Australian Government

BIOREGIONAL ASSESSMENTS

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

Conceptual modelling for the Cooper subregion

Product 2.3 for the Cooper subregion from the Lake Eyre Basin Bioregional Assessment

15 December 2016

A scientific collaboration between the Department of the Environment and Energy, Bureau of Meteorology, CSIRO and Geoscience 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 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 and Energy. The Department of the Environment and Energy, Bureau of Meteorology, CSIRO and Geoscience Australia are collaborating to undertake bioregional assessments. For more information, visit http://www.bioregionalassessments.gov.au.

Department of the Environment and Energy

The Office of Water Science, within the Australian Government Department of the Environment and Energy, is strengthening the regulation of coal seam gas and large coal mining development by ensuring that future decisions are informed by substantially improved science and independent expert advice about the potential water related impacts of those developments. For more information, visit https://www.environment.gov.au/water/coal-and-coal-seam-gas/office-of-water-science.

Bureau of Meteorology

The Bureau of Meteorology is Australia's national weather, climate and water agency. Under the *Water Act 2007*, the Bureau is responsible for compiling and disseminating Australia's water information. The Bureau is committed to increasing access to water information to support informed decision making about the management of water resources. For more information, visit http://www.bom.gov.au/water/.

CSIRO

Australia is founding its future on science and innovation. Its national science agency, CSIRO, is a powerhouse of ideas, technologies and skills for building prosperity, growth, health and sustainability. It serves governments, industries, business and communities across the nation. For more information, visit http://www.csiro.au.

Geoscience Australia

Geoscience Australia is Australia's national geoscience agency and exists to apply geoscience to Australia's most important challenges. Geoscience Australia provides geoscientific advice and information to the Australian Government to support current priorities. These include contributing to responsible resource development; cleaner and low emission energy technologies; community safety; and improving marine planning and protection. The outcome of Geoscience Australia's work is an enhanced potential for the Australian community to obtain economic, social and environmental benefits through the application of first class research and information. For more information, visit http://www.ga.gov.au.

ISBN-PDF 978-1-925315-29-5

Citation

Smith M, Pavey C, Ford J, Sparrow A, Karim F and Radke B (2016) Conceptual modelling for the Cooper subregion. Product 2.3 for the Cooper subregion from the Lake Eyre Basin Bioregional Assessment. Department of the Environment and Energy, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia.
http://data.bioregionalassessments.gov.au/product/LEB/COO/2.3.

Authorship is listed in relative order of contribution.

Copyright

Disclaimer

Cover photograph

Cooper Creek near Innamincka, SA, 23 May 2013

Credit: Dr Anthony Budd, Geoscience Australia

Australian Government
Department of the Environment and Energy
Bureau of Meteorology
Geoscience Australia

CSIRO

v20170118

Executive summary

Conceptual models are a simplified and generalised representation of a complex system. During development of conceptual models, the essence of how the key system components operate and interact is distilled. The Bioregional Assessment Programme (BA) conceptual models of causal pathways are developed to describe the logical chain of events – either planned or unplanned – that link coal resource developments to water-dependent assets.

Methods

This product details the conceptual model of causal pathways of the Cooper subregion, following the method described in companion submethodology M05 (as listed in Table 1). For the subregion it identifies:

- the key system components, processes and interactions, which essentially define pathways over and through which water can move (Section 2.3.2)
- the ecosystems in terms of landscape classes and their dependence on water (Section 2.3.3)
- the potential hydrological changes that may occur due to coal resource development by describing and documenting the baseline coal resource development (baseline) and coal resource development pathway (CRDP) (Section 2.3.4), including a summary of water management for coal resource development (Section 2.3.4.2)
- hazards from coal resource development using a hazard analysis approach (Section 2.3.5.2)
- causal pathways from coal resource development through to hydrological changes, both for baseline and CRDP (Section 2.3.5.3).

Summary of key system components, processes and interactions

The Cooper Basin is an Upper Carboniferous – Middle Triassic geological basin in north-eastern SA and south-western Queensland. The Cooper Basin is up to 2500 m thick, at subsurface depths of between 1000 and 4400 m. The southern Cooper Basin is marked by a series of troughs (e.g. Weena and Tenappera troughs) separated by ridges against which Permian sedimentary rocks thin or pinch out. The Cooper Basin unconformably overlies the Warburton Basin. Several granite bodies intrude the older Warburton geological Basin and underlie the Cooper Basin.

The watertable is hosted in the Namba Formation and Quaternary sediments, with regional flow south-westwards towards Lake Blanche. Groundwater within the Cadna-owie – Hooray Aquifer flows south towards and beyond Lake Frome. In the hydrostratigraphic units of the Cooper Basin, the regional groundwater flow direction is mainly towards the south-west.

There is limited recharge via diffuse infiltration of sporadic rain water, flood waters or streamflow to the groundwater system. The most significant source of groundwater to the Eromanga Basin sequence in the Cooper subregion is inflow from outside the subregion. Recharge to the Cooper Basin occurs by vertical leakage or cross-formation flow.

The southern Cooper subregion is part of the Cooper Creek – Bulloo river basin. Cooper Creek is characterised by complex channel networks and numerous wetlands and waterholes. Water is derived from runoff from headwater catchments. Streamflow in Cooper Creek and its tributaries varies greatly between years from almost no flow to significant flooding. Natural discharge of groundwater to surface takes place at springs, as well as in lakes. The Lake Blanche springs are fracture or fault-fed springs sourced by the Coorikiana Sandstone and Cenozoic aquifers.

Ecosystems

The ecosystems in the Cooper subregion are classified in terms of landscape classes and their dependence on water. Based on the Australian National Aquatic Ecosystem (ANAE) Classification Framework five elements are included in the classification: topography, landform, water source, water type and water availability. The majority of the preliminary assessment extent (PAE) for the Cooper subregion is dominated by the 'Dryland' landscape group (75.36%). Where landscapes are water-dependent, floodplain landscape classes comprise 13.10% by area of the PAE.

Coal resource development

There is no coal or coal seam gas (CSG) (i.e. stand-alone CSG) production occurring in the Cooper subregion as of December 2012. As a result, the baseline coal resource development (baseline) for the subregion does not have any coal resource developments.

As of early 2016, the only potential project in the CRDP likely to proceed to production is the Southern Cooper Basin Gas Project (Strike Energy Ltd main JV owner and operator), in the Weena Trough. Coal seams in the Patchawarra Formation of the geological Cooper Basin at depths of around 1900 to 2100 m are production targets at this prospect. It is anticipated that the project will enter production sometime during 2020 or 2021, with a reported production life of 20 years.

Water management

The Southern Cooper Basin Gas Project is located within the Far North Prescribed Wells Area (FNPWA) in SA. Groundwater in the FNPWA is managed under a water allocation plan (the Far North Water Allocation Plan, FNWAP).

In addition to the allocated volume for petroleum activities, the FNWAP also sets limits for drawdown effects at springs and at the SA border. Predicted drawdown must not exceed 1 m at the boundary of the Southwest Springs Zone, and must not exceed 0.5 m at a distance of 5 km from any individual spring. Furthermore, drawdown in excess of 10% of the pressure head at a state border is a trigger for consultation with the potentially-affected state.

Water for drilling and stimulation activities for the Southern Cooper Basin Gas Project will be sourced from shallow bores adjacent to the well site, or trucked in. Produced water will be stored in lined ponds. Pond size is dependent on predicted water production rate, predicted total produced water volumes, evaporation rates and site constraints. Ponds will be constructed according to standard Cooper Basin construction methods. Excavation and bunding will be used to elevate pond walls above ground level. Ponds will be located on existing disturbed areas as far as practicable. Impermeable liners will be installed in ponds where required.

At the completion of operations, after pond water has evaporated or been pumped out, the liner and any salt residue will be removed and disposed to an appropriately licensed facility, the ponds will be backfilled and re-profiled to match pre-existing surface contours, and the surface will be ripped to promote revegetation.

Data collected during production testing have shown that water production rates are in the order of 30 to 85 kL/day per well.

Hazard analysis

A dedicated hazard analysis, using Impact Modes and Effects Analysis (IMEA), is used to systematically identify activities that may initiate *hazards*, defined as events, or chains of events that might result in an *effect* (change in the quality and/or quantity of surface water or groundwater).

A large number of hazards are identified; some of these are beyond the scope of a BA and others are adequately addressed by site-based risk management processes and regulation. When ranked by mid-point of the hazard priority number the top ranked hazard considered for BA in the Cooper subregion associated with CSG operations is aquifer depressurisation, occurring through the activity of water and gas extraction during the production life-cycle. When ranked by hazard score, the hazard analysis identifies disruption of natural surface drainage as the most frequent hazard associated with CSG operations in the Cooper subregion.

Causal pathways

Hazards associated with CSG operations that are considered to be in scope for the BA in the Cooper subregion are grouped according to their hydrological pathway to impact and include: (i) 'Subsurface depressurisation and dewatering'; (ii) 'Subsurface physical flow paths'; (iii) 'Surface water drainage'; (iv) 'Operational water management'. These causal pathway groups represent models linking an activity with a potential impact on the groundwater or surface water.

Subsurface depressurisation and dewatering associated with the CRDP occurs when CSG operations intentionally dewater and depressurise subsurface hydrostratigraphic units; for example, depressurising a water-saturated target coal seam to induce desorption and subsequent extraction of CSG. Groundwater level or pressure is most commonly altered, but other gradients can also be changed via this process, such as temperature, density or chemical composition (water quality).

Subsurface physical flow paths involves physical modification of the rock mass or geological architecture by creating new physical paths that water may potentially infiltrate and flow along. Just because a new physical path is created does not necessarily mean that water will start flowing along it in preference to how it flowed before – it will still follow the path of least resistance, and be governed by pressure gradients. This causal pathway group can, however, potentially lead to direct hydraulic connection between the target strata and other hydrostratigraphic units (such as regional aquifers), by creating new zones of deformation in the rock mass. This may occur when the integrity of wells drilled for groundwater or gas extraction is compromised, or may occur due to hydraulic fracturing of coal seams.

A specific causal pathway in *subsurface physical flow paths* is hydraulic fracturing. In the Cooper subregion, hydraulic fracturing will be necessary to liberate gas from the Patchawarra Formation coals. The available evidence from initial CSG well testing by Strike Energy Ltd has shown that hydraulic fractures are contained within target coal seams and do not propagate beyond into adjacent hydrostratigraphic units. Thus, at this stage, there is no evidence that hydraulic fracturing activity in Cooper CSG fields will create new subsurface flow paths between hydrostratigraphic units. If new flow paths were created, this would propagate depressurisation into adjacent hydrostratigraphic units. In addition, any fluids injected during hydraulic fracturing operations will be contained within the target unit within the Patchawarra Formation. The Patchawarra Formation is not utilised as a groundwater source in the Cooper subregion.

Operational water management includes water produced from CSG extraction wells. This water is recovered and stored at the surface in lined and bunded ponds. There is no provision for release to surface water or reinjection in the Cooper subregion CRDP. Within the southern Cooper subregion, the surface water feature that could potentially be affected by a loss of containment is the ephemeral, low-gradient Strzelecki Creek. Downstream effects could propagate to Lake Blanche, 40 km to the south-west. Strzelecki Creek experiences large variations in discharge and flow duration, from no flow to flooding.

Surface water drainage involves the physical disruption and disturbance of surface topography and near-surface materials (vegetation, topsoil, weathered rock). Within the southern Cooper subregion, the surface water feature that could potentially be disrupted due to infrastructure for CSG operations is the ephemeral, low-gradient Strzelecki Creek. Downstream effects could propagate to Lake Blanche. The Southern Cooper Basin Gas Project is located adjacent to existing roads and gas pipelines, so the requirement for major infrastructure development will be small. However, this will depend upon the final layout of the CSG operations including well spacing and number of wells, and location and type of support infrastructure such as accommodation, roads, gas flowlines, water management infrastructure and processing infrastructure.

Gaps

Knowledge gaps relating to the hydrogeological architecture around the Cooper subregion CRDP include a lack of detailed understanding of the three-dimensional distribution of faults and other geological structures, the hydraulic parameters of target and adjacent formations, and the inter-aquifer connectivity between the Cooper Basin and the overlying Eromanga Basin.

Uncertainties around the well spacing, depth, production timeline and size of the CSG resource hamper the assessment of the potential impact of the CRDP, but do not significantly affect the identification of causal pathways and development of conceptual models for those pathways. Similar uncertainty exists around water production rates and water requirements for the CRDP.

Further work

This is the final product for the Cooper subregion from this iteration of the Bioregional Assessment Programme. Due to the limited coal resource development potential no numerical surface water or groundwater modelling, receptor impact modelling, risk or impact analysis or associated products are being produced.

Contents

Figures

Tables

Contributors to the Technical Programme

The following individuals have contributed to the Technical Programme, the part of the Bioregional Assessment Programme that undertakes bioregional assessments.

Role or team	Contributor(s)
Assistant Secretary	Department of the Environment and Energy: Matthew Whitfort
Programme Director	Department of the Environment and Energy: Anthony Swirepik
Technical Programme Director	Bureau of Meteorology: Julie Burke
Projects Director	CSIRO: David Post
Principal Science Advisor	Department of the Environment and Energy: Peter Baker
Science Directors	CSIRO: Brent Henderson Geoscience Australia: Steven Lewis
Integration	Bureau of Meteorology: Richard Mount (Integration Leader) CSIRO: Becky Schmidt
Programme management	Bureau of Meteorology: Louise Minty CSIRO: Paul Hardisty, Warwick McDonald Geoscience Australia: Stuart Minchin
Project Leaders	CSIRO: Alexander Herr, Kate Holland, Tim McVicar, David Rassam Geoscience Australia: Tim Evans Bureau of Meteorology: Natasha Herron
Assets and receptors	Bureau of Meteorology: Richard Mount (Discipline Leader) Department of the Environment and Energy: Glenn Johnstone, Wasantha Perera, Jin Wang
Bioregional Assessment Information Platform	Bureau of Meteorology: Lakshmi Devanathan (Team Leader), Derek Chen, Trevor Christie-Taylor, Melita Dahl, Angus MacAulay, Christine Panton, Paul Sheahan, Kellie Stuart, Carl Sudholz CSIRO: Peter Fitch, Ashley Sommer Geoscience Australia: Neal Evans
Communications	CSIRO: Helen Beringen, Department of the Environment and Energy: Amanda Forman, John Higgins, Lea Locke, Milica Milanja Geoscience Australia: Michelle McGranahan
Coordination	Bureau of Meteorology: Julie Burke, Brendan Moran, Eliane Prideaux, Sarah van Rooyen CSIRO: Ruth Palmer Department of the Environment and Energy: Anisa Coric, James Hill, Bronwyn McMaster, Emily Turner
Ecology	CSIRO: Anthony O'Grady (Discipline Leader), Caroline Bruce, Tanya Doody, Brendan Ebner, Craig MacFarlane, Patrick Mitchell, Justine Murray, Chris Pavey, Jodie Pritchard, Nat Raisbeck-Brown, Ashley Sparrow

Role or team	Contributor(s)
Geology	CSIRO: Deepak Adhikary, Emanuelle Frery, Mike Gresham, Jane Hodgkinson, Zhejun Pan, Matthias Raiber, Regina Sander, Paul Wilkes Geoscience Australia: Steven Lewis (Discipline Leader)
Geographic information systems	CSIRO: Jody Bruce, Debbie Crawford, Dennis Gonzalez, Mike Gresham, Steve Marvanek, Arthur Read Geoscience Australia: Adrian Dehelean, Joe Bell
Groundwater modelling	CSIRO: Russell Crosbie (Discipline Leader), Tao Cui, Warrick Dawes, Lei Gao, Sreekanth Janardhanan, Luk Peeters, Praveen Kumar Rachakonda, Wolfgang Schmid, Saeed Torkzaban, Chris Turnadge, Andy Wilkins, Binzhong Zhou
Hydrogeology	Geoscience Australia: Tim Ransley (Discipline Leader), Chris Harris-Pascal, Jessica Northey, Emily Slatter
Information management	Bureau of Meteorology: Belinda Allison (Team Leader) CSIRO: Qifeng Bai, Simon Cox, Phil Davies, Mick Hartcher, Geoff Hodgson, Brad Lane, Ben Leighton, David Lemon, Trevor Pickett, Shane Seaton, Ramneek Singh, Matt Stenson Geoscience Australia: Matti Peljo
Products	CSIRO: Becky Schmidt (Products Manager), Maryam Ahmad, Clare Brandon, Heinz Buettikofer, Sonja Chandler, Karin Hosking, Allison Johnston, Maryanne McKay, Linda Merrin, Joely Taylor, Sally Tetreault-Campbell, Catherine Ticehurst Geoscience Australia: Penny Kilgour, Kathryn Owen
Risk and uncertainty	CSIRO: Simon Barry (Discipline Leader), Jeffrey Dambacher, Jess Ford, Keith Hayes, Geoff Hosack, Adrian Ickowicz, Warren Jin, Dan Pagendam
Surface water hydrology	CSIRO: Neil Viney (Discipline Leader), Santosh Aryal, Mat Gilfedder, Fazlul Karim, Lingtao Li, Dave McJannet, Jorge Luis Peña-Arancibia, Xiaogang Shi, Tom Van Niel, Jai Vaze, Bill Wang, Ang Yang, Yongqiang Zhang

Acknowledgements

This technical product was reviewed by several groups:

- Discipline Leaders: Steven Lewis (geology), Anthony O'Grady (ecology)
- Senior Science Leaders: David Post (Projects Director), Steven Lewis (Science Director, Geoscience Australia), Brent Henderson (Science Director, CSIRO), Becky Schmidt (Products Manager)
- Technical Assurance Reference Group: Chaired by Peter Baker (Principal Science Advisor, Department of the Environment and Energy), this group comprises officials from the NSW, Queensland, South Australian and Victorian governments.

In addition, information, data, discussion and follow up provided by attendees at the external workshop for conceptual modelling of causal pathways in the Cooper subregion held in Adelaide in November 2015 was very beneficial to this product.

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 (IESC, 2015).

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 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 and Energy, 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 (see http://www.bioregionalassessments.gov.au/assessments for a map and further information):

- 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.

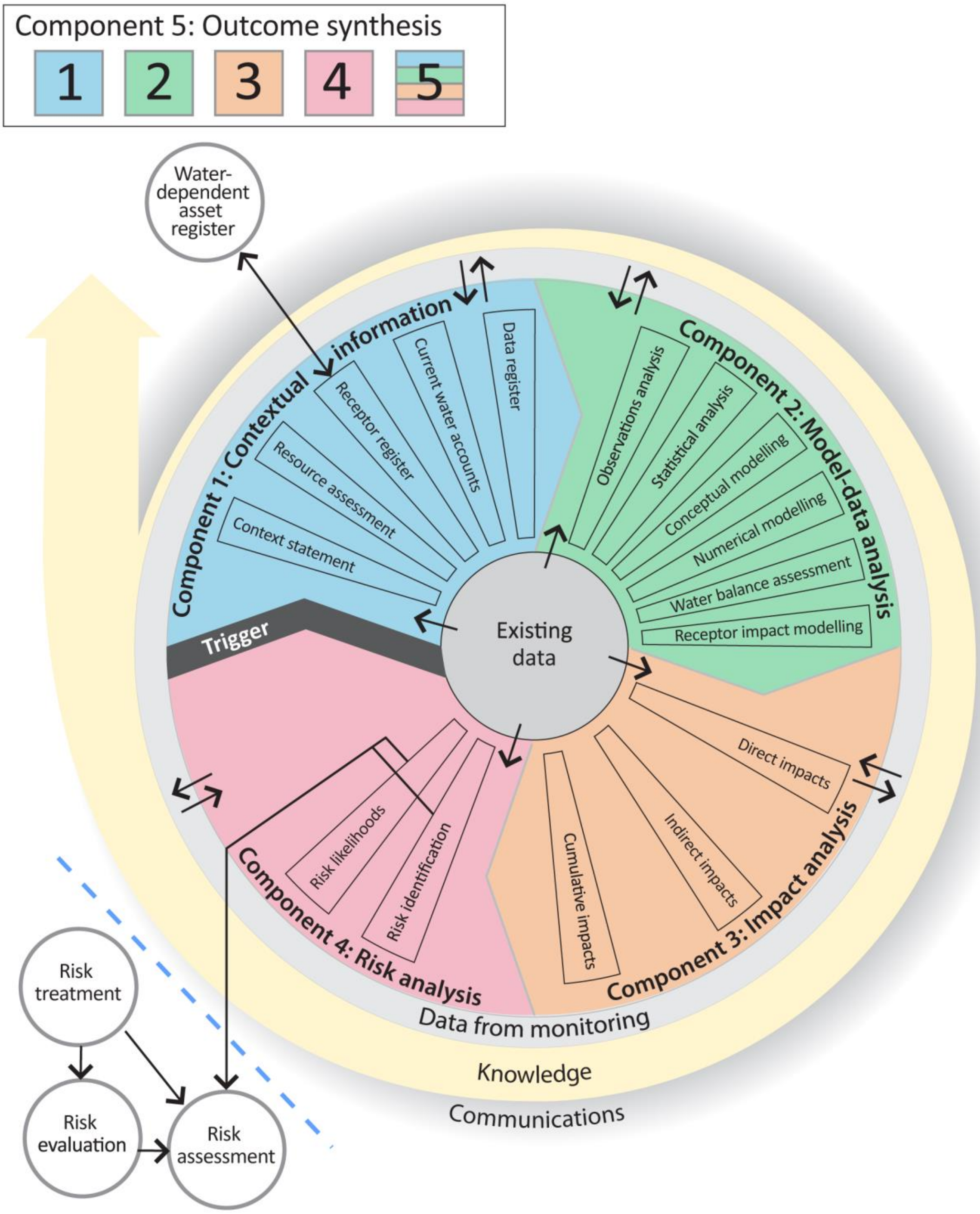

Figure 1 Schematic diagram of the bioregional assessment methodology

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

The overall scientific and intellectual basis of the BAs is provided in the BA methodology (Barrett et al., 2013). Additional guidance is required, however, about how to apply the BA methodology to a range of subregions and bioregions. To this end, the teams undertaking the BAs have developed and documented detailed scientific submethodologies (Table 1) to, in the first instance, support the consistency of their work across the BAs and, secondly, to open the approach to scrutiny, criticism and improvement through review and publication. In some instances, methodologies applied in a particular BA may differ from what is documented in the submethodologies – in this case an explanation will be supplied in the technical products of that BA. Ultimately the Programme anticipates publishing a consolidated 'operational BA methodology' with fully worked examples based on the experience and lessons learned through applying the methods to 13 bioregions and subregions.

