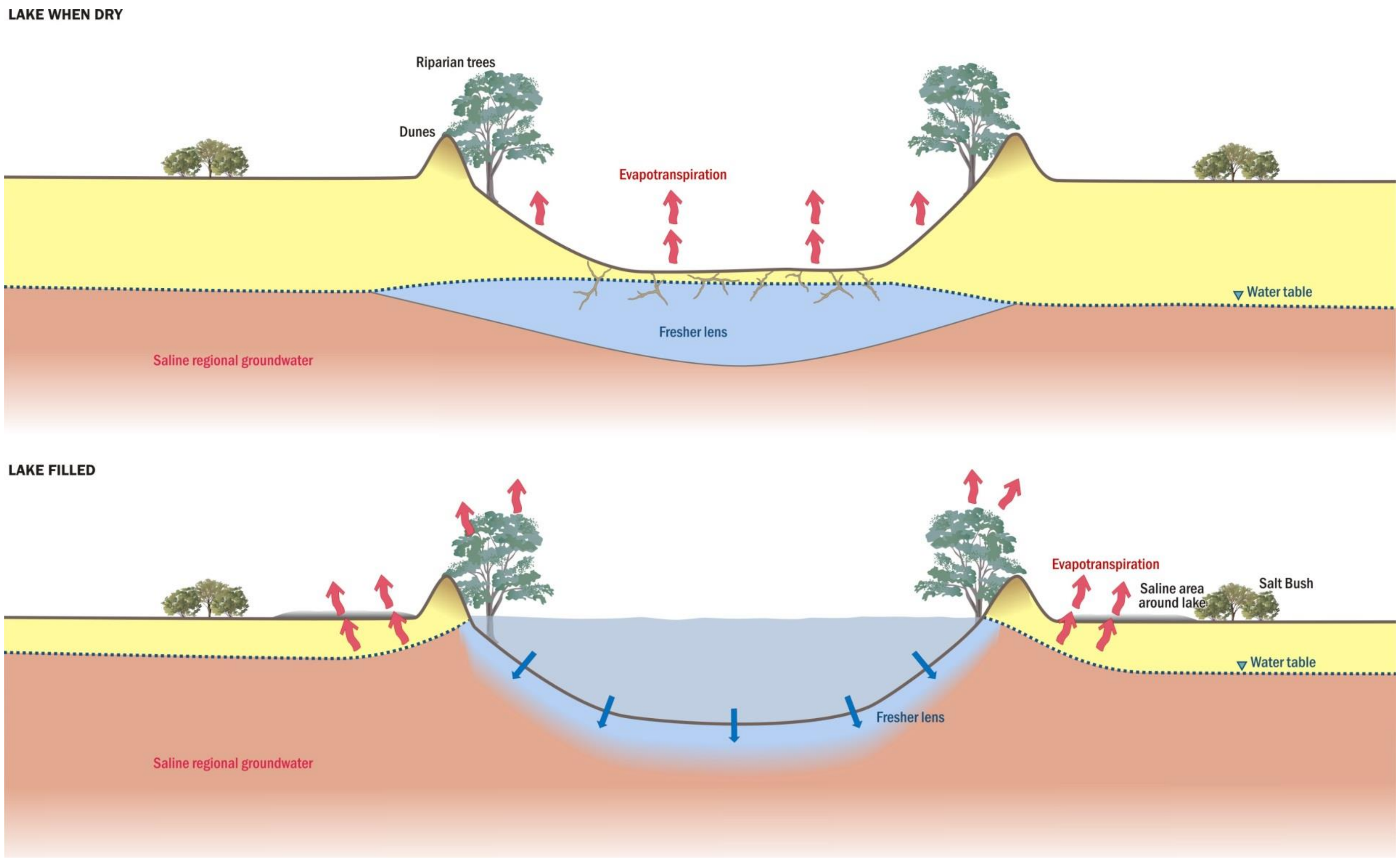

Figure 3.3 Conceptual model of evaporative influence GDEs in wet and dry phase

3.4.2 Mapping

The lakes studied by Costelloe et al. (2007) and Lake Hope (on the basis of Costelloe 2013) were selected and attributed as per Table 3.3 (Figure 3.4).