The relationship of the submethodologies to BA components and technical products is illustrated in Figure 2. While much scientific attention is given to assembling and transforming information, particularly through the development of the numerical, conceptual and receptor impact models, integration of the overall assessment is critical to achieving the aim of the BAs. To this end, each submethodology explains how it is related to other submethodologies and what inputs and outputs are required. They also define the technical products and provide guidance on the content to be included. When this full suite of submethodologies is implemented, a BA will result in a substantial body of collated and integrated information for a subregion or bioregion, including new information about the potential impacts of coal resource development on water and water-dependent assets.

Table 1 Methodologies

Each submethodology is available online at http://data.bioregionalassessments.gov.au/submethodology/XXX, where 'XXX' is replaced by the code in the first column. For example, the BA methodology is available at http://data.bioregionalassessments.gov.au/submethodology/bioregional-assessment-methodology and submethodology M02 is available at http://data.bioregionalassessments.gov.au/submethodology/M02. Submethodologies might be added in the future.

Code	Proposed title	Summary of content
bioregional-assessment-methodology	*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
M02	*Compiling water-dependent assets*	Describes the approach for determining water-dependent assets
M03	*Assigning receptors to water-dependent assets*	Describes the approach for determining receptors associated with water-dependent assets
M04	*Developing a coal resource development pathway*	Specifies the information that needs to be collected and reported about known coal and coal seam gas resources as well as current and potential resource developments
M05	*Developing the conceptual model of causal pathways*	Describes the development of the conceptual model of causal pathways, which summarises how the 'system' operates and articulates the potential links between coal resource development and changes to surface water or groundwater
M06	*Surface water modelling*	Describes the approach taken for surface water modelling
M07	*Groundwater modelling*	Describes the approach taken for groundwater modelling
M08	*Receptor impact modelling*	Describes how to develop receptor impact models for assessing potential impact to assets due to hydrological changes that might arise from coal resource development
M09	*Propagating uncertainty through models*	Describes the approach to sensitivity analysis and quantification of uncertainty in the modelled hydrological changes that might occur in response to coal resource development
M10	*Impacts and risks*	Describes the logical basis for analysing impact and risk
M11	*Systematic analysis of water-related hazards associated with coal resource development*	Describes the process to identify potential water-related hazards from coal resource development

Technical products

The outputs of the BAs include a suite of technical products presenting information about the ecology, hydrology, hydrogeology and geology of a bioregion and the potential 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 relationship of the technical products to BA components and submethodologies. 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 outlines in both Figure 2 and Table 2 indicate the information included in this technical product.

Technical products are delivered as reports (PDFs). Additional material is also provided, as specified by the BA methodology:

- unencumbered data syntheses and databases
- unencumbered tools, model code, procedures, routines and algorithms
- unencumbered forcing, boundary condition, parameter and initial condition datasets
- lineage of datasets (the origin of datasets and how they are changed as the BA progresses)
- gaps in data and modelling capability.

In this context, unencumbered material is material that can be published according to conditions in the licences or any applicable legislation. All reasonable efforts were made to provide all material under a Creative Commons Attribution 3.0 Australia Licence.

Technical products, and the additional material, are available online at http://www.bioregionalassessments.gov.au.

The Bureau of Meteorology archives a copy of all datasets used in the BAs. This archive includes datasets that are too large to be stored online and datasets that are encumbered. The community can request a copy of these archived data at http://www.bioregionalassessments.gov.au.

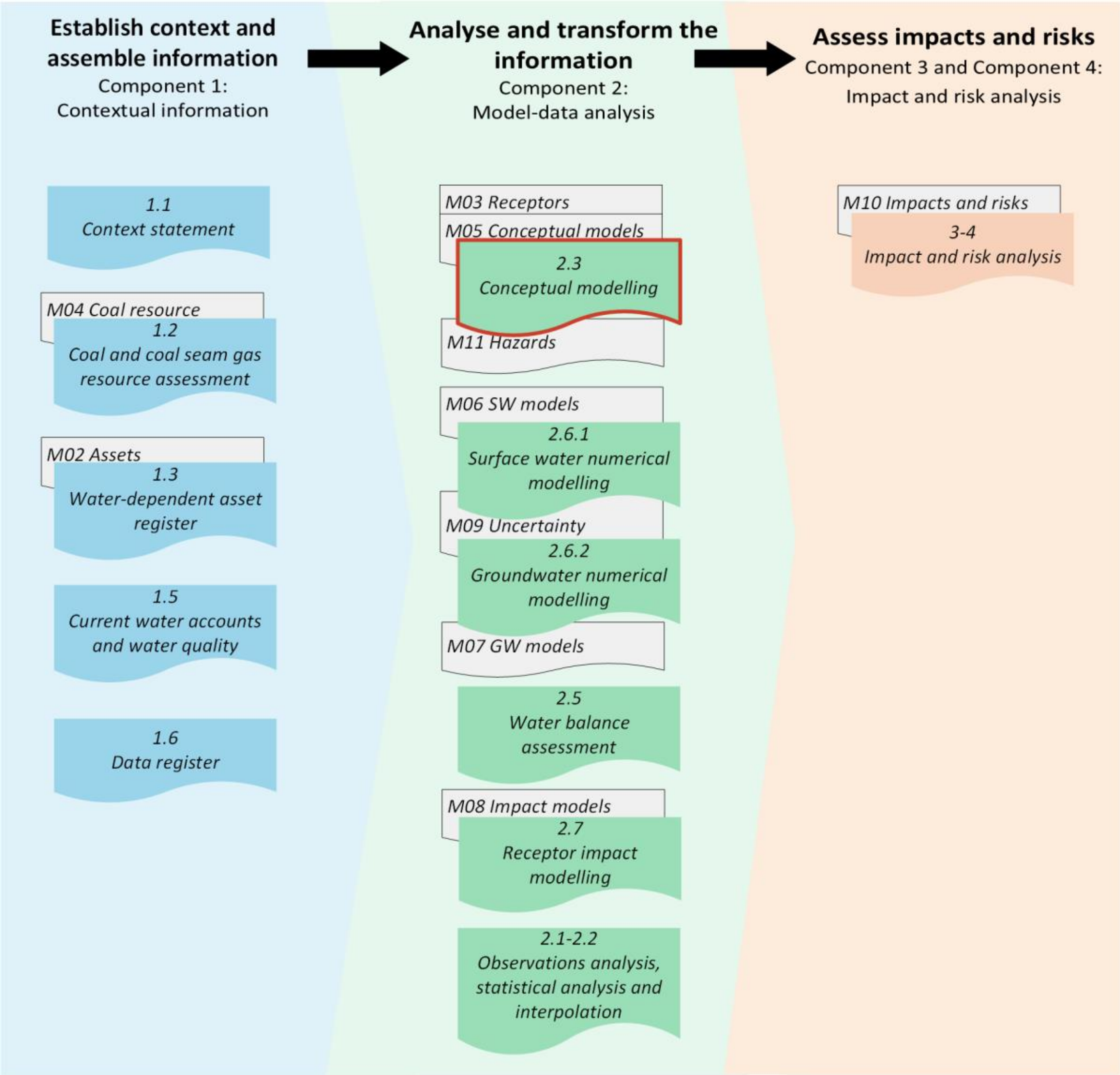

Figure 2 Technical products and submethodologies associated with each component of a bioregional assessment

In each component (Figure 1) of a bioregional assessment, a number of technical products (coloured boxes, see also Table 2) are potentially created, depending on the availability of data and models. The light grey boxes indicate submethodologies (Table 1) that specify the approach used for each technical product. The red outline indicates this technical product. The BA methodology (Barrett et al., 2013) specifies the overall approach.

Table 2 Technical products delivered for the Cooper subregion

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[a]. Other products – such as datasets, metadata, data visualisation and factsheets – are provided online. There is no product 1.4. Originally this product was going to describe the receptor register and application of landscape classes as per Section 3.5 of the BA methodology, but this information is now included in product 2.3 (conceptual modelling) and used in product 2.6.1 (surface water numerical modelling) and product 2.6.2 (groundwater numerical modelling). There is no product 2.4; originally this product was going to include two- and three-dimensional representations as per Section 4.2 of the BA methodology, but these are instead included in products such as product 2.3 (conceptual modelling).

Component	Product code	Title	Section in the BA methodology[b]	Type[a]
Component 1: Contextual information for the Cooper 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	PDF, HTML
	1.3	Description of the water-dependent asset register	2.5.1.3, 3.4	PDF, HTML, register
	1.5	Current water accounts and water quality	2.5.1.5	PDF, HTML
	1.6	Data register	2.5.1.6	Register
Component 2: Model-data analysis for the Cooper subregion	2.1-2.2	Observations analysis, statistical analysis and interpolation	2.5.2.1, 2.5.2.2	Not produced
	2.3	Conceptual modelling	2.5.2.3, 4.3	PDF, HTML
	2.5	Water balance assessment	2.5.2.4	Not produced
	2.6.1	Surface water numerical modelling	4.4	Not produced
	2.6.2	Groundwater numerical modelling	4.4	Not produced
	2.7	Receptor impact modelling	2.5.2.6, 4.5	Not produced
Component 3 and Component 4: Impact and risk analysis for the Cooper subregion	3-4	Impact and risk analysis	5.2.1, 2.5.4, 5.3	Not produced
Component 5: Outcome synthesis for the Cooper subregion	5	Outcome synthesis	2.5.5	Not produced

[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 format 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.
- '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.

- All reasonable efforts were made to provide all material under a Creative Commons Attribution 3.0 Australia Licence.
- All maps created as part of this BA for inclusion in this product used the Albers equal area projection with a central meridian of 140.0° East for the Lake Eyre Basin bioregion and two standard parallels of –18.0° and –36.0°.
- Visit http://bioregionalassessments.gov.au to access metadata (including copyright, attribution and licensing information) for datasets cited or used to make figures in this product.
- In addition, the datasets are published online if they are unencumbered (able to be published according to conditions in the licence or any applicable legislation). The Bureau of Meteorology archives a copy of all datasets used in the BAs. This archive includes datasets that are too large to be stored online and datasets that are encumbered. The community can request a copy of these archived data at http://www.bioregionalassessments.gov.au.
- The citation details of datasets are correct to the best of the knowledge of the Bioregional Assessment Programme at the publication date of this product. Readers should use the hyperlinks provided to access the most up-to-date information about these data; where there are discrepancies, the information provided online should be considered correct. The dates used to identify Bioregional Assessment Source Datasets are the dataset's published date. Where the published date is not available, the last updated date or created date is used. For Bioregional Assessment Derived Datasets, the created date is used.

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 18 January 2017, http://data.bioregionalassessments.gov.au/submethodology/bioregional-assessment-methodology.

IESC (2015) Information guidelines for the Independent Expert Scientific Committee advice on coal seam gas and large coal mining development proposals. Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development, Australia. Viewed 18 January 2017, http://www.iesc.environment.gov.au/publications/information-guidelines-independent-expert-scientific-committee-advice-coal-seam-gas.

2.3 Conceptual modelling for the Cooper subregion

This product firstly summarises key system components, processes and interactions for the geology, hydrogeology and surface water in the Cooper subregion. It describes its ecosystems using a landscape classification.

The product then characterises the two potential futures considered in bioregional assessments:

- *baseline coal resource development (baseline)*: a future that includes all coal mines and coal seam gas (CSG) fields that are commercially producing as of December 2012
- *coal resource development pathway (CRDP)*: a future that includes all coal mines and CSG fields that are in the baseline as well as those that are expected to begin commercial production after December 2012.

The difference in results between CRDP and baseline is the change that is primarily reported in a bioregional assessment. This change is due to the *additional coal resource development* – all coal mines and CSG fields, including expansions of baseline operations, that are expected to begin commercial production after December 2012.

The Impact Modes and Effects Analysis method is then used to identify *hazards*, defined as events, or chains of events, that might result in an *effect* (change in the quality and/or quantity of surface water or groundwater).

Next are presented *causal pathways*, the logical chain of events – either planned or unplanned – that link coal resource development and potential impacts on water resources and water-dependent assets. Causal pathways for hazards are identified by considering coal resource development activities, impact causes, impact modes and the resulting water-related effects. This product describes the causal pathways from the coal resource development to the hydrological changes (represented by hydrological response variables), for the baseline and CRDP.

2.3.1 Methods

Summary

The conceptual model of causal pathways characterises the *causal pathway*, the logical chain of events – either planned or unplanned – that link coal resource development and potential impacts on water and water-dependent assets. This section details the specific application to the Cooper subregion of methods described in the companion submethodology M05 (as listed in Table 1) for developing a conceptual model of causal pathways (Henderson et al., 2016). This is the final product for the Cooper subregion from this iteration of the Bioregional Assessment Programme. Due to the limited coal resource development potential, identified in Section 2.3.4, no numerical surface water or groundwater modelling, receptor impact modelling, risk or impact analysis or associated products are being produced for the purposes of the bioregional assessment in the Cooper subregion.

Key concepts and terminology are also explained, and the overall steps are summarised, including the: (i) synthesis of the key system components, processes and interactions for the geology, hydrogeology and surface water of the subregion; (ii) landscape classification; (iii) definition of the coal resource development pathway (CRDP) and additional coal resource development; (iv) identification of potential hazards; (v) identification of potential causal pathways from the coal resource development to hydrological changes; and (vi) characterisation of those potential causal pathways for the Cooper subregion.

This development of causal pathways closely follows the process laid out in the companion submethodology M05, although the understanding of the key system components, processes and interactions was explored with external stakeholders at a workshop in Adelaide in November 2015.

2.3.1.1 Background and context

This product presents information about the conceptual model of causal pathways for the Cooper subregion, which was developed using methods outlined in the companion submethodology M05 (as listed in Table 1) for developing a conceptual model of causal pathways (Henderson et al., 2016). The application to the Cooper subregion is described in Section 2.3.1.2, with more specific details in the individual sections that follow. The development of causal pathways is the main outcome of the BA for the Cooper subregion. These pathways may assist in future assessments that may occur in this subregion.

Conceptual models are abstractions or simplifications of reality. A number of conceptual models are developed for a bioregional assessment (BA), including conceptual models for geology, groundwater and surface water, which underpin the numerical modelling.

Another type of conceptual model is a conceptual model of causal pathways, which characterises the *causal pathway*, the chain of logic or activities – either planned or unplanned – that link coal resource development and potential impacts on water resources and water-dependent assets. The conceptual model of causal pathways brings together a number of conceptual models developed in a BA, and might be expressed in a variety of ways, with narrative, pictorial graphics, and influence diagrams all important.

The causal pathways play a critical role in focusing the BA on the most plausible and important *hazards*, defined as events, or chains of events, that might result in an *effect* (change in the quality and/or quantity of surface water or groundwater). The causal pathways associated with these hazards underpin the construction of groundwater and surface water models, and frame the assessment of the *severity* and *likelihood* of impacts to water-dependent assets. A *water-dependent asset* is an asset potentially impacted, either positively or negatively, by changes in the groundwater and/or surface water regime due to coal resource development. Some assets are solely dependent on incident rainfall and will not be considered as water dependent if evidence does not support a linkage to groundwater or surface water that will be impacted by coal resource development.

The construction of causal pathways requires the Assessment team to first synthesise and summarise the key system components, processes and interactions for the geology, hydrogeology and surface water of the subregion (as presented in Section 2.3.2). Emphasising gaps and uncertainties is as important as summarising what is known about how various systems work.

Section 2.3.3 presents the development of a *landscape classification*, which aims to systematically simplify a complex system that contains a large number of assets identified by the community. The landscape classification describes the main biophysical and human ecosystems, and provides a high-level conceptualisation of the subregion at the surface. Most assets are related to one or more *landscape classes*, which are defined for BA purposes as ecosystems with characteristics that are expected to respond similarly to changes in groundwater and/or surface water due to coal resource development. Landscape classes are present on the landscape across the entire subregion and their spatial coverage is exhaustive and non-overlapping. Conceptually, landscape classes can be considered as types of *ecosystem assets*, which are ecosystems that may provide benefits to humanity (Bureau of Meteorology, 2013; United Nations et al., 2014)

Section 2.3.4 then defines two potential futures (Figure 3), namely the:

- *baseline coal resource development* (baseline), a future that includes all coal mines and coal seam gas (CSG) fields that are commercially producing as of December 2012. For the Cooper subregion, there were no coal mines or CSG fields in commercial operation prior to December 2012
- *coal resource development pathway* (CRDP), a future that includes all coal mines and CSG fields that are in the baseline as well as those that are expected to begin commercial production after December 2012.

The difference in results between CRDP and baseline is the change that is primarily reported in a BA. This change is due to the *additional coal resource development* – all coal mines and CSG fields, including expansions of baseline operations, that are expected to begin commercial production after December 2012. Impacts that may occur due to additional coal resource development are assessed in detail in receptor impact modelling, and through numerical surface water and groundwater modelling. It is important to note that the receptor impact modelling and the numerical surface water and groundwater modelling are not taking place for the Cooper subregion, due to the limited coal resource development potential.

Figure 4 illustrates this fundamental comparison of these futures, with the baseline in the top half of the figure and the CRDP in the bottom half of the figure. It emphasises that in order to assess potential impact on assets, it is important to compare the changes in two types of variables at specific points in space and time:

- *hydrological response variables*, the hydrological characteristics of the system that potentially change due to coal resource development (for example, drawdown (Figure 4) or the annual streamflow volume)
- *receptor impact variables*, the characteristics of the system that, according to the conceptual modelling, potentially change due to changes in hydrological response variables (for example, condition of the breeding habitat for a given species, or biomass of river red gums).

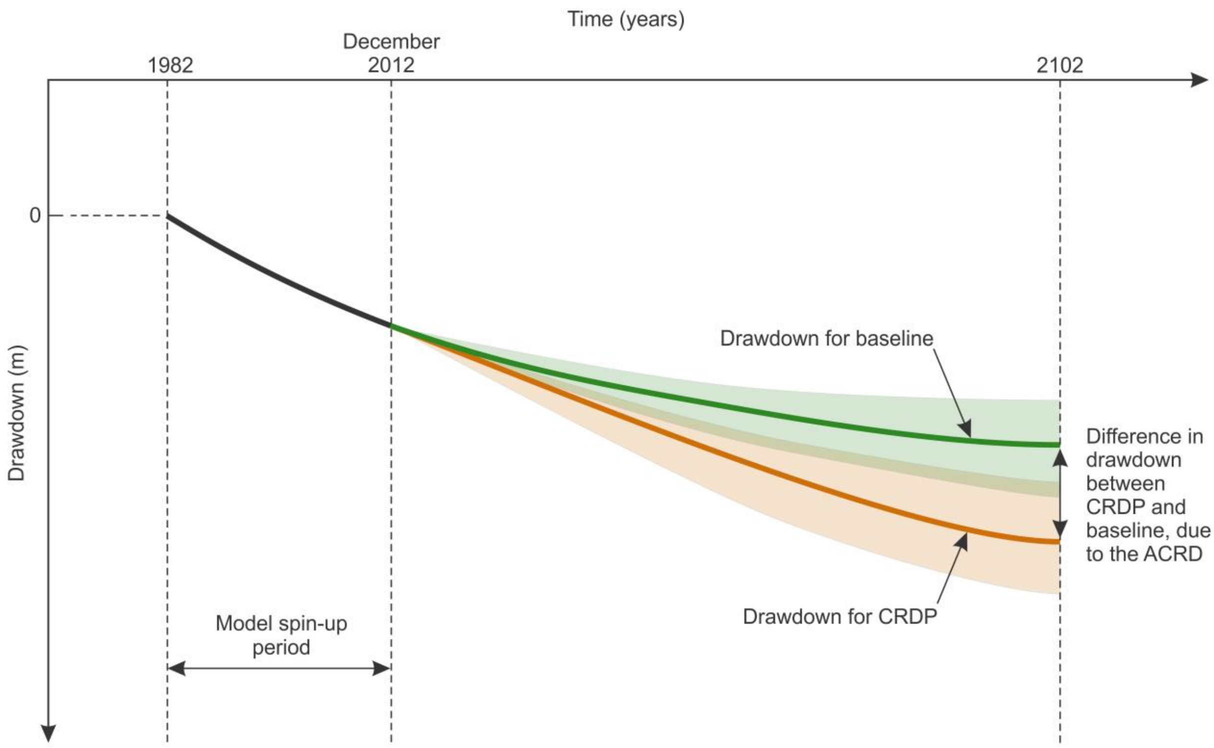

Figure 3 Generic example of drawdown at a specific location over time for the baseline coal resource development (baseline) and coal resource development pathway (CRDP). The difference in drawdown between CRDP and baseline is due to the additional coal resource development (ACRD)

The lighter shades indicate the uncertainty in results. Model spin-up period is a warm-up period for the models.