Table 3.3 Attribution of evaporative discharge GDEs

GDE attribute	Value
GDE type	Surface GW GDE
Rule name	Lakes
Rule part	Evaporative discharge
Confidence	Medium
Evidence	Journal article
Data source (for spatial geometry)	LEBRM AECM
Conceptual model	Evaporative discharge lakes
Aquifer geology	Unconsolidated sedimentary
Aquifer confinement	Unconfined
Aquifer porosity	Primary and secondary
Groundwater flow system*	Alluvial
Groundwater salinity	Euryhaline
Groundwater pH	Unknown
Aquifer recharge source	Combined
Groundwater connectivity regime (temporal)	Gaining/losing
Groundwater connectivity regime (spatial)	Aseasonal, ephemeral

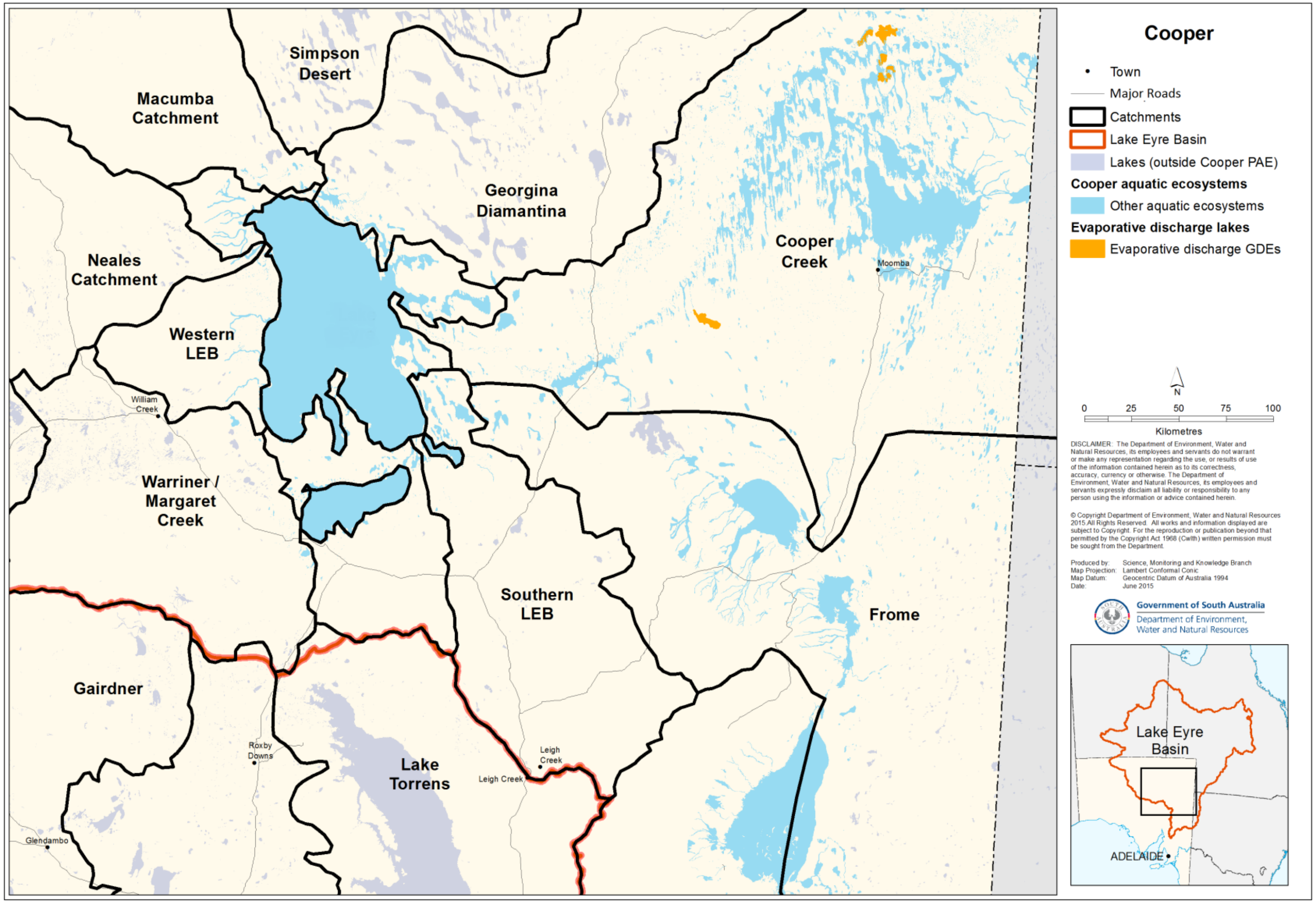

Figure 3.4 Potential evaporative influence GDEs in the Cooper PAE

3.5 Other known and potential groundwater dependent ecosystems

3.5.1 Terminal lakes

It has been proposed that Kati Thanda-Lake Eyre North and South and the Lake Frome to Lake Blanche complex of lakes are zones of terminal discharge for the regional shallow groundwater (Kellett et al. 2012; Allison and Barnes 1985). While the surface waters in these lakes dry out, the sediments remain saturated; this may be the result of a shallow groundwater table. The watertable becomes increasingly shallow towards Kati Thanda-Lake Eyre (Kellet et al. 2012), and has been recorded at less than one metre from the surface at Kati Thanda-Lake Eyre North (Ullman 1985) and Lake Frome (Allison and Barnes 1985). The depth of the tertiary sediments of the lakes is unknown. Evaporative discharge of groundwater is likely to be a contributing factor to the salinity of the lakes in addition to surface water inflows.

The GAB is artesian beneath the lakes, however there are GAB springs on the bed of Kati Thanda-Lake Eyre North and South, Lake Blanche, Lake Callabonna and Lake Frome (Gotch 2013). Due to the difficulty of accessing these sites, nothing is known about their hydrogeological structures, discharge rates or ecology. The presence