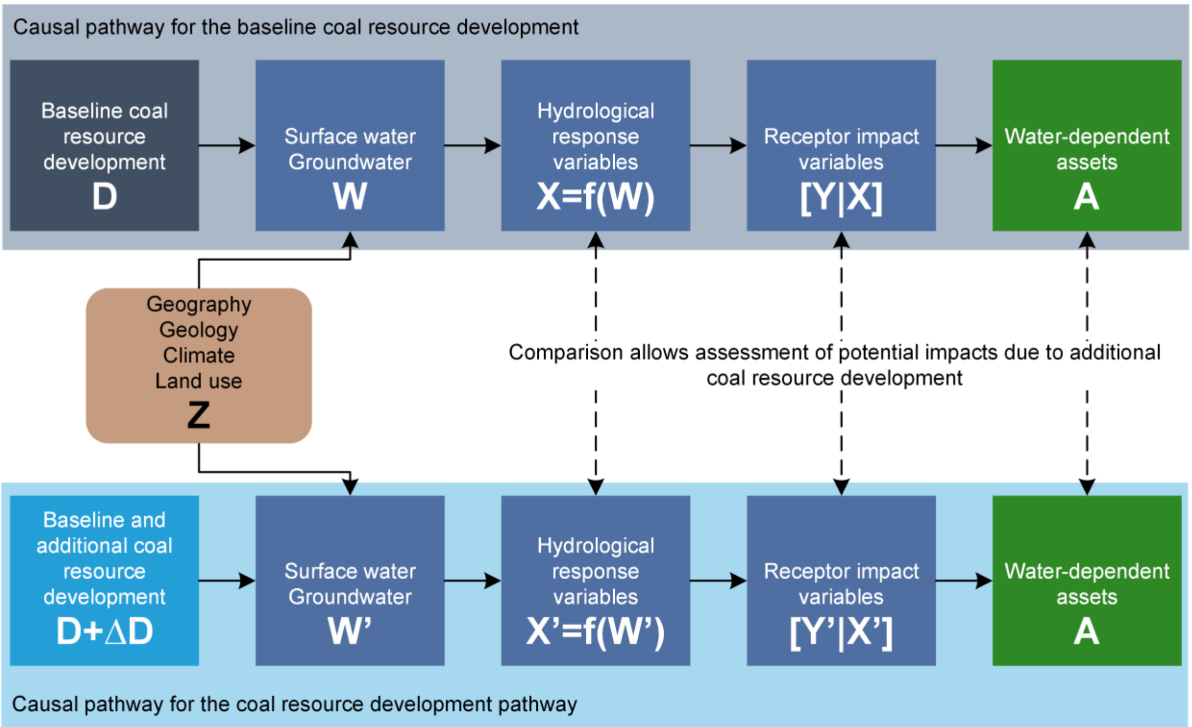

Figure 4 The difference in results between the coal resource development pathway (CRDP) and the baseline coal resource development (baseline) provides the potential impacts due to the additional coal resource development (ACRD)

Section 2.3.5 details the hazard analysis, using the Impact Modes and Effects Analysis (IMEA) method, as described in companion submethodology M11 (as listed in Table 1) for hazard analysis (Ford et al., 2016), and illustrated in Figure 5. Potential causal pathways for both baseline and CRDP are identified by considering:

- *activities* – planned events associated with a CSG operation or coal mine. For example, activities during the exploration and appraisal life-cycle stage in a CSG operation include drilling and coring, ground-based geophysics and surface core testing. Activities are grouped into components, which are grouped into life-cycle stages
- *impact causes* – activities (or aspects of an activity) that initiate a hazardous chain of events
- *impact modes* – the manner in which a hazardous chain of events (initiated by an impact cause) could result in an effect (change in the quality and/or quantity of surface water or groundwater). There might be multiple impact modes for each activity or chain of events
- *effects* – changes in the quantity and/or quality of surface water or groundwater. An effect is a specific type of an *impact* (any change resulting from prior events).

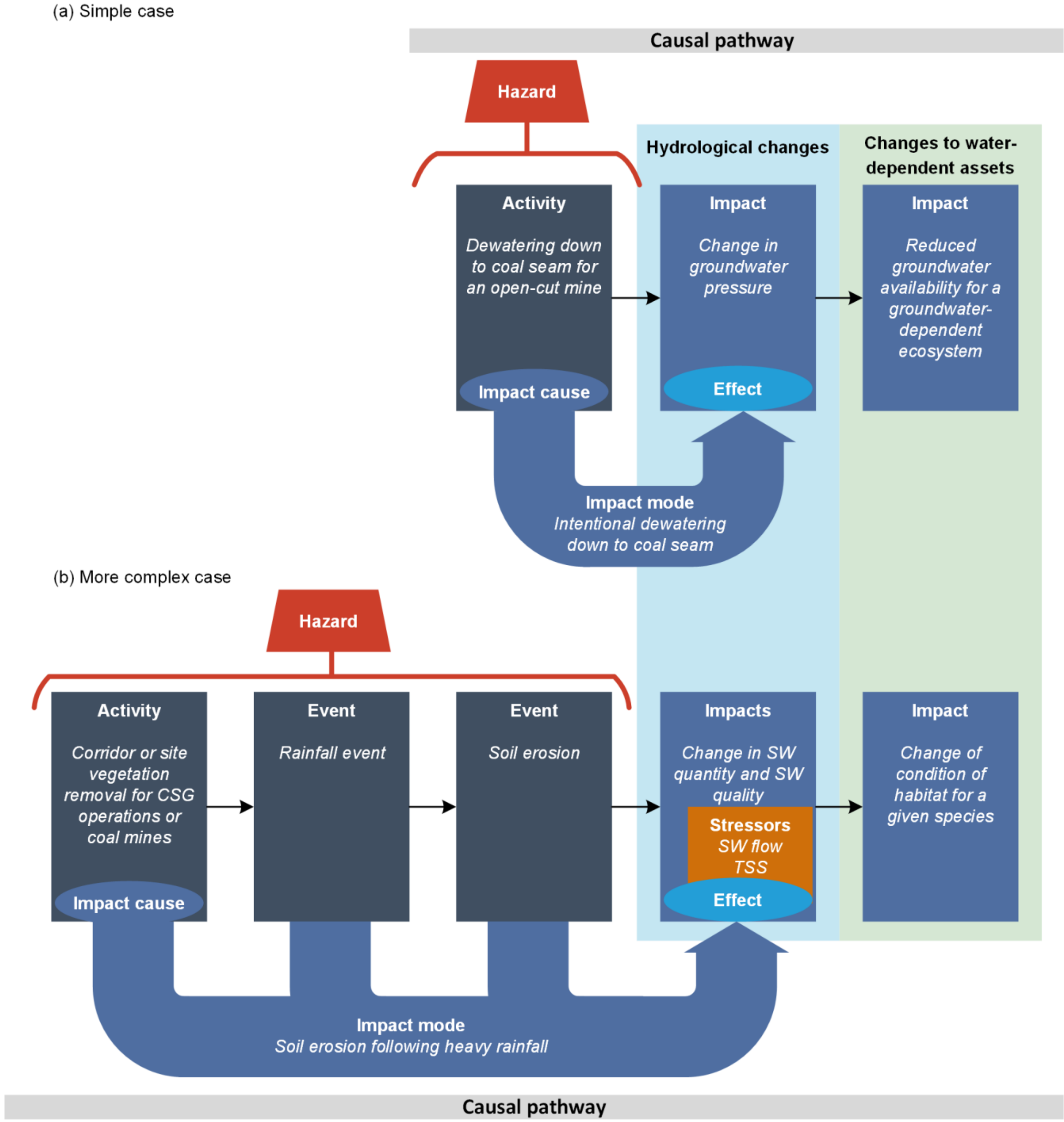

Figure 5 Hazard analysis using the Impact Modes and Effects Analysis. This figure shows how hazards identified using IMEA are linked to changes in hydrology and water-dependent assets via causal pathways

The italicised text is an example of a specified element in the Impact Modes and Effects Analysis. (a) In the simple case, an activity related to coal resource development directly causes a hydrological change which in turn causes an ecological change. The hazard is just the initial activity that directly leads to the effect (change in the quality and/or quantity of surface water or groundwater). (b) In the more complex case, an activity related to coal resource development initiates a chain of events. This chain of events, along with the stressor(s) (for example, surface water (SW) flow and total suspended solids (TSS)), causes a hydrological change which in turn causes an ecological change. The hazard is the initial activity plus the subsequent chain of events that lead to the effect.

This product only specifies the causal pathways from coal resource development to hydrological response variables (see Figure 4). For BAs undertaking receptor impact modelling, the subsequent causal pathways (from hydrological response variables to impacts on landscape classes and water-dependent assets) are reported in the companion product 2.7 (receptor impact modelling). These causal pathways are reported for only those landscape classes with potential hydrological changes, as reported in product 2.6.1 (surface water numerical modelling) and product 2.6.2 (groundwater numerical modelling). This is the final product for the Cooper subregion from this iteration of the Bioregional Assessment Programme. Due to the limited coal resource development potential, identified in Section 2.3.4, no numerical surface water or groundwater modelling, receptor impact modelling, risk or impact analysis or associated products are being produced.

2.3.1.2 Developing causal pathways

The approach undertaken in the Cooper subregion closely follows the process laid out in the companion submethodology M05 for developing a conceptual model of causal pathways (Henderson et al., 2016).

Given the limited scope for development of CSG resources in the Cooper subregion, no numerical groundwater or surface water modelling is being undertaken as part of this BA. As a result, several companion products are not required for the Cooper subregion assessment. These are:

- product 1.4 (description of the receptor register and the receptor register database)
- product 2.1-2.2 (observations analysis, statistical analysis and interpolation)
- product 2.5 (water balance assessment)
- product 2.6.1 (surface water numerical modelling)
- product 2.6.2 (groundwater numerical modelling)
- product 2.7 (receptor impact modelling)
- product 3-4 (impact and risk analysis).

The development of the causal pathways has benefitted greatly from information provided and discussions at the external workshop for causal pathways held in Adelaide on 11 and 12 November 2015. This workshop included participants from SA Department of State Development, SA Department of Environment Water and Natural Resources, SA Arid Lands Natural Resources Management Board, Strike Energy Limited, Beach Energy Limited, the Office of Water Science from the Australian Government Department of the Environment, the Assessment team and Science Leadership Group of the Bioregional Assessment Technical Programme. These participants were invited as they are the key knowledge holders for the parts of the subregion considered in the CRDP, and for which conceptual models have been developed.

The conceptual models of the springs discussed in this product rely heavily on work undertaken by SA Department of Environment Water and Natural Resources under the Lake Eyre Basin Springs Assessment. This work is summarised and reported on by Keppel et al. (2016) and Gotch et al. (2016). The geological conceptualisation was developed in collaboration with Geoscience Australia and Geological Survey of South Australia geologists, which has been reported in Hall et al. (2015), and the underpinning data released for public use as Geoscience Australia (Dataset 1).

The key system components, processes and interactions for the geology, hydrogeology and water-dependent landscape classification of the CRDP were summarised and potential causal pathways were discussed with stakeholders at this workshop. The potential causal pathways considered the CRDP, the impact causes and impact modes, the activities and the potential water-related effects identified by the IMEA. From this discussion, eight causal pathways were identified for the CRDP in the Cooper subregion; these are described in Section 2.3.5.

References

Bureau of Meteorology (2013) Guide to environmental accounting in Australia, Environmental Information Programme Publication Series no. 3, Bureau of Meteorology, Canberra, Australia. Viewed 24 July 2015, http://www.bom.gov.au/environment/doc/environmental_accounting_guide.pdf.

Ford JH, Hayes KR, Henderson BL, Lewis S Baker PA and Schmidt RK (2016) Systematic analysis of water-related hazards associated with coal resource development. Submethodology M11 from the Bioregional Assessment Technical Programme. Department of the Environment and Energy, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia. http://data.bioregionalassessments.gov.au/submethodology/M11.

Gotch T, Keppel M, Fels K and McKenzie J (2016) Lake Eyre Basin Springs Assessment: Ecohydrological conceptual models of springs in the western Lake Eyre Basin. DEWNR Technical report 2016/02. Government of South Australia, through the Department of Environment, Water and Natural Resources, Adelaide.

Hall L, Hill A, Troup A, Korsch R, Radke B, Nicoll R, Palu T, Wang L and Stacey A (2015) Cooper Basin architecture and lithofacies: regional hydrocarbon prospectivity of the Cooper Basin, Part 1. Record 2015/31. Geoscience Australia, Canberra.

Henderson B, Hayes KR, O'Grady A, Mount R, Lewis S, Schmidt RK, Dambacher J, Barry S, Holland K and Raiber M (2016) Developing the conceptual model of causal pathways. Submethodology M05 from the Bioregional Assessment Technical Programme. Department of the Environment and Energy, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia. http://data.bioregionalassessments.gov.au/submethodology/M05.

Keppel M, Gotch T, Inverarity K and Wohling D (2016) A hydrogeological and ecological characterisation of springs in the vicinity of Lake Blanche, Lake Eyre Basin, South Australia. DEWNR Technical report 2016/03. Government of South Australia, through the Department of Environment, Water and Natural Resources, Adelaide.

United Nations, European Commission, Food and Agriculture Organization of the United Nations, Organisation for Economic Co-Operation and Development and World Bank Group (2014) System of environmental-economic Accounting 2012: Experimental ecosystem accounting. United Nations, New York. Viewed 24 July 2015, http://unstats.un.org/unsd/envaccounting/seeaRev/eea_final_en.pdf.

Datasets

Dataset 1 Geoscience Australia (2016) Cooper Structure Surfaces. Bioregional Assessment Source Dataset. Viewed 26 May 2016, http://data.bioregionalassessments.gov.au/dataset/3046e93b-dd9f-41b1-ad12-d0f9c08c60a3.

2.3.2 Summary of key system components, processes and interactions

Summary

The Cooper Basin is an Upper Carboniferous – Middle Triassic geological basin in north-eastern SA and south-western Queensland. The Cooper Basin is up to 2500 m thick, at subsurface depths of between 1000 and 4400 m. The southern Cooper Basin is marked by a series of troughs (e.g. Weena and Tenappera troughs) separated by ridges against which Permian sedimentary rocks thin or pinch out. The Cooper Basin unconformably overlies the Warburton Basin. Several granite bodies intrude the Warburton Basin and underlie the Cooper Basin. A thick alteration profile (clay-rich blanket) exists on the basal unconformity of the Cooper Basin.

The focus of the development of causal pathways is the Weena Trough and the southern Cooper subregion. This is due to the absence of any coal seam gas (CSG)-only developments identified in the rest of the subregion. There is the potential for CSG resources from interbedded shale and coal in other parts of the basin, such as the western flank, but such composite unconventional hydrocarbon resources are outside the scope of bioregional assessments (BAs). Rocks in the Weena Trough are interbedded fluvial sandstone, coal and shale. Cooper Basin strata above the Patchawarra Formation are not encountered. The Patchawarra Formation is therefore the uppermost unit of the Cooper Basin, directly underlying rocks of the Eromanga Basin. The Eromanga Basin is up to 1500 m thick. The geological Lake Eyre Basin is up to 400 m thick over the southern Cooper Basin. The Lake Eyre Basin sequence, comprising the basal Eyre Formation, the Namba Formation and Quaternary sediments, unconformably overlies the Winton Formation of the Eromanga Basin.

The watertable is hosted in the Namba Formation and Quaternary sediments, with regional flow south-westwards towards Lake Blanche. Groundwater within the Cadna-owie – Hooray Aquifer of the Great Artesian Basin flows south towards and beyond Lake Frome. Regional groundwater flow in the Cooper Basin is mainly towards the south-west.

The Rolling Downs Group aquitard is greater than 370 m thick. There is also a thick weathering overprint on the Winton Formation of about 100 m thickness which reduces the effective hydraulic conductivity of the Winton Formation.

There is limited recharge via diffuse infiltration of sporadic rain water, flood waters or streamflow to the groundwater system. The most significant source of groundwater recharge to the Eromanga Basin sequence in the Cooper subregion is inflow from outside the subregion. Recharge to the Cooper Basin occurs by vertical leakage or cross-formation flow.

The southern Cooper subregion is part of the Cooper Creek – Bulloo river basin. Cooper Creek is characterised by complex channel networks and numerous permanent and ephemeral wetlands. Water is derived from runoff from headwater catchments. Streamflow in Cooper Creek and its tributaries varies greatly between years from almost no flow to significant flooding.

Natural discharge to surface takes place at springs, as well as in lakes. The Lake Blanche springs are sourced from the Coorikiana Sandstone and Cenozoic aquifers via a fracture zone or fault pathway.

2.3.2.1 Scope and overview

This section summarises the geology and hydrogeology of the southern part of the Cooper subregion (hereafter referred to as the southern Cooper Basin), as shown in Figure 6. This is due to the absence of any CSG-only developments identified in the rest of the subregion. As the Bioregional Assessment Programme is focused on coal and CSG resource developments, this product does not consider other unconventional gas systems (such as shale or tight gas), composite unconventional gas systems (a hydrocarbon resource characterised by multiple potential reservoir types within the gas saturated zone. For example, it may be a stacked shale gas and coal seam gas resource), or conventional gas resources because it is not possible to separate the source within a composite system. The area lies within the preliminary assessment extent (PAE) described in companion product 1.3 for the Cooper subregion (Sparrow et al., 2015), and focuses on the area of the coal resource development pathway (CRDP) described in Section 2.3.4.

The product incorporates the information provided in companion product 1.1 for the Cooper subregion (Smith et al., 2015b), and includes further information on the geology and hydrogeology developed during the course of the BA. This summary describes the baseline coal resource development (baseline) of the subregion, which did not have coal mining or coal seam gas developments as of December 2012.

2.3.2.2 Geology and hydrogeology

The detailed review of the geology of the southern Cooper Basin presented in this section builds on information presented in companion product 1.1 for the Cooper subregion (Smith et al., 2015b). New data incorporated herein includes stratigraphy and palynology from wells, reinterpreted geological models of the geological Cooper Basin (Hall et al., 2015), reinterpreted stratigraphy and geological history for the Weena Trough (discussed at the external conceptual modelling for causal pathways workshop). Further information on the geological history and unconventional gas resource potential for the Cooper Basin as a whole can be found in Hall et al. (2015).

The Cooper Basin is an Upper Carboniferous – Middle Triassic basin in north-eastern SA and south-western Queensland (Figure 6). The geological basin covers approximately 130,000 km^2 with a package of sedimentary rocks up to 2500 m thick at depths of between 1000 m and 4400 m (Smith et al., 2015b).

Exploration activity is currently focused on conventional oil and gas resources, as well as newly-identified unconventional hydrocarbon plays. These include the extensive basin-centred and tight gas accumulations in the Gidgealpa Group, CSG and deep dry CSG associated with the Patchawarra and Toolachee formations, as well as the less extensive shale gas plays in the Roseneath and Murteree shales (Goldstein et al., 2012; Menpes et al., 2012). As noted in Section 2.3.4, there is only one potential CSG-only resource identified in the subregion.

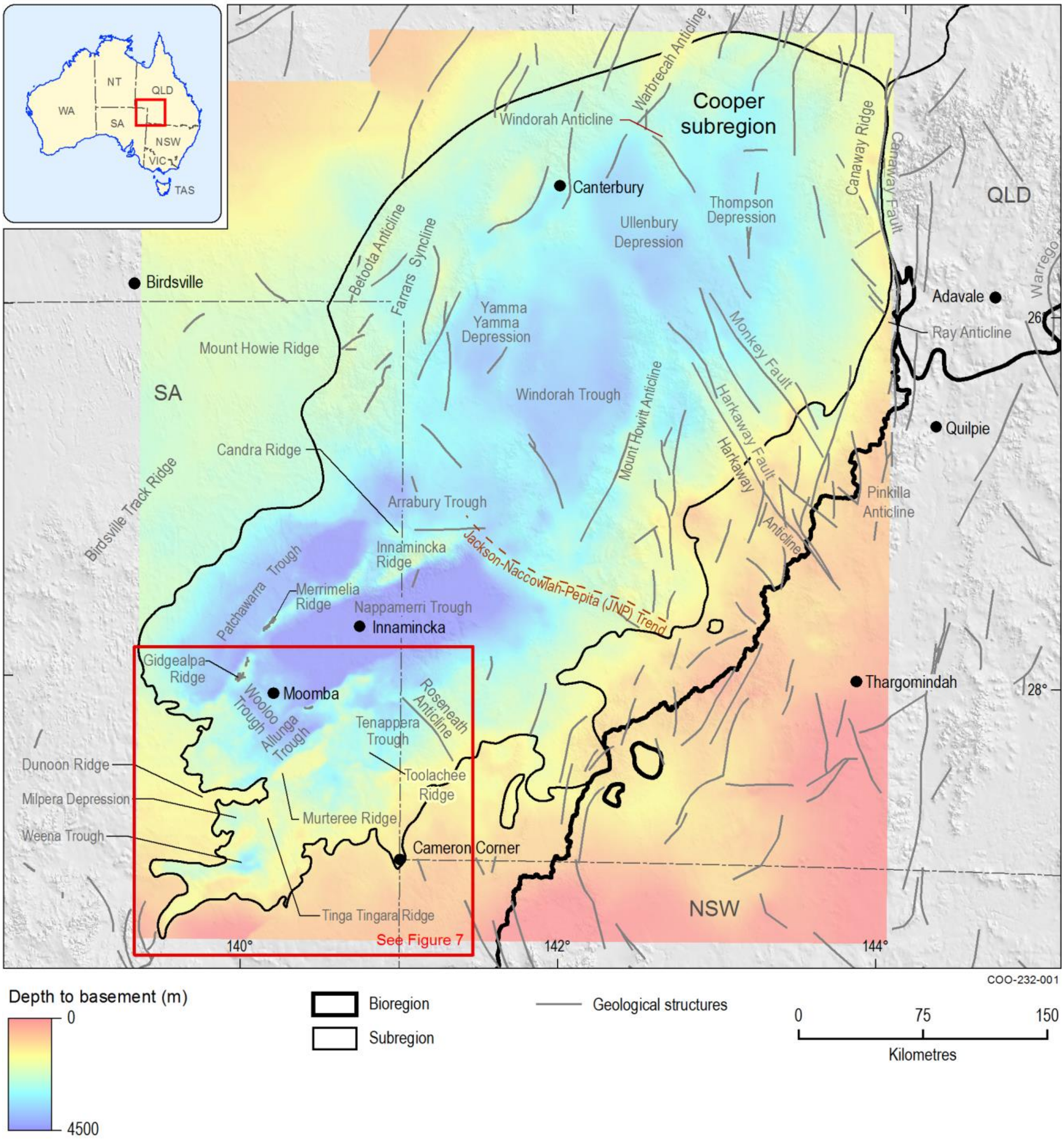

Figure 6 Cooper subregion showing depth to pre-Permian basement rocks and major structural features

Data: Geoscience Australia (Dataset 3), SA Department of State Development (Dataset 2), Hall et al (Dataset 13)

The Cooper Basin is divided into northern and southern areas, separated by the Jackson-Naccowlah-Pepita (JNP) Trend (Figure 6). These areas show different structural and sedimentary histories (Fergusson and Henderson, 2013; Heath, 1989). Depocentres south of the JNP Trend are generally deeper and contain a thicker and more stratigraphically complete Permian succession than those to the north (Fergusson and Henderson, 2013; Hill and Gravestock, 1995). The three major troughs in the south-west (Patchawarra, Nappamerri and Tenappera) are separated by the Gidgealpa-Merrimelia-Innamincka (GMI) and Murteree Ridges, which approximately trend north-east (Figure 6), parallel to the main depositional axis of the basin (Gravestock and Jensen-Schmidt, 1998). The Weena and Tenappera troughs on the southern margin of the basin are separated by the Tinga Tingana Ridge, which strikes north-south (Figure 7). In the northern Cooper Basin, the Permian succession is thinner than in the south, and the major depocentres, including the Windorah Trough and Ullenbury Depression, are generally less well defined (Draper, 2002; Fergusson and Henderson, 2013).

The southern Cooper Basin is a region marked by a series of troughs separated by ridges against which Permian sedimentary rocks thin or pinch out. The elongate and orthogonal alignment of troughs and ridges (Figure 6 and Figure 7) appears to reflect a structural fabric inherited from the underlying Warburton Basin as well as subsequent compressional tectonics; however, this basement relief is additionally modified by glacial scouring across the Cooper Basin (Boucher, 2001a).

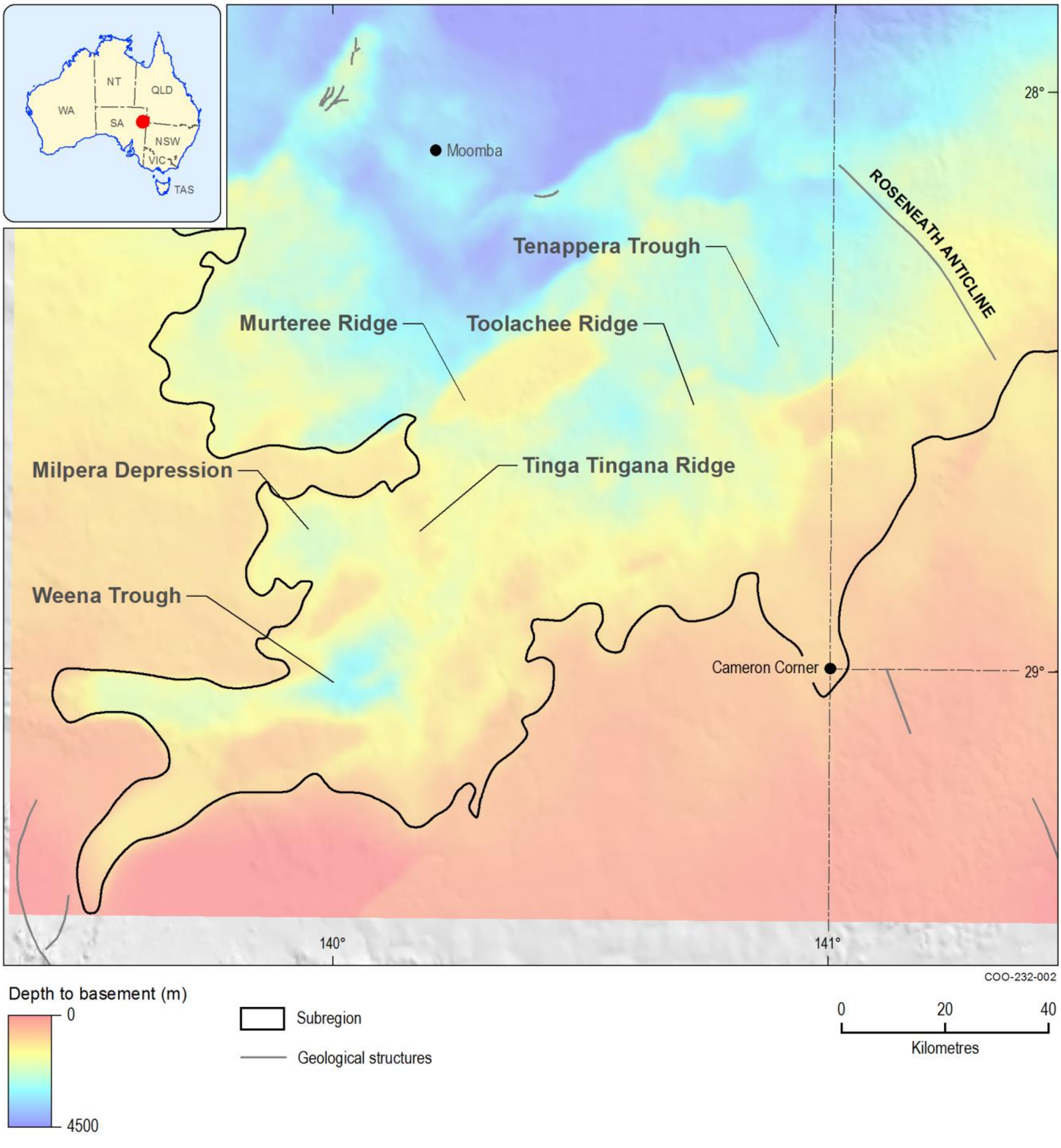

Figure 7 Southern Cooper Basin showing depth to pre-Permian basement rocks and major structural features

Data: SA Department of State Development (Dataset 2), Hall et al (Dataset 13)

2.3.2.2.1 Basement to the southern Cooper Basin

The Cooper Basin unconformably overlies the sedimentary and volcanic rocks of the Cambrian – Ordovician Warburton Basin. The Warburton Basin consists of a sequence of marine sedimentary rocks deposited in a range of environments from the continental shelf to the deeper ocean (Fergusson and Henderson, 2013).

Devonian rocks are intersected in the Warrabin and Barrolka troughs, beneath the north-east trending Cooper Basin, and can be identified from seismic data (Draper et al., 2004; Fergusson and Henderson, 2013; Murray, 1994).

Numerous granite bodies intrude the Warburton Basin and underlie the Cooper Basin. Early Devonian granites occur beneath the southern Cooper Basin in Queensland and SA. Middle Carboniferous and early Permian granites are present beneath the Nappamerri Trough, and include the Big Lake Suite granodiorite (Gatehouse et al., 1995; Meixner et al., 2012).

The Warburton Basin sequence comprises siltstone and sandstone, with some reported volcanic rocks and dolostones. Fractures in brittle siltstones are capable of producing commercial oil and gas, for example Moolalla-1, Lycosa-1, Sturt-6, Sturt-7 and Challum-19 (Primary Industries and Resources SA, 2003). Sandstone porosity ranges from 5% to 20%, although permeability requires interconnected fracture networks. The porosity of volcanic rocks is up to 17% due to dissolution of feldspar and glasses, although, as for the sandstones, permeability requires interconnected fracture networks (Radke, 2009).

A thick alteration profile, however, exists on the basal unconformity of the Cooper Basin over the Warburton Basin. This profile probably developed in the late Carboniferous and early Permian. The profile developed as a result of pre-Cooper Basin weathering combined with low-temperature hydrothermal alteration. The profile generally exceeds 40 m but varies in thickness, thinning onto highs and ridges. Because of the alteration of feldspars to muscovite and illite, the alteration profile forms a seismically mappable semi-regional seal (Boucher, 2001b). As this regional alteration profile acts as an aquiclude, hydrogeological connectivity between the base of the Cooper Basin and the Warburton Basin is unlikely.

2.3.2.2.2 Stratigraphy of the Cooper Basin

This section incorporates data and information made available following completion of companion product 1.1 for the Cooper subregion (Smith et al., 2015b). This includes incorporation of recent drilling results and reprocessing at basin scale of structure surfaces and isopachs (Hall et al., 2015), as well as a reinterpretation of the stratigraphy of the Weena Trough based on recent drilling and re-analysis of palynology (Morton, in review). The stacked basin architecture of the Cooper subregion is shown in the stratigraphic column (Figure 10) and cross-sections (Figure 8 and Figure 9). As noted previously, the focus of this work is the southern Cooper Basin.

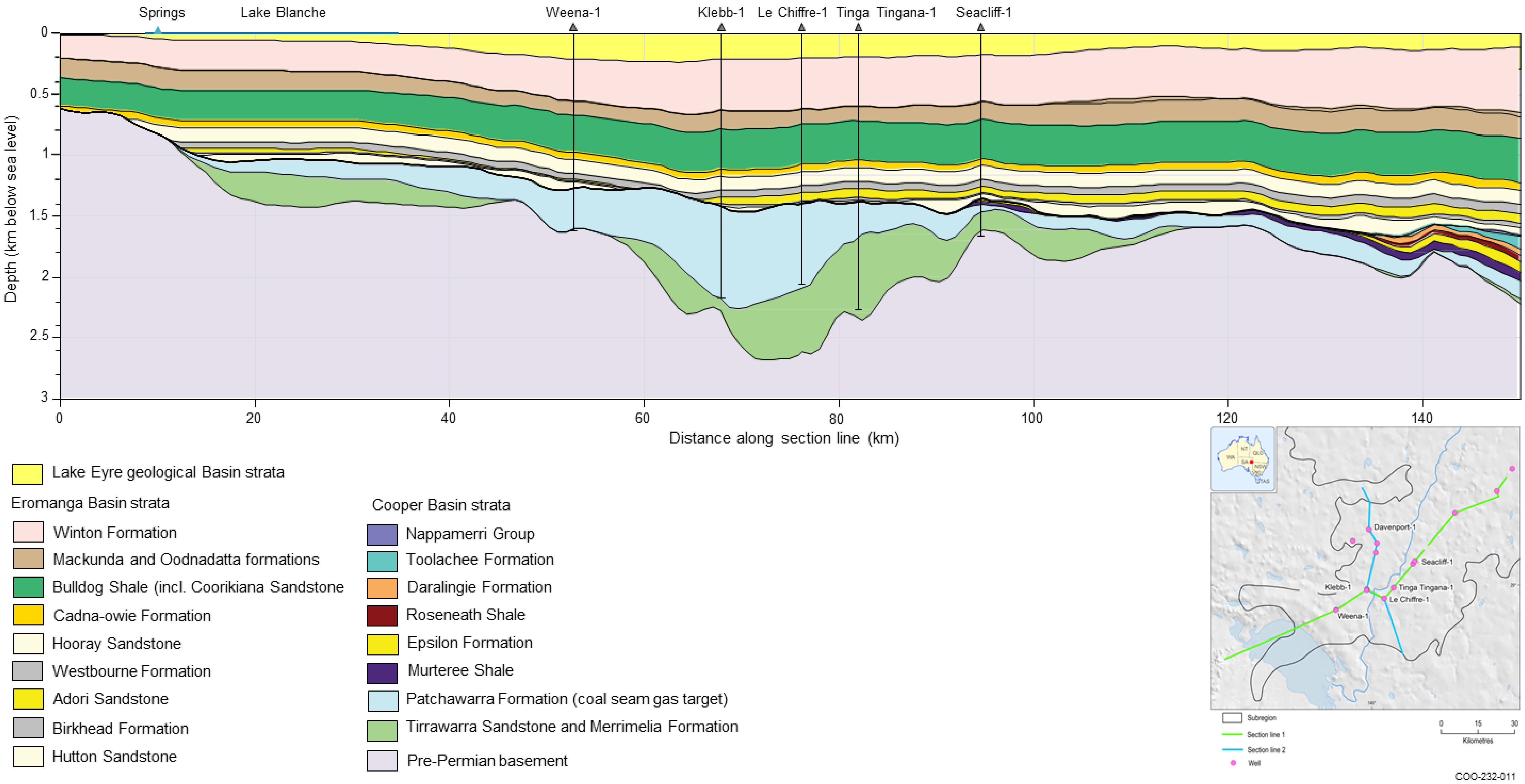

Figure 8 Geological cross-section 1 through the Tenappera and Weena troughs to Lake Blanche showing the stratigraphic variation between these areas. Cross section locations shown in map on bottom right

The Patchawarra Formation is thicker in the Weena Trough and adjacent areas, and directly underlies Eromanga Basin units.
Data: Bioregional Assessment Programme (Dataset 11), Hall et al. (Dataset 13)

This figure has been optimised for printing on A3 paper (420 mm x 297 mm).

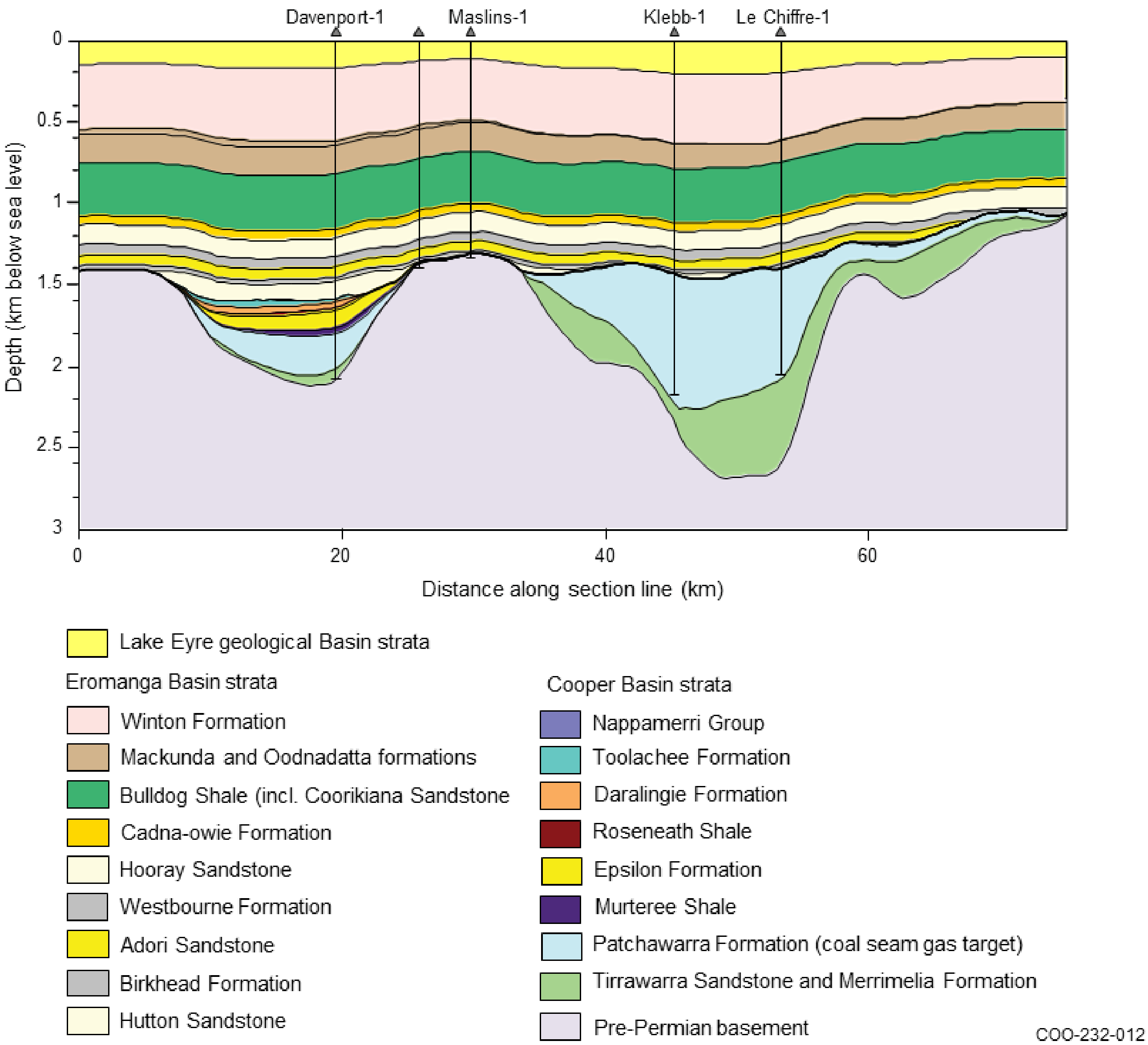

Figure 9 Geological cross-section 2 through the Milpera Depression and Weena Trough to Lake Blanche showing the stratigraphic variation between these areas. The Patchawarra Formation is thicker in the Weena Trough and adjacent areas, and directly underlies Eromanga Basin units. Cross-section locations shown in Figure 8

Data: Hall et al. (Dataset 13)

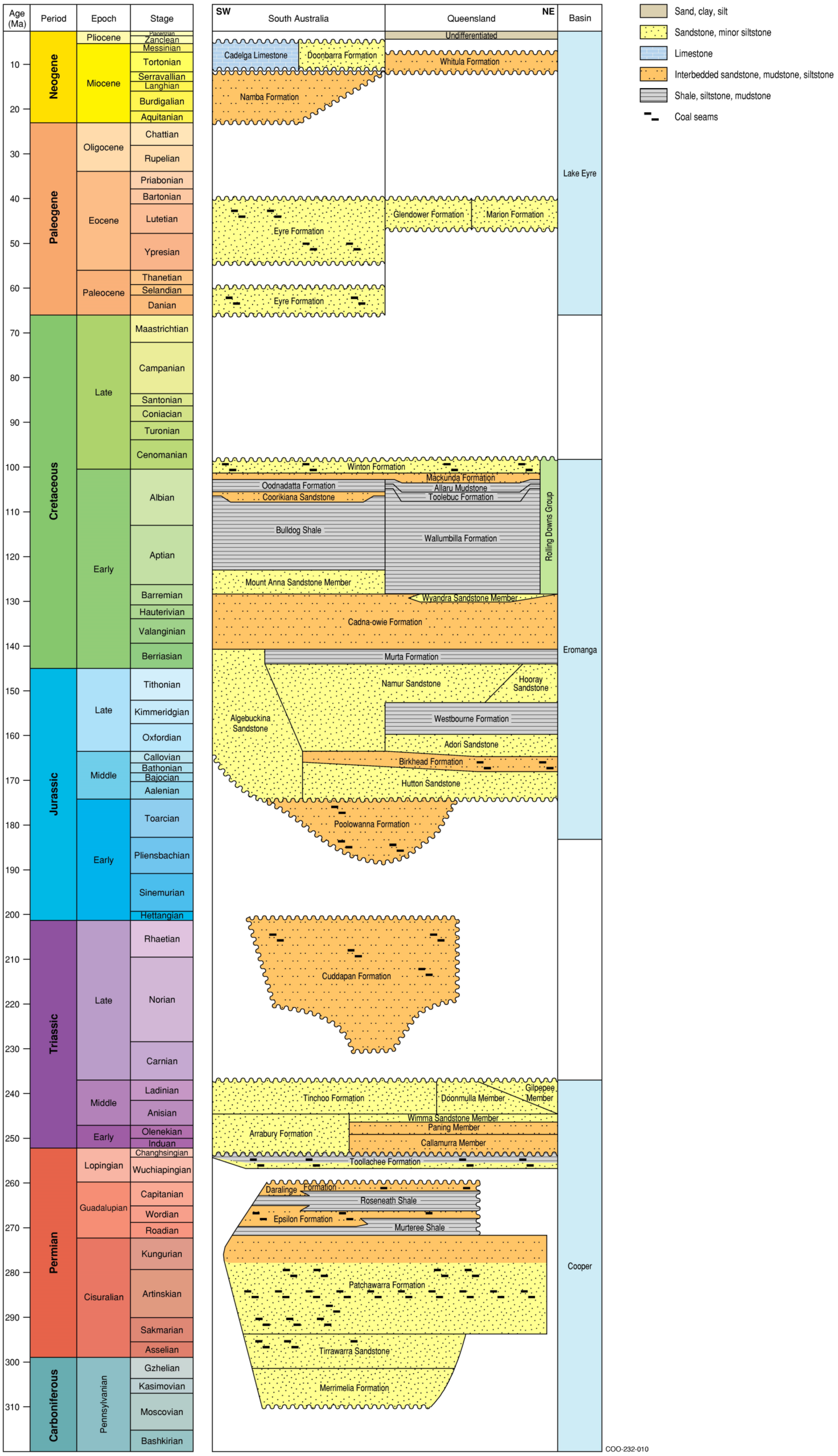

Figure 10 Stratigraphic column for the Cooper subregion

Data: Hall et al. (2015); Ransley et al. (2015); Smith et al. (2015b)

This figure has been optimised for printing on A3 paper (297 mm x 420 mm).

Cooper Basin

The recent stratigraphic reinterpretation by Morton (in review) on re-calibrated palynological ages in eastern Australian basins (Nicoll et al., 2015) has highlighted unique features of the Cooper Basin stratigraphy in the Weena Trough. A revised stratigraphy for the Weena Trough and surrounding parts of the Cooper Basin, incorporating this reinterpretation, has been developed by Morton (in review), and is summarised in this section. A schematic representation of this stratigraphy is shown in Figure 11.

Figure 11 Simplified stratigraphy of the Weena Trough, southern Cooper Basin

The sequence in the Weena Trough consists of interbedded fluvial sand, coal and shale. Distinctive features associated with the Epsilon Formation in the remainder of the Cooper Basin are not encountered in the Weena Trough. A shale unit, referred to as the 'intra-Patchawarra shale', is recorded in all wells in the Weena Trough (Figure 11). This unit has been interpreted to have been deposited in a distal pro-glacial lake setting (Morton, in review).

The intra-Patchawarra shale member is recognised in Klebb wells, Le Chiffre-1, Tinga Tingana-1 and Weena-1 (Morton, in review). These shales had previously been logged as either the Murteree or Roseneath shales. Additionally, the reinterpretation of Permian Patchawarra Formation originally logged as basement, indicates that the Patchawarra Formation is much thicker than previously interpreted, with basement being consequently much deeper (Figure 8 and Figure 9).

The top of the Permian section (comprising the Murteree Shale, Epsilon Formation, Roseneath Shale and Toolachee Formation) is not recorded in the Weena Trough area. The lithologic character of the Weena Trough includes sand, shale and coal beds, which suggests a more complex depositional model compared to the Tenappera Trough area, and the rest of the Cooper Basin (Morton, in review).

The Toolachee Formation is also not present in the Weena Trough; nor are the Daralingie Formation and Roseneath Shale. The Murteree Shale appears to pinch out south of the Tinga Tingana High, and is not present in the Weena Trough around the Klebb wells, Le Chiffre-1, Weena-1 or Forge-1 (Morton, in review). In the Weena Trough and toward Lake Blanche, the Patchawarra Formation is therefore the uppermost unit of the Cooper Basin, directly underlying rocks of the Eromanga Basin (Figure 8 and Figure 9). The 400 to 600 m thick Patchawarra Formation intersected in Le Chiffre-1 and Klebb-1 in the Weena Trough consists of interbedded coal, carbonaceous shale, very fine- to medium-grained sandstone, and claystone (Strike Energy Limited, 2014a; 2014b). As discussed in companion product 1.2 for the Cooper subregion (Smith et al., 2015a) and in Section 2.3.4, the Vu and Vm3 coal seams of the Patchawarra Formation are the targets for CSG development in the Cooper subregion.