of these springs could warrant classification of the lakes as GDE (as they were classified in the WAD (Denny and Berens 2014)) however it is not clear to what extent the lake ecosystems are dependent on this groundwater discharge. The springs could be refuges for species that colonise the lakes when they fill, in which case the lake ecosystems may be relying on the springs. It is likely that the lakes exert a stronger influence on the ecology of the springs (by providing hydrological connectivity between the springs and hydrological disturbance with rising and falling lake levels and salinity).

In summary, there is potential that the salt lakes at the terminus of the LEB are a) a type of evaporative influence GDE, or b) are dependent on GAB discharge, or both, however there remains significant uncertainty at this point and therefore lakes were classified as ‘unknown’ GDE type for this project due to insufficient knowledge on which to classify the lakes.

3.5.2 Dune storage groundwater dependent ecosystems

Discharge of groundwater stored in dunes following major flood events to adjacent wetlands and waterholes is another type of GDE that has been documented as occurring at a site in Goyders Lagoon in the Diamantina catchment (Costelloe 2008). In Queensland, a conceptual model for another type of dune GDE (“Rule-Set 08C”) has been developed and mapped as occurring in the Queensland portion of the Cooper PAE (DSITIA 2015). Both dune GDE types (Costelloe 2008 and DSITIA 2015) are highly likely to occur in the Cooper PAE in dunefield regions, however the spatial data in SA is of insufficient resolution and coverage to apply mapping rules.

4 Conclusions

This report has presented the current state of knowledge about non-GAB groundwater dependent ecosystems in the Arckaringa and Cooper PAEs of the LEB for the purposes of the LEB bioregional assessment. Pictorial conceptual models and spatial mapping have been used to represent this knowledge.