Eromanga Basin

The stratigraphy of the Eromanga Basin is discussed in this section, and shown in Figure 10; this version is based on information for the southern Cooper Basin, and information from the external conceptual modelling of causal pathways workshop. Figure 12 shows the spatial extents of the lower Eromanga Basin sequences in the southern Cooper Basin.

As the Westbourne Formation thins and wedges out, the Adori, Hooray and Namur sandstones become collectively the Namur Sandstone. The overlying Murta Formation defines the extent of the Namur Sandstone.

The Birkhead Formation has a slightly greater westward extent than the Westbourne Formation and thus separates the Namur Sandstone from the underlying Hutton Sandstone. The Algebuckina Sandstone refers to the undifferentiated sandstone under the Cadna-owie Formation, where the Birkhead Formation wedges out.

On the south-east side of the Central Eromanga Depocentre where older units are absent, the Hooray Sandstone has broad extent out to the boundary of the Eromanga Basin.

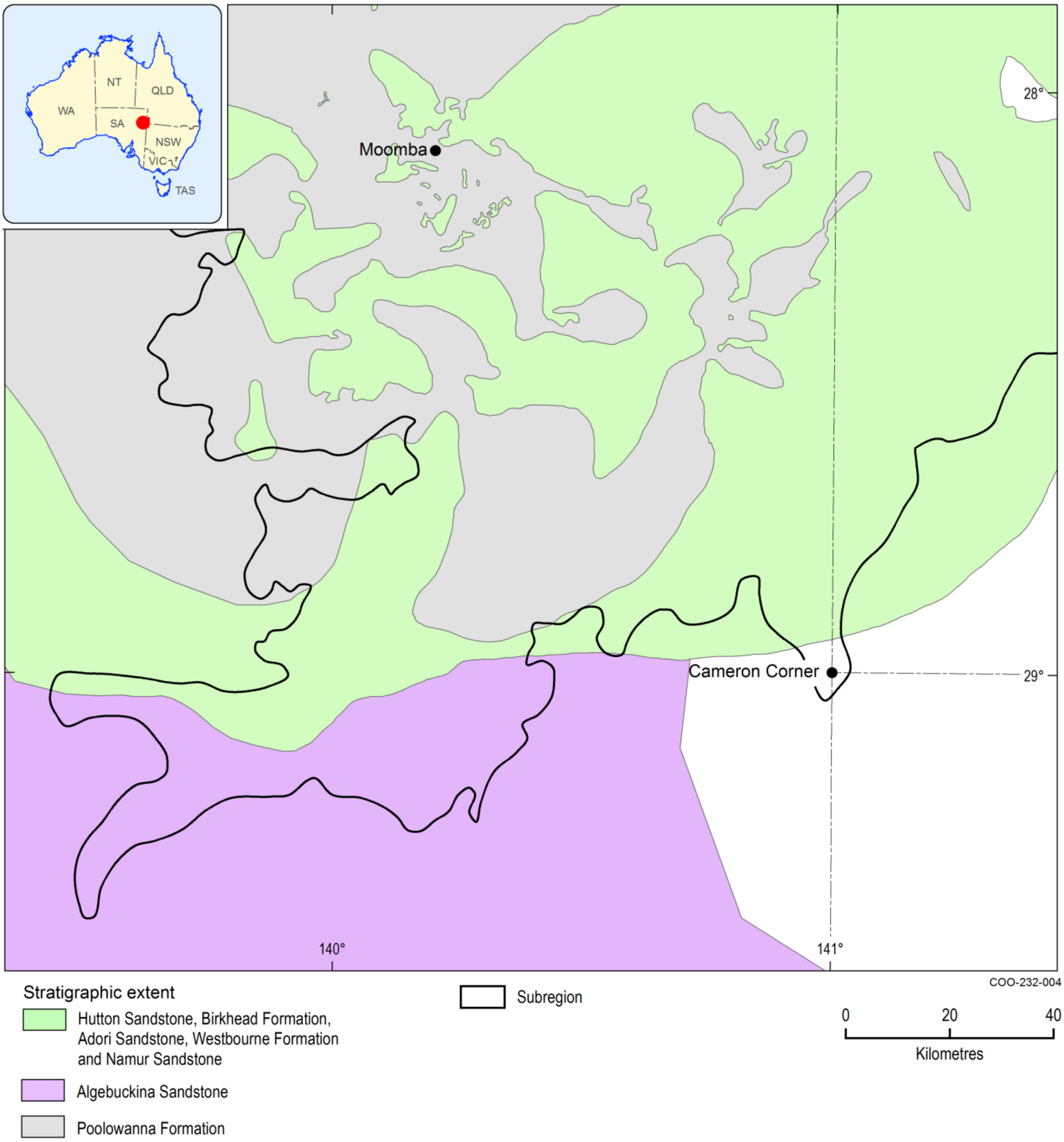

Figure 12 Extent of Eromanga Basin units below the Cadna-owie Formation

Data: Geoscience Australia (Dataset 1, Dataset 12)

The Cadna-owie Formation is a marginal marine unit with a much broader extent; it always overlies the Algebuckina Sandstone. The Trinity Well Sandstone Member of the Cadna-owie Formation can be considered as a western facies equivalent to the Wyandra Sandstone Member, which is present in Queensland.

Within the overlying Rolling Downs Group, the nomenclatural changes are primarily determined by the limit of the south-western extent of the Toolebuc Formation. Beyond the Toolebuc Formation extent, the underlying upper part of the Wallumbilla Formation and the overlying Allaru Mudstone can no longer be readily differentiated and are grouped as the Oodnadatta Formation. The Coorikiana Sandstone is a spatially extensive, coarsening-upward sandstone unit with minor siltstone interbeds (Sheard et al., 2012). It differentiates the Oodnadatta Formation from the underlying Bulldog Shale. The Rolling Downs Group extends across the entire southern Cooper Basin.

Lake Eyre Basin

The geology of the Lake Eyre Basin sedimentary rocks is described in companion product 1.1 for the Cooper subregion (Smith et al., 2015b). The geological Lake Eyre Basin is up to 400 m thick in the southern Cooper Basin, where it overlies the Weena Trough (Figure 13). In the southern Cooper Basin the Cenozoic Lake Eyre Basin sequence thickens westward across the Weena Trough region. At approximately 50 m thickness in Queensland, there is a progressive thickening to over 200 m above the Weena Trough, then with a slight thinning to the west. Northward there is a slight thickening in the Tenappera Trough but a distinct thinning on the adjoining Murteree Ridge.

The Lake Eyre Basin sequence unconformably overlies the Winton Formation of the Eromanga Basin. This Cenozoic sequence comprises the basal Paleocene-Eocene Eyre Formation which is disconformably overlain by the Miocene Namba Formation. A relatively thin layer of Quaternary sediment (mainly sand) covers the Namba Formation throughout the southern Cooper Basin. The thickness of the Quaternary sediment is rarely recorded but known to be as much as 60 m in parts of the southern Cooper Basin, although evidence from drilling in the Weena Trough region suggests here it is only about 5 m. However, the pervasive seif dune topography across the subregion almost approaches a comparable scale of relief (Figure 13).

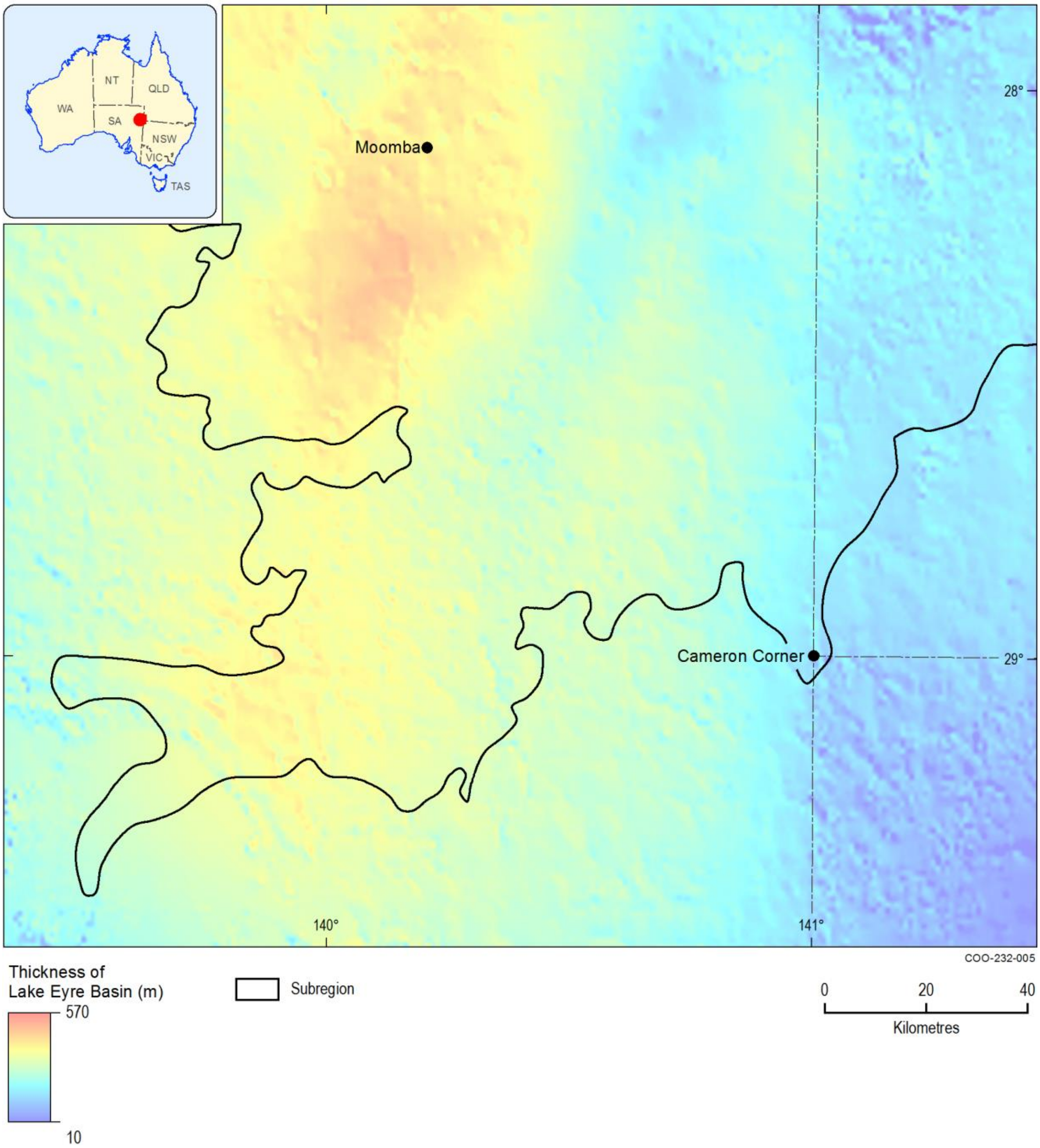

Figure 13 Thickness of the geological Lake Eyre Basin in the southern Cooper Basin

Data: Bioregional Assessment Programme (Dataset 4)

2.3.2.2.3 Groundwater flow directions, groundwater recharge and discharge

Lake Eyre Basin, regional watertable and surface drainage interactions

The regional watertable of the Great Artesian Basin (Kellett et al., 2012) is hosted in the Namba Formation and Quaternary sediments across the Weena Trough region. The watertable is broad and of low gradient across the southern Cooper Basin (Figure 14).

The watertable over the Weena Trough infers regional flow south-westwards towards Lake Blanche and adjacent salt lakes extending from Lake Frome through to lakes Callabonna, Blanche and Gregory. These are ephemeral salt lakes that precipitate halite from groundwater brine

(Kellett et al., 2012). The southern side of this regional groundwater sink features a steep watertable gradient off the Flinders Ranges.

North of the Weena Trough the watertable gradients are more convoluted with a subtle groundwater mound centred over the Dunoon Ridge, and an adjoining subtle north–south depression centred over the Murteree High.

The watertable mapping and highly ephemeral nature of flow implies that Strzelecki Creek is not reliant on the watertable. It is likely that flow in Strzelecki Creek may contribute to recharging the watertable aquifer on the rare occasions water flows and is able to infiltrate the creek bed.

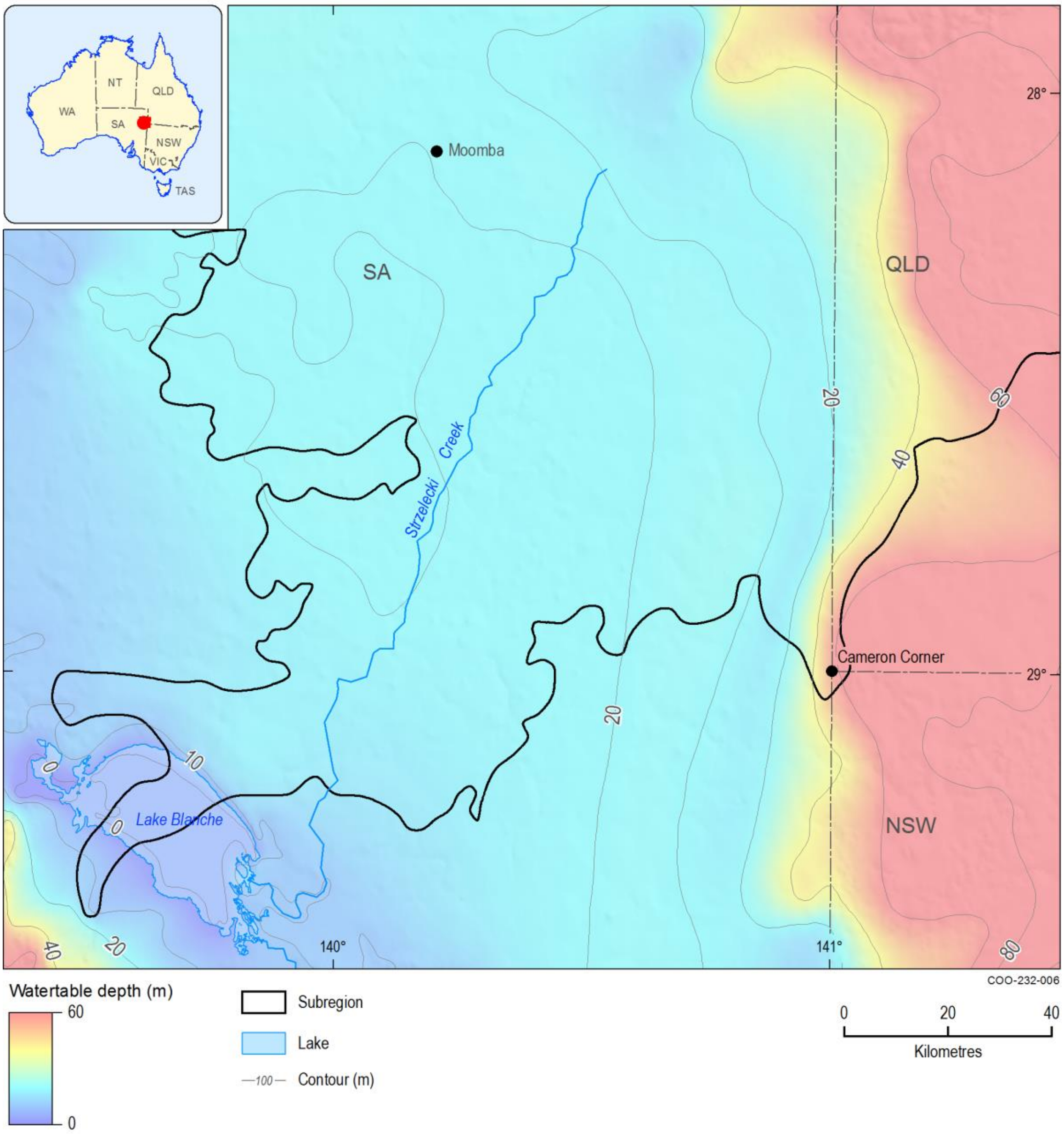

Figure 14 Subsurface depth to regional watertable in the southern Cooper Basin

Data: Geoscience Australia (Dataset 5), SA Department of State Development (Dataset 6)

Groundwater flow in the Eromanga Basin and Cooper Basin

The direction of groundwater flow in the Cadna-owie – Hooray Aquifer is inferred to be similar to that of the watertable, towards the series of salt lakes between Lake Frome and Lake Gregory (Keppel et al., 2016; Ransley et al., 2015). Keppel et al. (2016) identified that groundwater head data used previously to constrain the flow directions in the Cadna-owie – Hooray Aquifer (J-K aquifer) in the southern Cooper Basin were likely from bores which were screened in other hydrostratigraphic units. Subsequently, the potentiometric surface of the Cadna-owie – Hooray Aquifer was reinterpretated as part of the Lake Eyre Basin Springs Assessment (LEBSA). The revised flow in the Cadna-owie – Hooray Aquifer indicates a southward flow towards and beyond Lake Frome, and this flow direction is generally interpreted for the other Eromanga Basin units. Flow is also inferred to occur from the northern end of the Flinders Ranges (crystalline basement) north towards Lake Blanche, this flow path terminates at Lake Blanche, represented by a low in the contours on the south-western margin of the lake (

Figure 15). A general south-westerly flow direction is shown by potentiometric surfaces presented by Dubsky and McPhail (2001) for the Cooper Basin hydrostratigraphic units; however, the data used to develop the potentiometric surfaces did not extend south of the Tinga Tingana Ridge.

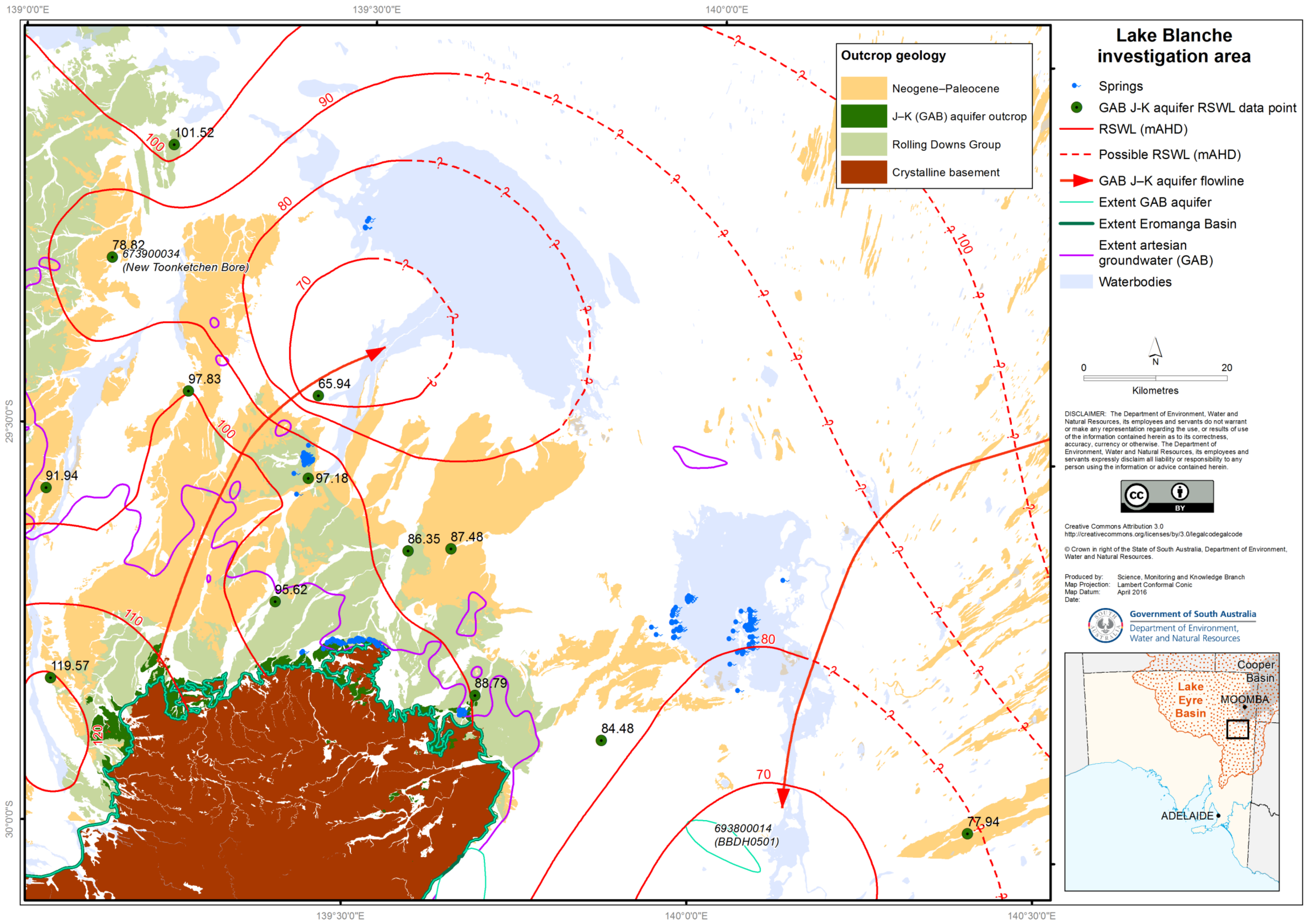

Figure 15 Reduced standing water level (RSWL) of the Cadna-owie – Hooray Aquifer (J-K aquifer) and groundwater flow directions in the southern Cooper Basin

Source: Figure 2-6 from Keppel et al (2016)

This figure has been optimised for printing on A3 paper (420 mm x 297 mm).

2.3.2.2.4 Hydrogeological connectivity

The issue of hydrogeological connectivity of basement with the Cooper Basin sequence has been discussed briefly in Section 2.3.2.2.1.