The project has highlight significant gaps in knowledge about the distribution and processes driving ecosystems dependent on shallow groundwater in both regions in South Australia. There is very little on-ground data for non-GAB groundwater resources in both regions. Investigations into surface water–groundwater interactions and tree water use in the Neales River catchment (Costelloe et al. 2005; 2006; 2008; Ryu et al. 2014) have advanced our knowledge base improving our ability to map and understand GDEs in that region. Analysis of remotely sensed imagery has been used to map potential for GDEs in both regions (White et al. 2014; Kellett et al. 2012; BoM 2015), however this has produced conflicting results, emphasising the importance of on-ground data to ground truth these methods. Investigations currently underway in the Neales catchment and lower Diamantina will further advance our knowledge in those regions but the Cooper PAE remains particularly poorly studied. With large areas of the Cooper PAE currently used for petroleum production, and further exploration underway, industry may has data and knowledge that could assist in mapping and understanding GDEs in the Cooper. There remain some significant data issues for the Cooper PAE that limit the ability of agencies to assess the water-related impacts on GDEs from large coal mining or CSG, should they be proposed, because there is high uncertainty about the distribution and processes driving GDEs. These limitations are:

1. Multiple and overlapping spatial geometries for aquatic ecosystems
2. Lack of vegetation structure mapping over most of the Cooper PAE
3. Lack of shallow groundwater mapping.

Despite these limitations, this work has demonstrated application of the mapping rule sets approach used in Queensland (DSITIA 2015) with consistent GDE classification applied in the South Australian portion of the Cooper PAE (albeit with low confidence and limited extent). The mapping rule sets approach is a useful method but reliant on supporting spatial data. Two key recommendations for GDE mapping are that there needs to be improvement in the spatial data sets used to map GDEs and on-ground investigations to determine groundwater dependence of different aquatic ecosystems. Work by private industries may be able to contribute to this as well as recent vegetation and soil surveys of Gillen and Reid (2013) and investigations into shallow groundwater in the Neales catchment (DEWNR 2015b).

This report presents the conceptual understanding about non-GAB-dependent GDE types in the SA LEB; alignment of these types with other classifications is shown in Table 4.1.

Further work to finalise the LEBSA and LEBRM data products will be to consolidate the aquatic ecosystem mapping data sets the LEBRM (Miles and Miles 2015), LEBSA non-GAB GDE mapping (this project) with GAB spring wetland (Lewis et al. 2013, White et al. 2015) and GAB diffuse discharge (Turner et al. 2015) mapping.

Table 4.1 Alignment of GDE types in the SA LEB with other typologies

Conceptual model presented / discussed in this report	LEBRM[1]	SAAE type[2]	GDE Atlas Type[3]	DSITIA Type[4]
Waterhole GDE (Cooper / Arckaringa)	Waterhole	Seasonal/Ephemeral watercourse waterhole	Surface expression GDE	Alluvia – lower catchment
Riparian woodlands (Cooper / Arckaringa)	In-channel Habitat / Floodplain	Floodplain	Subsurface expression GDE	Alluvia – lower catchment
Evaporative influence GDE (Cooper)	Lake (connected)		Surface expression GDE	None
Dune GDEs: Costelloe (2008) model – not mapped in SA	Lake (connected)	Inland interdunal Lake	Surface expression GDE	None
Dune GDE (DSITIA 2015) – not mapped in SA	Claypan & other		Sub-surface expression GDE	Dunefields GDEs
Lakes with GAB springs	Terminal lakes	Terminal lakes	Surface expression GDE	None

[1]Imgraben and McNeil (2015), [2]Fee and Scholz (2010), [3]BoM (2015), [4]DSITIA (2015)

Appendices

A. Arckaringa groundwater dependent ecosystem attribute modifications

The G*roundwater source* attributes from Miles and Miles (2015) were applied to the *Aquifer geology* and *Aquifer confinement* fields as follows:

Groundwater source (Miles and Miles 2015)	GDE aquifer geology	GDE aquifer confinement
NA	Not applicable	Not applicable
Unknown	Unknown	Unknown
Alluvial	Unconsolidated sedimentary	Unconfined
Combined	Unknown	Unknown
Confined artesian	Fractured and consolidated sedimentary	Confined
Unconfined	Fractured rock	Unconfined

B. Groundwater dependent ecosystem attribute definitions

The following attributions were adopted from the Qld Cooper GDE mapping (DSITIA 2015)

GDE attribute	Field name	Valid options and definitions
GDE type	GDE_TYPE	Surface GW GDE – ecosystem dependent on the surface expression of groundwater Subsurface GW GDE – ecosystem dependent on subsurface presence of groundwater Non-GDE – known to not be a GDE Unknown (/no data)
Rule name	GDE_RULE_NAME	Name of mapping rule
Rule part	GDE_RULE_PART	Part of mapping rule
Confidence	GDE_CONF	Confidence in GDE attribution (high, medium or low)
Evidence	GDE_EVI	Type of evidence supporting rule
Data source (for spatial geometry)	GDE_DATA_SRC	LEBRM AECM – LEB Rivers Monitoring Aquatic Ecosystem Classification and Mapping (Miles and Miles 2015 SA Veg Structure – LEBRM AECM (additional polygons added using the geometry of SA Vegetation Structure)
Conceptual model	GDE_C_MODEL	See Section 3
Aquifer geology	GDE_AQ_GEOL	Unconsolidated sedimentary Fractured rock Cavernous Fractured and cavernous Fractured and consolidated sedimentary Unknown (/no data)
Aquifer confinement	GDE_AQ_CONFIN	Unconfined Confined Semi-confined Unknown (/ no data)
Aquifer porosity	GDE_AQ_POROSITY	Primary Secondary Tertiary Primary and secondary Secondary and tertiary

GDE attribute	Field name	Valid options and definitions
		All Unknown (/no data)
Groundwater flow system*	GDE_GFS	Shallow alluvial Basin Bedrock Perched Unknown (/no data)
Groundwater salinity	GDE_GW_SALINITY	Fresh – (< 1 500 mg/L TDS) Brackish - (1 500 – 3 000 mg/L TDS) Saline - (3 000 – 35 000 mg/L TDS) Hypersaline - (>35 000 mg/L TDS) Euryhaline (Fluctuating) Stratified Unknown (/no data)
Groundwater pH	GDE_GW_PH	Acidic – less than 6 pH Neutral – between 6 and 8 pH Alkaline – greater than 8 pH Fluctuating Unknown (/no data)
Aquifer recharge source	GDE_AQ_RECH	Infiltration local / distant Inundation local / distant Combination Palaeo Unknown (/no data)
Groundwater connectivity regime (temporal)	GDE_GW_CON_SP	Connected, gaining – where a groundwater table intersects the GDE and the hydraulic gradient is towards the GDE (e.g. spring wetlands) groundwater levels are above the water level in the stream, under these conditions the groundwater system discharges water to th stream and as a result increases the flow in the stream Connected, losing – where a groundwater table intersects the GDE and the hydraulic gradient is away from the GDE groundwater levels are lower than water levels in the stream, and water from the stream discharges into the groundwater system Connected, variable gaining/losing – where a groundwater table intersects the GDE and the hydraulic gradient temporally varies towards and away from the GDE (e.g. spring wetlands) Disconnected, losing – where a groundwater table does not intersect the GDE zone of unsaturation exists between the bed of a river and the groundwater table immediately beneath it Unknown (/no data)
Groundwater connectivity regime (spatial)	GDE_GW_CON_TE	Aseasonal, ephemeral – only has groundwater connection after unpredictable rainfall and runoff events Aseasonal, intermittent – has groundwater connection during alternating wet and dry periods, but less frequently and/or less regularly than seasonal connectivity Seasonal – has groundwater connection during alternating wet and dry periods on a regular basis according to season Near permanent – has groundwater connection that may be static or flowing, with varying levels. However there is a

GDE attribute	Field name	Valid options and definitions
		possibility that the flow could cease during long or extreme conditions (e.g. rare or non-cyclic conditions) Permanent – has groundwater connection that may be static or flowing, with varying levels. However is predictably connected to groundwater Unknown (/no data)

*Note: DSITIA (2015) have further sub-attributes for these attributes

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