Cooper Basin – Eromanga Basin connectivity

A large area of Patchawarra Formation lies in contact with the basal unconformity of the Eromanga Basin west of the Tinga Tingana Ridge. This region of Patchawarra Formation extends across the Weena Trough, and most of the Milpera Depression. Eastwards and northwards from this region of Patchawarra Formation, progressively younger Cooper Basin formations lie at the basal Eromanga unconformity (Figure 8 and Figure 9).

The extents of Jurassic units at the basal unconformity to the Eromanga Basin over the southern Cooper Basin comprise the Hutton Sandstone, Algebuckina Sandstone and Poolawanna Sandstone. Downgradient of the Southern Cooper Basin Gas Project (the only proposed coal resource development in the subregion, see Section 2.3.4) and towards the lakes, the Patchawarra Formation may be considered as a leaky aquitard or partial aquifer, and to be in direct contact with aquifers or partial aquifers of the basal Eromanga Basin (Figure 16). The Hutton Sandstone is 40 to 60 m thick over the southern Cooper Basin and thickens northwards, along with the Algebuckina Sandstone (>150 m).

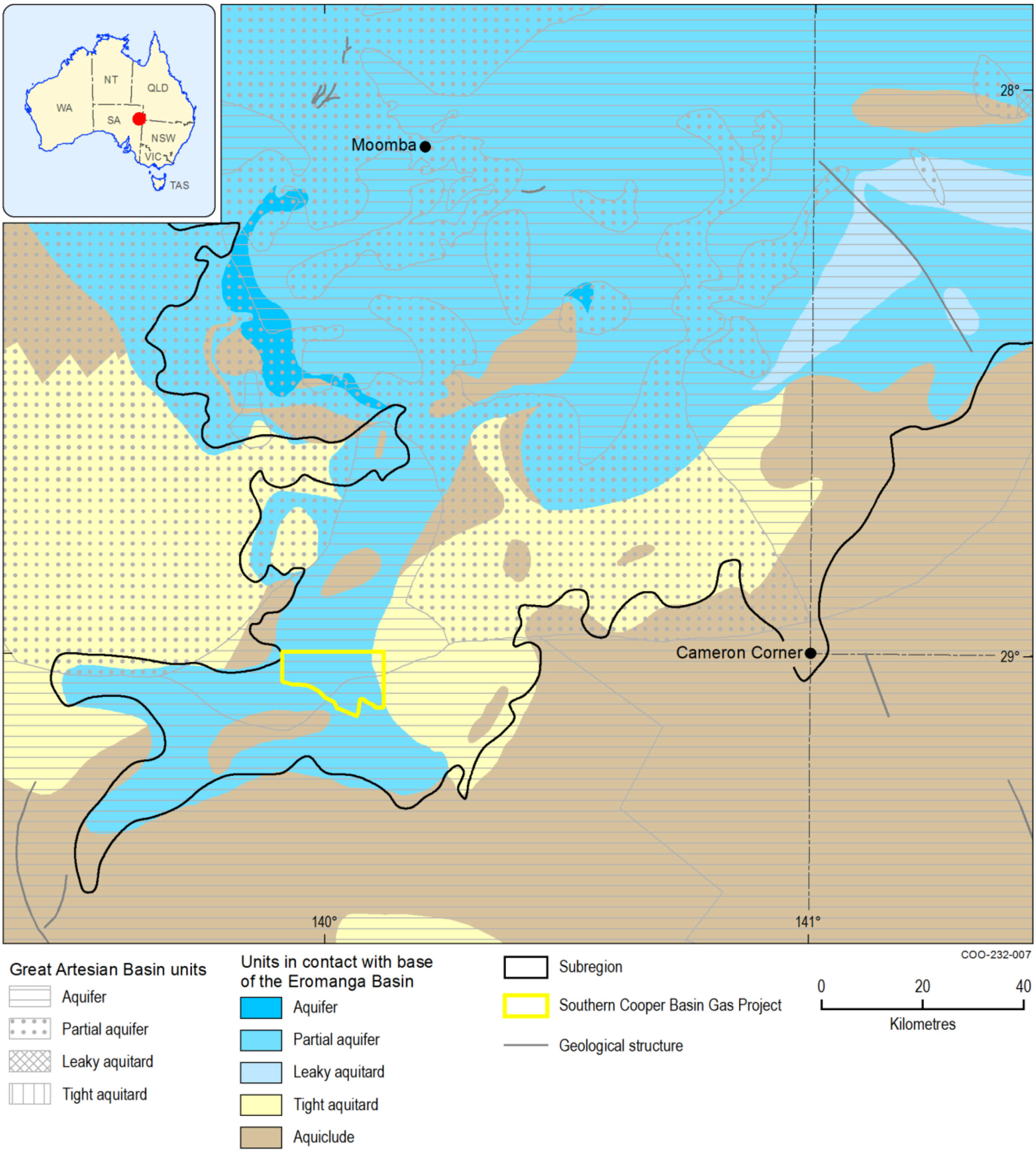

Figure 16 Potential hydrogeological connectivity between the base of the Eromanga Basin and the top of the southern Cooper Basin

Data: Geoscience Australia (Dataset 7, Dataset 8)

Only in the northern sector of the southern Cooper Basin is the Poolowanna Formation aquitard present at the basal unconformity, but with many erosional windows and embayments enabling contact of the Hutton Sandstone with the Cooper Basin. This lies outside the area of the Southern Cooper Basin Gas Project.

Connection between Eromanga Basin hydrostratigraphy

Due to stratigraphic thinning of units towards the margins of the Eromanga Basin, the sequence of units from the base of the Eromanga Basin up to and including the Cadna-Owie Formation is generally grouped and referred to as the J-K aquifer. Hydraulic connection of the Hutton

Sandstone with the Namur Sandstone (Cadna-owie – Hooray Aquifer) appears possible only through the window in the Birkhead Formation, that is, where this part of the sequence is identified as the Algebuckina Sandstone, at the southern end of the Tinga Tingana Ridge (Figure 12).

The total thickness of the Eromanga Basin across the southern Cooper subregion exceeds 1000 m, increasing to more than 1500 m thickness in the Tenappera Trough. The Rolling Downs Group (considered a tight aquitard and comprising the combined Wallumbilla Formation, Toolebuc Formation, Allaru Mudstone, Bulldog Shale and Oodnadatta Formation) comprises between 32% and 39% of the total Eromanga Basin sequence in the Weena Trough region, and is always greater than 370 m thick. The Coorikiana Sandstone appears to be an important potential source for several bores and springs on the floor of Lake Blanche, according to recent work undertaken for LEBSA (Keppel et al., 2016). However, the Coorikiana Sandstone is underlain by thick, very low permeability Bulldog Shale (a regional aquitard) and overlain by thick, very low permeability Oodnadatta Formation.

Polygonal faulting is pervasive within the entire Rolling Downs Group, as evident in seismic interpretation of the Lake Hope area (Watterson et al., 2000), and exposed in the floor of Lake Gregory (Ransley et al., 2015). This style of intraformational faulting may introduce a potential for inter-aquifer connectivity across an aquitard (Ransley et al., 2015, p. 38). Where polygonal faulting is mapped within the Great Artesian Basin, head differences between the Rolling Downs Group and overlying and underlying aquifers show that the aquitard is not compromised by these structural features (Smerdon et al., 2012). In the southern Cooper subregion the considerable thickness of the aquitard (Figure 17) would argue against any significant vertical transmissivity. In addition, there is no substantive evidence available for the role of intra-formational faulting in vertical transmissivity in the Rolling Downs Group for the southern Cooper Basin.

In this region of the Eromanga Basin there is a thick weathering overprint on the Winton Formation, an alteration zone of about 100 m thickness (see Map 18 in Ransley et al., 2015). In this zone, the rocks are weathered to clays, thus further reducing the effective hydraulic conductivity of the Winton Formation.

Collectively, the very thick Rolling Downs Group in the southern Cooper Basin and an upper aquifer with a thick upper regional seal are considered to provide a very low permeability barrier in the Rolling Downs Group, significantly diminishing the potential for vertical hydraulic transmissivity.

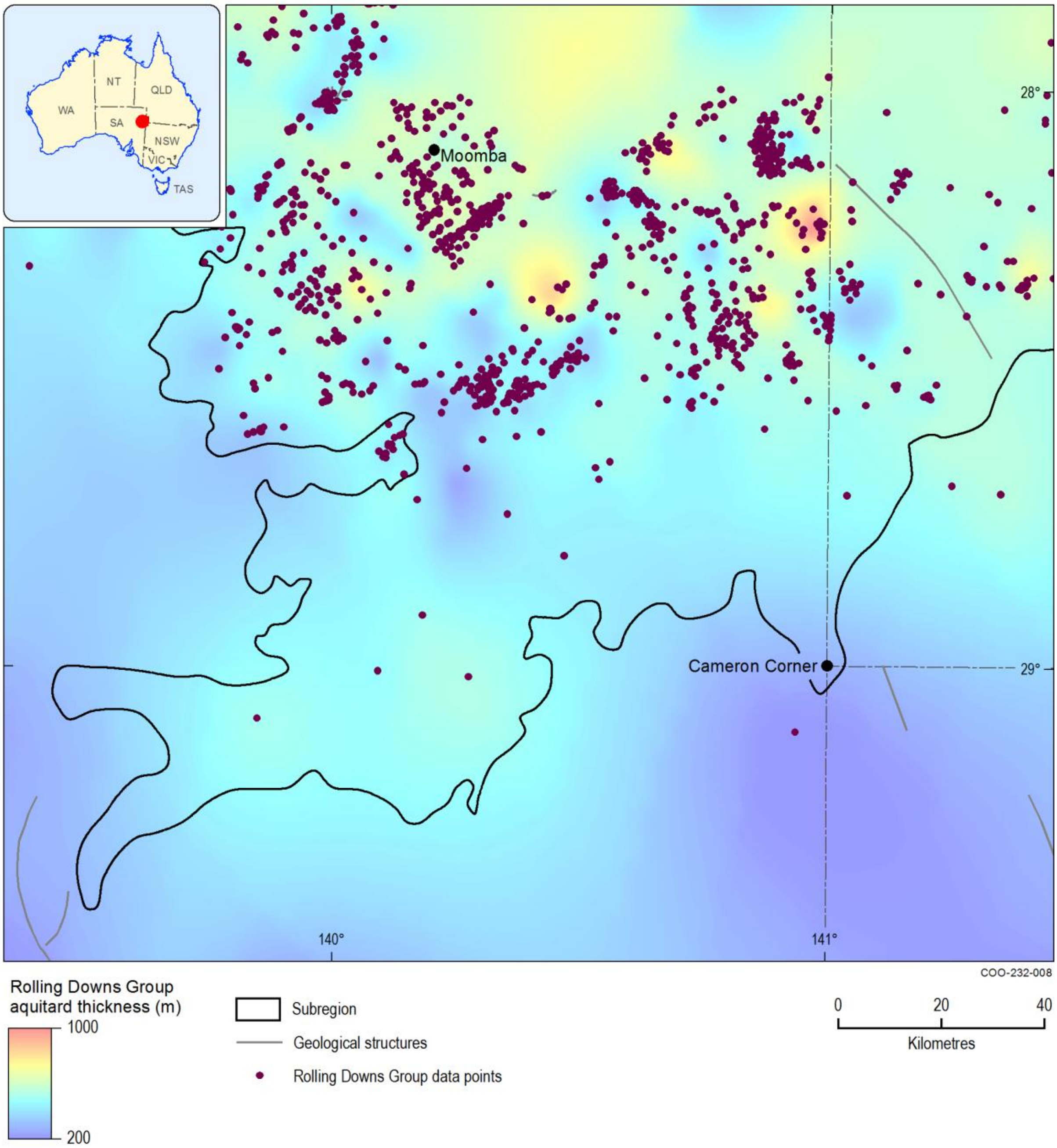

Figure 17 Thickness of the Rolling Downs Group aquitard over the southern Cooper Basin

Data: Geoscience Australia (Dataset 9)

Eromanga Basin – Lake Eyre Basin connectivity

The Eyre Formation is a relatively consistent aquifer, in that it has a fairly uniform lithological character and is relatively undeformed. It is characterised by a silcrete overprint at the top of the formation (Alley, 1998; Callen et al., 1995). This silcrete is a potentially impermeable barrier to upward groundwater migration. The thickness of this Eyre Formation aquifer ranges from about 12 to 60 m over the Weena Trough. However, there are greater thickness variations over the Tenappera Trough (thicker) and Murteree High (thinner) areas.

The overlying Namba Formation is a regional aquitard comprising fine-grained lacustrine sediments, but with random channel sands forming localised linear aquifers. The Namba

Formation is generally thicker than the Eyre Formation, and the greatest difference in thickness is across the Weena Trough where the Namba aquitard exceeds threefold the Eyre Formation thickness (e.g. Weena-1: 158.5 m Namba Formation over 44.5 m Eyre Formation).

2.3.2.2.5 Lake Blanche springs

The watertable surface in the southern Cooper Basin indicates low-gradient groundwater flow only as far as the nearby regional sink – the groundwater discharge zone along an arcuate band extending from Lake Frome through lakes Callabonna, Blanche and Gregory (Figure 18).

Previous work identified that the springs on the floor of Lake Blanche were sourced from an Eromanga Basin aquifer, but not enough data was available to assign a particular source aquifer with confidence (Hydrogeologic Pty Ltd, 2014). The Hutton Sandstone (basal Eromanga Basin aquifer) has been identified as having a direct connection with the Patchawarra Formation in the Weena Trough, as a result of revised stratigraphy presented in Section 2.3.2.2.2.

As part of the broader Bioregional Assessment Programme, the SA Government was commissioned to undertake a number of projects, including the LEBSA. Hydrogeochemical information and springs field surveys carried out on the Lake Blanche springs by the South Australian Department of Environment, Water and Natural Resources (DEWNR) are of specific interest for the Cooper subregion. From this work, conceptual models, knowledge base tables and spring typologies were developed and reported by Keppel et al. (2016). These conceptual models recognise that hydrogeological changes from groundwater extraction and contamination influence the flow rate, pH, conductivity and dissolved oxygen content of discharge waters. These drivers, in turn, influence the spring vegetation communities, endemic and relict flora, and endemic fauna (Keppel et al., 2016; SA Department of Environment Water and Natural Resources, 2015b).

The spring typology of the Lake Blanche Spring complex is described as predominantly flat depressions, or salt lake (non-brine density type) springs (Gotch et al., 2016; Keppel et al., 2016). The springs are sourced by water from the Coorikiana Sandstone and the Cenozoic aquifers, as shown by distinct hydrogeochemical characteristics, including chlorine-36 isotopic analyses, stable isotopes of hydrogen and oxygen and strontium isotopes. The water reaches the surface via a fracture or fault pathway, shown by reconnaissance electrical geophysical surveys (Keppel et al., 2016; SA Department of Environment Water and Natural Resources, 2015a). Some water input may be contributed from the watertable aquifer as well. Springs may occur as isolated sand mounds or fringing seeps (Keppel et al., 2016; SA Department of Environment Water and Natural Resources, 2015b).

2.3.2.3 Surface water

The area of the Cooper subregion is 130,000 km^2 of which 118,128 km^2 (91%) is included in the Cooper Creek – Bulloo river basin and 11,932 km^2 (9%) in the Diamantina–Georgina river basin.

Cooper Creek and the Thomson, Barcoo and Bulloo rivers are the major waterways in the Cooper subregion (Figure 18). The stream below the junction of Thomson and Barcoo rivers is known as Cooper Creek and is characterised by complex channel networks and numerous wetlands and waterholes. The Strzelecki Creek is another major waterway in the southern part of the Cooper subregion. It originates in the Strzelecki reserve and flows to Lake Blanche. The Coongie Lakes

Ramsar Wetlands are located in the lower part of the Cooper creek basin, in the far north-east of SA (Figure 18). The Ramsar site includes the Cooper Creek system from the Queensland–SA border downstream to Lake Hope, the north-west branch of the Cooper Creek. The flow in Cooper Creek is highly seasonal often producing floods during summer rainfall (McMahon et al, 2008). Since 1970, a total of 39 floods have been recorded at Windorah with almost half categorised as major floods. During a large flood, floodplain between Currareva and Nappa Merrie becomes a huge inland sea broken only by a few ridges and numerous stunted trees (Bureau of Meteorology, 2015). Water quality information such as total phosphorus (TP), total nitrogen (TN), electrical conductivity (EC) and turbidity is scarce for this basin. EC levels are normally low and stable. Turbidity is high and subject to varying trends as a result of local influences.

Flow in Cooper Creek has not yet been affected by diversion of water for irrigated agriculture or major dams or weirs (McMahon et al., 2005). In the water resource plan for the Cooper Creek, the Queensland Government reserved 2000 ML of unallocated water (200 ML for general reserve, 1300 ML for strategic reserve and 500 ML for the town and community reserve) to meet future demand (DERM, 2011).

Previous monitoring data for waterbodies within the Lake Eyre Basin have indicated that a number of water quality parameters, such as nutrients and turbidity, are often elevated and can exceed existing default trigger values (Sheldon and Fellows, 2010; Sternberg et al., 2014). Sheldon and Fellows (2010) showed there are marked water quality differences relating to periods of floods and no-flow conditions from 15 waterholes sampled across Cooper Creek during 2001 to 2004. Data from the Lake Eyre Basin Rivers Assessment (LEBRA) water quality monitoring sites also showed a general pattern of increasing salinity throughout the low or no-flow periods, followed by sharp lowering during high-flow events. A number of LEBRA reports show electrical conductivity generally increasing from the upper to lower catchment, suggesting waterholes in the lower Cooper are naturally more saline (e.g. Sternberg et al., 2014; Mathwin et al., 2015). At some sites there is a distinct initial rise in salinity when the first flood water arrives (Cockayne et al., 2013).

Turbidity is high and subject to varying trends as a result of local influences. It appears turbidity decreases from upstream to downstream and then increases again before the Cooper Creek crosses the Queensland–SA border. Due to isolated waterholes forming during extended dry seasons in this basin, differing turbidity trends may be more representative of local influences than generally deteriorating water quality further downstream (DERM, 2011). In situ measurements at 17 sites (during spring 2011 and autumn 2012) show the turbidity varies from 4 to 354 Nephelometric Turbidity Units (NTU), with a mean and median of 124 and 126 NTU respectively across the Cooper creek basin (Cockayne et al., 2013).

The Cooper subregion contributes surface water predominantly to Cooper creek basin and a small proportion to Diamantina river basin by its floodplain pathways and numerous creeks. Both of these river basins are characterised by large variations in discharge and flow duration. Streamflow monitoring stations are relatively sparse in the Cooper subregion.

Water in the Cooper creek basin is predominantly derived from runoff from headwater catchments. The Thomson and Barcoo rivers, which originate outside the Cooper subregion, play an important role providing inflow into Cooper Creek. Transmission losses are generally very high. The long-term (1901 to 2003) average modelled runoff coefficient in the Cooper creek basin varies from a low of 1.2% for the Alice River at Barcaldine to a high of 6.6% for the Thomson River at Stonehenge. The runoff coefficients are 5.8% at Currareva and 1.6% at Nappa Merrie (McMahon et al., 2005).

Streamflow in Cooper Creek and its tributaries varies greatly between years from almost no flow to significant flooding, and between months with no flow for some months. Watercourses in this basin are ephemeral and carry water mostly between January and July. The maximum monthly flow varies depending on the location of the gauging site and contributing catchment area, with some sites having very high flows (up to 15,900 GL/month for Cooper Creek at Currareva). Both annual and monthly flows generally increase down the catchment, although there are exceptions to this trend. On average there is flow in Cooper Creek at Nappa Merrie about 60% of the time. The flow duration curves are steep for all gauging sites in the Cooper creek basin, confirming the observation that streamflow is highly variable and that there is little groundwater contribution to the overall flow (McMahon et al., 2005).

Records of large floods in the Cooper Creek extend back as far as the late 19th century, with the most significant episodes of flooding occurring in 1893, 1906, 1949, 1955, 1963, 1974, 1990 and 2000 (Bureau of Meteorology, 2015). Due to its low gradient, water flows very slowly on the floodplain. For a large flood, it takes around 16 days for the water to pass through the floodplain with a wave speed of 0.3 m/second, while for a small flood the speed can be as low as 0.1 m/second (Costelloe et al., 2003). The long travel time allows the air and earth to absorb much of the water on the flat floodplain. On average, the water of the Cooper Creek reaches Lake Eyre only once every six years (Kingsford et al., 1999). For the biggest flood in the recorded history of Cooper Creek (1974), around 25,000 GL of water inundated the creek and 40% of the water was lost by the time the flood peak arrived in Callamurra near the Queensland–SA border. For flow events below 5000 GL, the transmission loss is often above 80% (McMahon et al., 2005). The Coongie Lake is often found as the terminus of flow in the Cooper Creek for small to medium floods. The lakes and channels downstream of Coongie Lake receive flow less frequently and dry out more frequently (Costelloe, 2013).

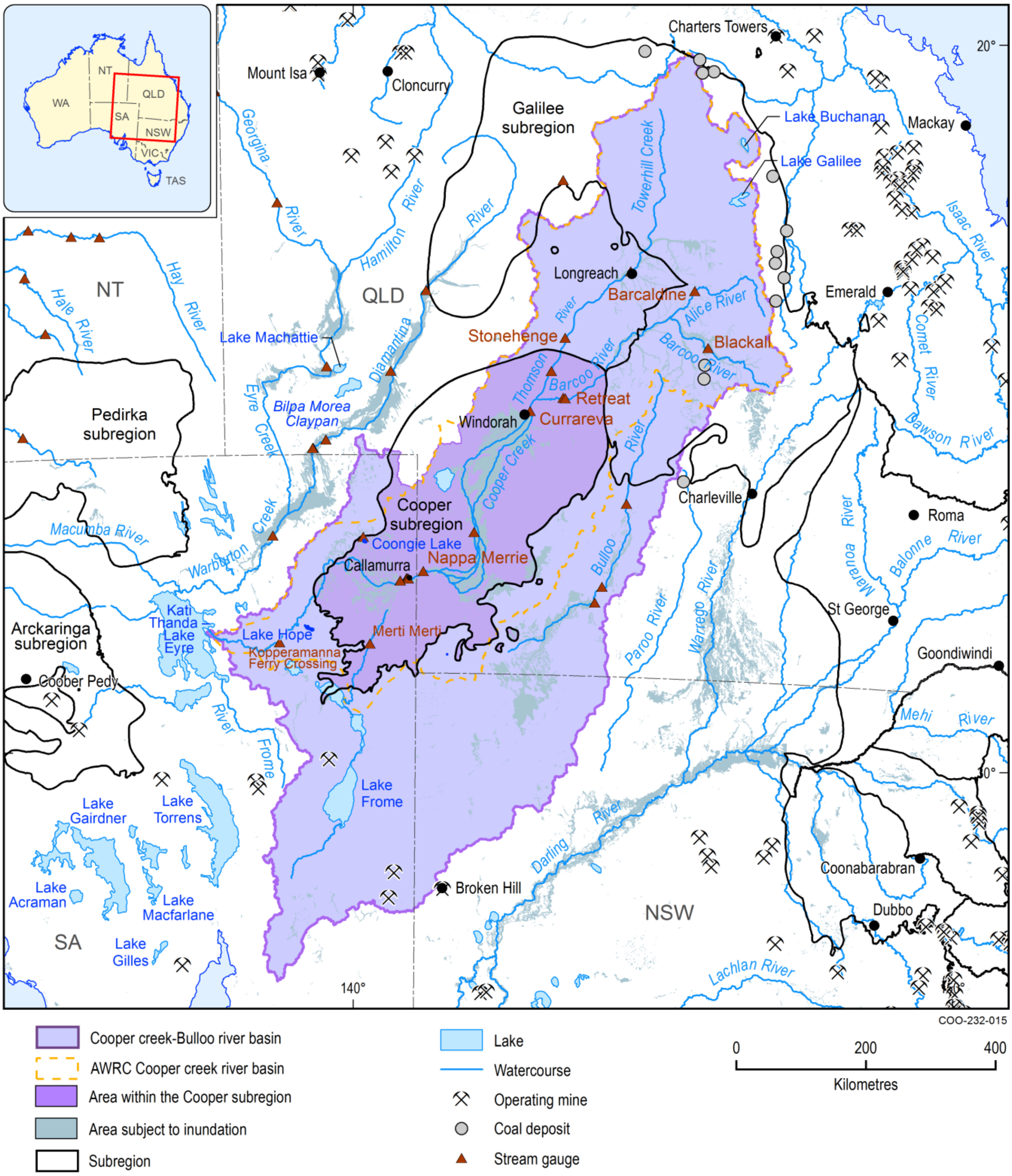

Figure 18 Cooper subregion and associated nearby river basins showing stream network and water bodies

Data: Geoscience Australia (Dataset 10)

2.3.2.4 *Water balance*

The only source of potential rainfall recharge to the Eromanga Basin is via the Innamincka Dome, which lies over the Innamincka Ridge. No other Eromanga Basin units crop out in the Cooper subregion. Some limited recharge via diffuse infiltration of sporadic rain water, flood waters or streamflow through Quaternary and Cenozoic cover sequences may occur, although this is likely to be effectively zero, as a result of extremely low rainfall and high evaporation (Cresswell et al., 2012; Love et al., 2013). The most significant source of groundwater to the Eromanga Basin sequence in the Cooper subregion is inflow from areas outside the subregion.

Groundwater recharge to the Cooper Basin sequence can only occur through vertical leakage from adjacent aquifers or cross-formation flow.

Natural leakage or natural discharge to surface takes place at springs and areas of seepage, as well as in lakes, which are abundant around the margins of the Central Eromanga Basin (Love et al., 2013; Radke et al., 2000).

Figure 15 highlights groundwater discharge to the surface at Lake Blanche.

Surface water is present in ephemeral drainages and terminal salt lake systems in the subregion. The drainage network is active following large rain events in the headwaters, and is subject to spectacular flood flows. Springs are the only recognised groundwater contribution to the surface water system in the southern Cooper Basin.

2.3.2.5 Gaps

Knowledge gaps include the nature and influence of any geological structures and their role in hydrogeological processes in the southern Cooper subregion. The flow direction and water quality of the Cooper Basin hydrostratigraphy is not well defined in the southern Cooper Basin. The potential for connectivity between the basal Eromanga Basin and the Patchawarra Formation has been identified, but there is no substantive evidence currently available to assess this further. This represents a major knowledge gap.

The surface water hydrology of the Strzelecki Creek is also not well characterised. Apart from the presence of discharge springs in Lake Blanche, the connection between the groundwater and surface water systems in the southern Cooper subregion is interpreted from regional water table mapping, which shows that the water table is 10 to 20 m below ground, except at Lake Blanche. This needs to be supported by more local-scale investigations.

Water quality data for the subregion are limited; therefore, conclusions cannot be made on spatial and temporal variability of commonly measured water quality parameters.

References

Alley NF (1998) Cainozoic stratigraphy, palaeoenvironments and geological evolution of the Lake Eyre Basin. Palaeogeography, Palaeoclimatology, Palaeoecology 144(3–4), 239–263.

Boucher R (2001a) Cooper Basin Ridges - Are they structural? MESA Journal 21, 30–32.

Boucher RK (2001b) Nature and origin of the altered zone at the base Cooper Basin unconformity, South Australia. Primary Industries and Resources SA. Viewed 23 February 2016, https://sarigbasis.pir.sa.gov.au/WebtopEw/ws/samref/sarig1/image/DDD/RB200100012.pdf.

Bureau of Meteorology (2015) Flood warning system for the Cooper Creek catchment, river brochures. Bureau of Meteorology, Australian Government, Australia. Viewed 04 December 2015, http://www.bom.gov.au/qld/flood/brochures/cooper/cooper.shtml.

Callen RA, Alley NF and Greenwood DR (1995) Lake Eyre Basin. In: Drexel JF and Preiss WV (eds) The Geology of South Australia. Volume 2, The Phanerozoic. South Australian Geological Survey, Adelaide, Australia, 188–194.

Cockayne B, Schmarr D, Duguid A and Mathwin R (2013) Lake Eyre Basin Rivers Assessment 2012 monitoring report. A report to the Department of Sustainability, Environment, Water, Population and Communities (SEWPaC), Canberra.

Costelloe JF (2013) Hydrological assessment and analysis of the Cooper Creek catchment, South Australia. Report by the University of Melbourne to the South Australian Arid Lands Natural Resources Management Board, Port Augusta.

Cresswell R, Smerdon BD, Rousseau-Gueutin P, Simon S, Taylor A, Davies P and Habermehl M (2012) Chapter 6: Hydrodynamics. In: Smerdon BD and Ransley TR (eds) Water resource assessment for the Central Eromanga region. A report to the Australian Government from the CSIRO Great Artesian Basin Water Resource Assessment. CSIRO Water for a Healthy Country Flagship, Australia.

Department of State Development (2015) Stratigraphic revision of the Pemian units in the Weena Trough, SW Cooper Basin. Adelaide, South Australia.

DERM (2011) Cooper Creek water resource plan 2011. Queensland Department of Environment and Resource Management. Water Planning South West, Brisbane.

DEWNR (2015a) Hydrogeological investigations of springs in the Lake Blanche region, Lake Eyre Basin, South Australia. Preliminary results. South Australian Department of Environment Water and Natural Resources.

DEWNR (2015b) LEBSA Lake Blanche springs conceptualisations update. South Australian Department of Environment Water and Natural Resources.

Draper JJ (2002) Cainozoic. In: Draper JJ (ed.) Geology of the Cooper and Eromanga Basins, Queensland. Queensland Natural Resources and Mines, Brisbane, 60–62.

Draper JJ, Boreham CJ, Hoffmann KL and McKellar JL (2004) Devonian petroleum systems in Queensland. In: Boult P, Johns D and Lang S (eds) PESA Eastern Australasian Basins Symposium II. Conference proceedings. Petroelum Exploration Society of Australia, 297–318.

Dubsky M and McPhail A (2001) Environmental impact research report (EIR) SA Cooper Basin well Operations statement of environmental objectives (SEO) water pressure and salinity module report. SA Chamber of Mines and Energy.

Fergusson CL and Henderson RA (2013) Chapter 3: Thomson Orogen. In: Jell PA (ed.) Geology of Queensland. Geological Survey of Queensland.

Gatehouse CG, Fanning CM and Flint R (1995) Geochronology of the Big Lake Suite, Warburton Basin in north-eastern South Australia. Geological Survey of South Australia, Quarterly Geological Notes 128, 8–16.

Goldstein B, Menpes S, Hill A, Wickham A, Alexander E, Jarosz M, Pepicelli D, Malavazos M, Staritski K, Taliangis P, Coda J, Hill D and Webb M (2012) Roadmap for unconventional gas projects in South Australia. DMITRE.

Gotch T, Keppel M, Fels K and McKenzie J (2016) Lake Eyre Basin Springs Assessment: ecohydrological conceptual models of springs in the western Lake Eyre Basin. DEWNR Technical report 2016/02. Government of South Australia, through the Department of Environment, Water and Natural Resources, Adelaide.

Gravestock DI and Jensen-Schmidt B (1998) Chapter 5: Structural setting. In: Gravestock DI, Hibburt JE and Drexel JF (eds) The Petroleum Geology of South Australia, Vol 4: Cooper Basin. SA Department of Primary Industries and Resources, Adelaide, Australia, 47–68.

Hall L, Hill A, Troup A, Korsch R, Radke B, Nicoll R, Palu T, Wang L and Stacey A (2015) Cooper Basin architecture and lithofacies: Regional hydrocarbon prospectivity of the Cooper Basin, Part 1. Record 2015/31. Geoscience Australia, Canberra. http://dx.doi.org/10.11636/Record.2015.031

Heath R (1989) Exploration in the Cooper Basin. The APPEA Journal 29(1), 366–378.

Hill AJ and Gravestock DI (1995) Chapter 8 Late Palaeozoic: Cooper Basin. In: Drexel JF and Preiss WV (eds) The Geology of South Australia. Volume 2, The Phanerozoic. South Australian Geological Survey, Adelaide, Australia, 78–87.

Hydrogeologic Pty Ltd (2014) Hydrogeological assessment for multi-well exploration and appraisal production testing from deep coal in PEL 96 Southern Cooper Basin. Prepared for Strike Energy Limited.

Keppel M, Gotch T, Inverarity K and Wohling D (2016) A hydrogeological and ecological characterisation of springs in the vicinity of Lake Blanche, Lake Eyre Basin, South Australia. DEWNR Technical report 2016/03. Government of South Australia, through the Department of Environment, Water and Natural Resources, Adelaide.

Love AJ, Wohling D, Fulton S, Rousseau-Gueutin P and De Ritter S (eds) (2013) Allocating water and maintaining springs in the Great Artesian Basin, Volume II: groundwater recharge, hydrodynamics and hydrochemistry of the Western Great Artesian Basin. National Water Commission, Canberra.

Mathwin R, Duguid A, Sternberg D, Cockayne B, Schmarr and McNeil, D (2015) Lake Eyre Basin Rivers Assessment (LEBRA) 2013/14 monitoring report. A report to the Department of the Environment, Canberra, ACT. Viewed 17 May 2016, http://www.lakeeyrebasin.gov.au/resource/lake-eyre-basin-rivers-assessment-lebra-201314-monitoring-report.

McMahon TA, Murphy R, Little P, Costelloe JF, Peel MC, Chiew FHS, Hays S, Nathan R and Kandel DD (2005) Hydrology of Lake Eyre Basin. Sinclair Knight Merz (SKM) Pty Ltd, Melbourne.

McMahon TA, Murphy RE, Peel MC, Costelloe JF and Chiew FH (2008) Understanding the surface hydrology of the Lake Eyre Basin: part 2-streamflow. Journal of Arid Environments, 72(10), 1869-–1886.

Meixner AJ, Kirkby AL, Lescinsky DT and Horspool N (2012) The Cooper Basin 3D map Version 2: thermal modelling and temperature uncertainty. Geoscience Australia, Canberra.

Menpes S, Hill A and Sansome (2012) Unconventional hydrocarbon plays in the Permian succession, South Australia. In: Mares T (ed.) Eastern Australasian Basins Symposium IV. Petroleum Exploration Society of Australia, Special Publication. Viewed 23 February 2016, http://www.petroleum.statedevelopment.sa.gov.au/__data/assets/pdf_file/0005/212000/EABSIV_Permian_Menpes_Final_1.pdf.

Morton JGG (in review) Weena Trough stratigraphic review study: summary report, Report Book 2016/00002. Department of State Development, South Australia, Adelaide.

Murray CG (1994) Basement cores from the Tasman Fold Belt System beneath the Great Artesian Basin in Queensland. Record no. 1994/10. Geological Survey of Queensland, Brisbane.

Nicoll R, McKellar J, Esterle J, Crowley J, Laurie J, Wood G, Ayaz SA and Bodorkos S (2015) CA-IDTIMS dating of tuffs, calibration of palynostratigrapy and stratigraphy of the Bowen and Galilee basins. Bowen Basin Symposium 2015. Brisbane.

Primary Industries and Resources South Australia (2003) Cooper Basin acreage release – Block 2003-A. MESA Journal 31, 42–46.

Radke B, Ferguson J, Cresswell R, Ransley T and Habermehl M (2000) Hydrochemistry and implied hydrodynamics of the Cadna-owie – Hooray Aquifer, Great Artesian Basin. Bureau of Rural Sciences, Canberra.

Radke BM (2009) Hydrocarbon and geothermal prospectivity of sedimentary basins in Central Australia; Warburton, Cooper, Perdirka, Galilee, Simpson and Eromanga Basins. Record 2009/25. Geoscience Australia, Canberra.

Ransley TR, Radke BM, Feitz AJ, Kellett JR, Owens R, Bell J, Stewart G and Carey H (2015) Hydrogeological atlas of the Great Artesian Basin. Geoscience Australia, Canberra.

Sheard MJ, White MR, Stoian L and Jagodzinski E (2012) Explanatory notes for MARREE 1:250 000 geological map, sheet SH54-5. Report Book 2012/00004. Department for Manufacturing, Innovation, Trade, Resources and Energy, South Australia, Adelaide. Viewed 23 February 2016, https://sarigbasis.pir.sa.gov.au/WebtopEw/ws/samref/sarig1/image/DDD/RB201200004.pdf.

Sheldon F and Fellows CS (2010) Water quality in two Australian dryland rivers: spatial and temporal variability and the role of flow. Marine and Freshwater Research 61, 864–874.

Smerdon BD, Ransley TR, Radke BM and Kellett JR (2012) Water resource assessment for the Great Artesian Basin. A technical report to the Australian Government from the CSIRO Great Artesian Basin Water Resource Assessment. CSIRO Water for a Healthy Country Flagship, Australia.

Smith M, Cassel R and Evans T (2015a) Coal and coal seam gas resource assessment for the Cooper subregion. Product 1.2 for the Cooper subregion from the Lake Eyre Basin Bioregional Assessment. Department of the Environment, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia. Viewed 23 February 2016, http://data.bioregionalassessments.gov.au/product/LEB/COO/1.2.

Smith M, Karim F, Sparrow A, Cassel R and Hall L (2015b) Context statement for the Cooper subregion. Product 1.1 for the Cooper subregion from the Lake Eyre Basin Bioregional Assessment. Department of the Environment, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia. Viewed 23 February 2016, http://data.bioregionalassessments.gov.au/product/LEB/COO/1.1.

Sparrow A, Raisbeck-Brown N and Wang J (2016) Description of the water-dependent asset register for the Cooper subregion. Product 1.3 for the Cooper subregion from the Lake Eyre Basin Bioregional Assessment. Department of the Environment, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia. Viewed 23 February 2016, http://data.bioregionalassessments.gov.au/product/LEB/COO/1.3.

Sternberg D, Cockayne B, Schmarr D, Duguid A, Mathwin R and McNeil D (2014). Lake Eyre Basin Rivers Assessment (LEBRA) 2012/13 Monitoring Report. Department of the Environment, Canberra. Viewed 17 April 2016, http://www.lakeeyrebasin.gov.au/publications/lake-eyre-basin-rivers-assessment-201213-monitoring-report.

Strike Energy Limited (2014a) Klebb-1 PEL 96 – South Australia well completion report. SA Department of State Development Resources and Energy, Adelaide.

Strike Energy Limited (2014b) Le Chiffre-1 PEL 96 – South Australia well completion report. SA Department of State Development Resources and Energy, Adelaide.

Watterson J, Walsh J, Nicol A, Nell PAR and Bretan PG (2000) Geometry and origin of a polygonal fault system. Journal of the Geological Society 157(1), 151–162.

Datasets

Dataset 1 Geoscience Australia (2015) GABATLAS - Hutton Aquifer and Equivalents - Thickness and Extent. Bioregional Assessment Source Dataset. Viewed 10 October 2015, http://data.bioregionalassessments.gov.au/dataset/97def8b6-2c88-41cf-b77a-3433dfdc4470.

Dataset 2 Bioregional Assessment Programme (2015) National Geoscience Mapping Accord (NGMA) Cooper Eromanga Basins Basement z Depth v01. Bioregional Assessment Derived Dataset. Viewed 11 November 2016, http://data.bioregionalassessments.gov.au/dataset/5f0151bc-c786-4f13-8ea8-f31d406b34f2.

Dataset 3 Geoscience Australia (2013) Great Artesian Basin major geological structural elements (GABWRA). Bioregional Assessment Source Dataset. Viewed 11 November 2016, http://data.bioregionalassessments.gov.au/dataset/8dbe0a37-408a-4458-b4cb-fb896b830cc5.

Dataset 4 Bioregional Assessment Programme (2016) Depth to Cenozoic in the Great Artesian Basin. Bioregional Assessment Derived Dataset. Viewed 11 December 2015, http://data.bioregionalassessments.gov.au/dataset/afe14004-adb5-4608-a76b-0e1e1eacf74f.

Dataset 5 Geoscience Australia (2013) Water table elevation of the Great Artesian Basin (GABWRA). Bioregional Assessment Source Dataset. Viewed 26 May 2016, http://data.bioregionalassessments.gov.au/dataset/08f01dba-ec93-4c00-8e29-2b25a1948a33.

Dataset 6 SA Department of State Development (2015) Petroleum Wells. Bioregional Assessment Source Dataset. Viewed 10 October 2015, http://data.bioregionalassessments.gov.au/dataset/54a47829-05db-443c-83e2-5bf0f3b53a99.

Dataset 7 Geoscience Australia (2013) Base Great Artesian Basin hydrogeological units in contact with Basement. Bioregional Assessment Source Dataset. Viewed 26 May 2016, http://data.bioregionalassessments.gov.au/dataset/72ef29b5-221c-4bd2-9eeb-f63992028862.

Dataset 8 Geoscience Australia (2013) Potential hydraulic interconnection at the base of the Great Artesian Basin (GABWRA). Bioregional Assessment Source Dataset. Viewed 26 May 2016, http://data.bioregionalassessments.gov.au/dataset/3ad5cab2-f3a7-4d1c-99d3-b24b94b6dbf8.

Dataset 9 Geoscience Australia (2015) GABATLAS - Rolling Downs Aquitard - Thickness and Extent. Bioregional Assessment Source Dataset. Viewed 10 October 2015, http://data.bioregionalassessments.gov.au/dataset/0c4f0e0e-2d1d-4dee-9a57-36ecdd1d9a1f.

Dataset 10 Bureau of Meteorology (2011) Geofabric Surface Catchments - V2.1. Bioregional Assessment Source Dataset. Viewed 26 May 2016, http://data.bioregionalassessments.gov.au/dataset/ea1b6f6c-e8a3-4c78-a463-044c89857fc0.

Dataset 11 Bioregional Assessment Programme (2015) Weena Trough Cross Section Lines. Bioregional Assessment Derived Dataset. Viewed 11 December 2015, http://data.bioregionalassessments.gov.au/dataset/5e0e162a-f321-4396-8109-75fcf5e60cb6.

Dataset 12 Geoscience Australia (2015) GABATLAS - Evergreen-Poolowanna Aquitard and Equivalents - Thickness and Extent. Bioregional Assessment Source Dataset. Viewed 18 May 2016, http://data.bioregionalassessments.gov.au/dataset/b9c0d451-e7f0-4810-95eb-51fa6d9f552b.

Dataset 13 Geoscience Australia (2016) Cooper Structure Surfaces. Bioregional Assessment Source Dataset. Viewed 26 May 2016, http://data.bioregionalassessments.gov.au/dataset/3046e93b-dd9f-41b1-ad12-d0f9c08c60a3.

2.3.3 Ecosystems

Summary

The Cooper subregion (130,000 km^2) is within the Lake Eyre Basin bioregion. The Cooper preliminary assessment extent (PAE) occurs in south-west Queensland and north-east SA. Key features of the Cooper PAE are its large area, sparse human population density and unpredictable rainfall resulting in natural and human systems driven by resource pulses and boom-bust dynamics. The low human population results in the natural vegetation being relatively intact. A landscape classification was developed to present a conceptualisation of the main biophysical and human systems at the surface of the Cooper PAE and to describe their hydrological connectivity.

The approach taken was developed in close collaboration and with strong guidance from experts that have extensive experience with the landscapes of the PAE both in Queensland and SA, and who have contributed to the development of similar classification systems. The classification and typology were developed and refined following a six-step approach. The classification is based on five elements derived from the Australian National Aquatic Ecosystem (ANAE) Classification Framework: topography, landform, water source, water type and water availability. In addition, each area was identified as either remnant or non-remnant vegetation. This classification produced a typology consisting of 19 landscape classes that were then collapsed into eight broad landscape groups that were either non-water dependent, floodplain/lowland riverine, or non-floodplain (including upland riverine). The 'Dryland' landscape group dominated the area of the PAE (75.36%). Of the water-dependent landscape classes, 13.10% of the area of the PAE consists of floodplain landscape classes and 11.54% consists of non-floodplain landscape classes. The dominant landscape class on floodplains is 'Wetland GDE, remnant vegetation' (8.57% by area of the PAE). In contrast, a terrestrial GDE landscape class, 'Non-floodplain terrestrial GDE, remnant vegetation' (6.18% by area of the PAE) dominated the non-floodplain environment. The dominant stream landscape class is 'Temporary, lowland stream', which consists of 94.59% of the total stream network.

Each landscape group is described and representative areas of the PAE are mapped in this product. Aspects of water dependency within each landscape group are documented.

2.3.3.1 Landscape classification

2.3.3.1.1 Methodology

The Cooper subregion is within the Lake Eyre Basin bioregion. It covers an area of 130,000 km^2 of which two-thirds is in south-west Queensland with the remainder in north-east SA. The majority of the subregion is within the Cooper Creek – Bulloo river basin with a small part in the north-west within the Diamantina–Georgina river basin. Key features of the Cooper subregion are its large area, sparse human population density (only 1032 residents in the 2011 census) and unpredictable rainfall resulting in natural and human systems driven by resource pulses and boom-bust dynamics. The low human population results in the natural vegetation being relatively intact. The dominant land use in the subregion is grazing of sheep and cattle on natural pastures (grazing native vegetation). Other major land uses are nature conservation and mining (represented by an area of mining and intensive gas treatment, storage and distribution at Moomba). There is no pasture modification or intensive production within the Cooper PAE.

For BA purposes, a landscape classification was developed to characterise the nature of water dependency among the assets of the Cooper PAE. Specifically, landscape classification is used to characterise the diverse range of water-dependent assets into a smaller number of classes for further analysis. It is based on key landscape properties related to patterns in geology, geomorphology, hydrology and ecology. The aim of the landscape classification is to systematically define geographical areas into classes based on similarity in physical and/or biological and hydrological character. The landscape classification includes natural and human ecosystems. The objective of the landscape classification is to present a conceptualisation of the main biophysical and human systems at the surface and describe their hydrological connectivity. Hydrological connectivity describes how biophysical factors such as flow regime influence the spatial and temporal patterns of connection between elements of the water cycle. These elements include surface water and/or groundwater systems (Pringle, 2001). For example, surface water connectivity can be longitudinal along the river channel itself, lateral during overbank flows and vertical where surface water is in contact with underlying groundwater (Boulton et al., 2014).

The landscape classification approach in the BAs provides a mechanism by which receptor impact modelling (product 2.7) can be undertaken on a large number of assets. The rationale for this process is that a landscape class represents a water-dependent ecosystem that has a characteristic hydrological regime. As part of the landscape classification process, the landscape classes are classified into landscape groups. Landscape groups are sets of landscape classes that share hydrological properties. Subsequent in the BA process, the landscape groups are amalgamated into larger entities to enable receptor impact modelling (product 2.7) to take place. However, receptor impact modelling is not being undertaken for the Cooper subregion. Therefore, this landscape classification should be used to assist in clarifying aspects of the conceptual modelling of causal pathways for the Cooper subregion (Section 2.3.5). In particular, it provides clarity on the relative amount of the Cooper PAE that is water dependent and, therefore, likely to be impacted by the coal resource development pathway.

Multiple classification methodologies have been developed to provide consistent and functionally relevant representations of water-dependent ecosystems in Australia and globally. An example is the Australian National Aquatic Ecosystem (ANAE) Classification Framework. The approach outlined in this product has built on and integrated these existing classification systems.

Classification and typology of landscape elements (polygons)

The approach was developed in collaboration with and guidance from experts that have extensive experience with the landscapes of the Cooper PAE both in Queensland and SA. These experts have contributed to the development of similar classification systems such as the ANAE (Aquatic Ecosystems Task Group, 2012a). The classification and typology were developed and refined following a six-step approach that was undertaken for the entire Lake Eyre Basin bioregion and first used for the Galilee subregion. This approach has been applied to the Cooper PAE and is summarised in Table 3.

Table 3 A summary of the six steps undertaken to develop and refine a classification for the Lake Eyre Basin bioregion and then a typology of landscape classes in the Cooper PAE

Step number	Description	Comment
1	Review existing classifications (refer to Section 2.3.3.1.2).	
2	Develop 5-element ANAE-based classification following expert input (3 workshops, Adelaide and Brisbane).	A typology of 180 potential landscape classes was developed.
3	Apply classification to Cooper datasets followed by initial lumping of some elements (e.g. 'Landform' was reduced from five categories to two, specifically; wetland (including estuarine, riverine, lacustrine, palustrine) and non-wetland).	A typology with 27 landscape classes was developed.
4	Apply 'Broad Habitat' element to each of the landscape classes where applicable. Thus each existing class can be 'remnant' or 'non-remnant'.	Typology modified to include 50 potential landscape classes.
5	Expert feedback sought on the modified typology.	Typology undergoes minor refinement.
6	Further reduce typology by lumping of categories within some elements. Specifically, near-permanent and intermittent lumped for 'Water Availability'. 'Water Type' only considered for disconnected wetlands.	Final typology established.

The classification is based on five elements derived from the ANAE. The first division is based on topography and is at level 2 (landscape scale) of the ANAE structure. The Cooper PAE is divided into floodplain and non-floodplain areas. This division allows broad classification of which landscape components might be influenced by flooding regimes that are more likely to support water-dependent biota.

The next division is based on landform and is at ANAE level 3 (system). Polygons were divided into wetland and non-wetland. Wetlands were classified as either lacustrine, palustrine or riverine based on the wetland class field in the Queensland wetland mapping (DSITIA, Dataset 3) and South Australian wetlands groundwater-dependent ecosystem (GDE) classification (DEWNR, Dataset 4).

The remainder of the classification was based on habitat variables also at level 3 of the ANAE structure. These variables were water type, water availability and groundwater source, specifically:

- water type (brackish/saline, fresh)
- water availability (permanent, near-permanent (wet greater than 80% of time), intermittent or ephemeral)
- water source (groundwater dependent or non-groundwater dependent).

Water availability and water type were inferred from Queensland and SA wetland and GDE mapping datasets (DSITIA, Dataset 2; DSITIA, Dataset 3; DEWNR, Dataset 4). Water type was determined from wetland mapping for wetlands and from GDE mapping for non-wetlands.

In addition to the five elements of the classification derived from the ANAE, an additional variable was used that identified a polygon as either remnant or non-remnant vegetation. This distinction is based on the Queensland remnant regional ecosystem (RE) mapping from 2013 (Queensland Herbarium, Dataset 1). This approach distinguishes relatively intact from 'human-modified' landscapes. This distinction has consequences for defining where important habitats and biota may occur when considering assets and their likely distribution.

During development of the landscape classification for the Lake Eyre Basin bioregion a number of differences in structure between the current 'fit-for-purpose' classification and that of the Lake Eyre Basin River Monitoring Project (LEBRM) (Miles and Miles, 2014) were identified. A summary of additional elements from the LEBRM Classification Framework that were considered during the classification process is provided in Table 4. It should be noted that although the additional information was often deemed to be useful, in several cases the data were not available. Furthermore, although the LEBRM is also based on the ANAE, several additional elements come from the South Australian Aquatic Ecosystems (SAAE) Classification Framework (Fee and Scholz, 2010)

Table 4 A summary of additional elements that were considered when developing the landscape classification for the Lake Eyre Basin bioregion

Classification element description	Components of LEBRM Classification Framework identified as important by South Australian experts
Topography: floodplain, non-floodplain	
Landform: lacustrine, palustrine, riverine, non-wetland	LEBRM includes habitat attributes 'size' and 'landform transport zone'.
Water source: groundwater, non-groundwater	LEBRM includes combined categories and then determines whether surface water or groundwater is dominant (i.e. classes include 'combined: surface water dominant', 'combined: groundwater dominant' and 'combined: unknown'). LEBRM includes 'water source'.
Water type: brackish/saline, fresh	LEBRM has four salinity classes: 'fresh' (<1,000 mg/L), 'brackish' (1,000–3,000 mg/L), 'saline' (3,000–10,000 mg/L) and 'hypersaline' (>10,000 mg/L). This approach attempts to link ecological response and thresholds. Desirable in South Australia because of elevated salinities.
Water availability: intermittent/ephemeral/uncertain, near permanent (wet >80% of time)	LEBRM divides 'water regime' into two sub-attributes/elements, specifically: • inflow frequency (permanent, seasonal, ephemeral, highly ephemeral) • persistence (permanent, mid-term (i.e. ≥1 year) but not permanent, annual (i.e. ≤1 year)).

A spatially complete layer of all classed polygons was produced by using geographic information system (GIS) software to run a spatial union on the input layers that included the remnant and non-remnant features. Landscape classes were defined using the five elements from the ANAE structure with their nomenclature reflecting key water dependency attributes (Table 5). As an example, an area classified as 'remnant', 'non-floodplain', 'wetland', 'disconnected, 'saline' has the landscape class: 'Non-floodplain disconnected saline wetland, remnant vegetation'. In other words, this area is not on a floodplain and is surface water dependent (not connected to groundwater) and associated with a saline wetland.

Classification and typology of the stream network

Streams in the PAE were classified based on their catchment position, water regime and association with GDEs. Catchment position (i.e. upland *versus* lowland) is of limited use in the Cooper PAE compared to other subregions with a stronger elevational gradient. In the Cooper PAE there is a general increase in salinity, aridity and flow duration from upper to lower sections of the catchment. Rivers and streams can also receive significant baseflow inputs from local and regional groundwater systems and act as recharge sources to support GDEs. Water regime is critical in determining suitable habitat for biota and physical features of the channel and riparian zone.

The stream network had not previously been classified in the Cooper PAE, which meant that the Assessment team completed this part of the landscape classification. The stream network data were based on the Geofabric v2 cartographic mapping of river channels derived from 1:250,000 topographic maps (Bureau of Meteorology, Dataset 5). The Geofabric is a purpose-built GIS that maps Australian rivers and streams and identifies how stream features are hydrologically connected. The water regime of these stream networks was also defined (near-permanent or temporary) using the Queensland pre-clearing and remnant ecosystems mapping data (Queensland Herbarium, Dataset 1). Mapping of valley bottom flatness (MrVBF) (CSIRO, Dataset 6) was used to classify streams as either upland or lowland following methods outlined in Brooks et al. (2014).

2.3.3.1.2 Landscape classification

Typology of landscape classes

The Assessment team defined a set of landscape classes that represent the main biophysical and human systems in the Cooper subregion. This typology consists of 19 landscape classes that can be reduced into 8 landscape groups (Table 5 and Table 6). The distribution of landscape classes in the Cooper subregion is shown in Figure 19.

The typology includes aspects of existing wetland models such as those developed for Queensland that form part of the Queensland Government's Wetland*Info* website (DERM, 2015). Similar wetland models are available for wetlands in other areas of the Lake Eyre Basin bioregion. These include models intended to cover the entire Lake Eyre Basin (Imgraben and McNeil, 2015), NSW including arid regions (Claus et al., 2011) and the semi-arid (northern) section of the Murray-Darling Basin (Price and Gawne, 2009). Each of these suites of models was consulted in the development of the landscape classification for the Lake Eyre Basin bioregion (Table 3, step 1). However, each has strengths and weaknesses and none covers the entire geographical area or environmental heterogeneity needed. Therefore, no existing approach was considered suitable to adopt in its entirety for the BA for the Cooper subregion. The concordance of the Lake Eyre Basin typology with that from Queensland Government's Wetland*Info*, as an example, is summarised in Table 7.

The typology of landscape classes included two landscape classes that are non-water dependent: 'Dryland' and 'Dryland, remnant vegetation'. Together, these landscape classes occupy 75.36% of the Cooper PAE (Table 5). Of the water-dependent landscape classes, the area covered by floodplain and non-floodplain landscape classes is 13.10% and 11.54%, respectively.

Naming conventions for landscape classes

The naming conventions for polygon landscape classes are detailed below.

1. *Floodplain/non-floodplain*. Out of the ten landscape classes that are non-floodplain, all but two non-floodplain landscape classes have 'non-floodplain' as the first word of the landscape class name. The exceptions are the two landscape classes (which are non-floodplain, non-wetlands) in the 'Dryland' landscape group. 'Floodplain' is used in the name only for the landscape classes that are 'disconnected' (surface water dependent, not connected to groundwater).
2. *Wetland/non-wetland*. The next word in the name of each landscape class indicates if it is a wetland or not. If it is a wetland, it will either be a groundwater-dependent ecosystem ('wetland GDE') or surface water-dependent ecosystem ('disconnected wetland'). If the landscape class is not a wetland, the term 'non-wetland' or 'terrestrial' will appear.
3. *Salinity*. Saline disconnected wetlands are indicated as 'disconnected saline wetland'. Salinity is indicated only for disconnected wetlands.
4. *Remnant/non-remnant*. The broad habitat separation of 'remnant' or 'non-remnant' is indicated last in the landscape class name. Only the term 'remnant vegetation' is included in the name of the landscape class. If this does not appear, then the landscape class is 'non-remnant vegetation'.

The stream network is defined from a smaller set of criteria. The naming conventions for streams follow this order: 'temporary' or 'near-permanent', then 'lowland' or 'upland'.

Table 5 Typology of landscape classes in the Cooper PAE based on polygons with land area and percentage of PAE

Landscape group	Landscape class number	Landscape class	Total land area (km^2)	Percentage of PAE (%)
Dryland	1	Dryland	435.53	0.62%
	2	Dryland, remnant vegetation	52,640.78	74.74%
	Total		**53,076.31**	**75.36%**
Floodplain, non-wetland	3	Floodplain disconnected non-wetland, remnant vegetation	486.59	0.69%
	Total		**486.59**	**0.69%**
Floodplain or lowland riverine wetland GDE	4	Wetland GDE	172.57	0.25%
	5	Wetland GDE, remnant vegetation	6,037.50	8.57%
	Total		**6,210.07**	**8.82%**
Floodplain or lowland riverine disconnected wetland	6	Floodplain disconnected wetland, remnant vegetation	9.53	0.01%
	Total		**9.53**	**0.01%**
Floodplain, terrestrial GDE	7	Terrestrial GDE	3.14	0.00%
	8	Terrestrial GDE, remnant vegetation	2,513.79	3.57%
	Total		**2,516.93**	**3.58%**
Non-floodplain (including upland riverine) wetland GDE	9	Non-floodplain wetland GDE	1,171.91	1.66%
	10	Non-floodplain wetland GDE, remnant vegetation	2,352.85	3.34%
	Total		**3,524.76**	**5.00%**
Non-floodplain (including upland riverine), disconnected wetland	11	Non-floodplain disconnected wetland	2.99	0.00%
	12	Non-floodplain disconnected wetland, remnant vegetation	124.85	0.18%
	13	Non-floodplain disconnected saline wetland	2.60	0.00%
	14	Non-floodplain disconnected saline wetland, remnant vegetation	55.67	0.08%
	Total		**186.11**	**0.26%**
Non-floodplain, terrestrial GDE	15	Non-floodplain terrestrial GDE	73.89	0.10%
	16	Non-floodplain terrestrial GDE, remnant vegetation	4,351.81	6.18%
	Total		**4,425.70**	**6.28%**
Grand total			**70,436.00**	**100%**

Data: CSIRO (Dataset 7)

Table 6 Typology of stream network classes in the Cooper PAE with total length and percentage of total stream network in the PAE

Landscape group	Landscape class number	Landscape class	Total length (km)	Percentage of total stream network (%)
Floodplain or lowland riverine disconnected wetland	17	Near-permanent, lowland stream	17.09	0.06%
Floodplain or lowland riverine disconnected wetland	18	Temporary, lowland stream	24,874.12	94.59%
Non-floodplain (including upland riverine) disconnected wetland	19	Temporary, upland stream	1404.77	5.34%
Total			**26,295.98**	**100%**

Data: CSIRO (Dataset 7)

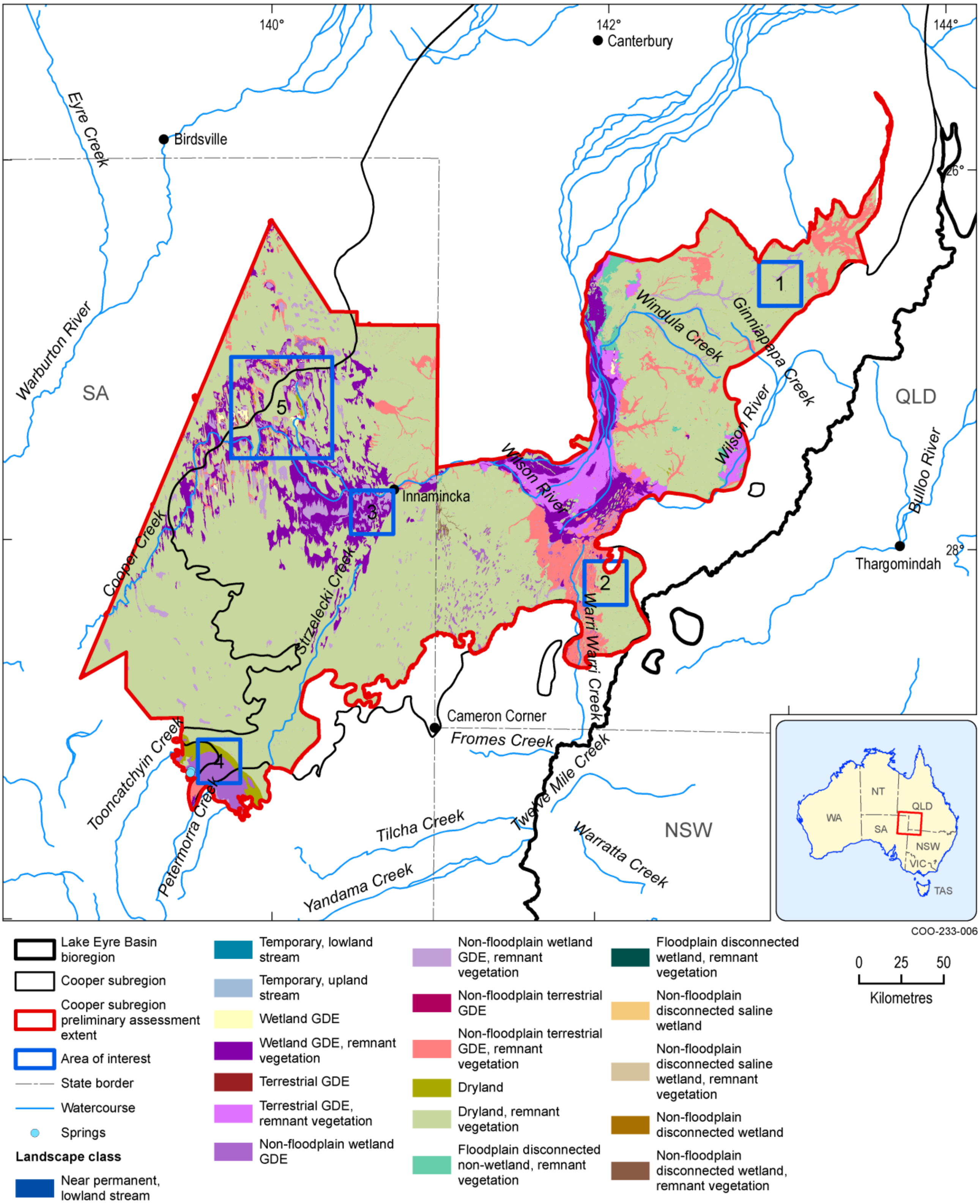

Figure 19 Landscape classes of the Cooper PAE

Data: CSIRO (Dataset 7)

Boxes indicate areas of interest that are covered by Figure 20, Figure 21, Figure 22, Figure 23 and Figure 24.

GDE = groundwater-dependent ecosystem

Table 7 Comparison of the landscape classes and landscape groups from the Cooper PAE classification and typology with the Queensland Wetland*Info* models

GDE = groundwater-dependent ecosystem; GAB = Great Artesian Basin

Landscape group	Landscape class	Queensland Wetland*Info* models	Comments
Dryland	Dryland	Not applicable	
Floodplain, non-wetland	Floodplain disconnected non-wetland	Not applicable	
Floodplain or lowland riverine wetland GDE	Wetland GDE	GDEs: alluvia – lower catchment GDEs: alluvia – closed drainage systems GDEs: sedimentary rocks (GAB)	
Floodplain or lowland riverine disconnected wetland	Floodplain disconnected wetland	Arid and semi-arid floodplain lake Arid and semi-arid tree swamp Arid and semi-arid lignum swamp Arid and semi-arid grass, sedge, herb swamp	Models do not separate disconnected wetlands from GDEs. Swamp models do not separate floodplain from non-floodplain.
Floodplain, terrestrial GDE	Terrestrial GDE	GDEs: alluvia – lower catchment GDEs: alluvia – closed drainage systems	
Non-floodplain (including upland riverine) wetland GDE	Non-floodplain wetland GDE	GDEs: alluvia – upper/mid catchment GDEs: wind-blown inland sand dunefields GDEs: sedimentary rocks (GAB)	
Non-floodplain (including upland riverine) disconnected wetland	Non-floodplain disconnected wetland	Arid and semi-arid non-floodplain lake Arid and semi-arid tree swamp Arid and semi-arid lignum swamp Arid and semi-arid grass, sedge, herb swamp	Models do not separate disconnected wetlands from GDEs. Swamp models do not separate floodplain from non-floodplain.
	Non-floodplain disconnected saline wetland	Arid and semi-arid saline lake Arid and semi-arid saline swamp	
Non-floodplain, terrestrial GDE	Non-floodplain terrestrial GDE	GDEs: alluvia – upper/mid catchment GDEs: wind-blown inland sand dunefields	

2.3.3.1.3 Description of landscape classes

This section provides a description of the landscape groups in the classification. Eight landscape groups are recognised.

Floodplains

A floodplain can be defined broadly as that area of a landscape that occurs between a river system and the enclosing valley walls and is exposed to inundation or flooding during periods of high discharge (Rogers, 2011). For the Lake Eyre Basin, floodplains are considered to be alluvial plains that have an average recurrence interval of 50 years or less for channelled or overbank streamflow (Aquatic Ecosystems Task Group, 2012b). Floodplain and lowland riverine areas derived from Quaternary alluvial deposits are widely distributed across the Cooper PAE. The river systems within the Cooper subregion feature extensive floodplains. For example, in some areas the breadth of the floodplain of the Cooper Creek exceeds 60 km.

'Floodplain, non-wetland' landscape group

Some areas of floodplain within the Cooper PAE are classed as disconnected, non-wetland. The 'Floodplain, non-wetland' landscape group supports terrestrial vegetation that is not groundwater dependent and relies on rainfall and local runoff. Within the PAE the landscape class 'Floodplain, disconnected non-wetland, remnant vegetation' is prominent in the north-east, bordering the eastern margin of Cooper Creek floodplain, and in the east bordering the Wilson River (Figure 19).

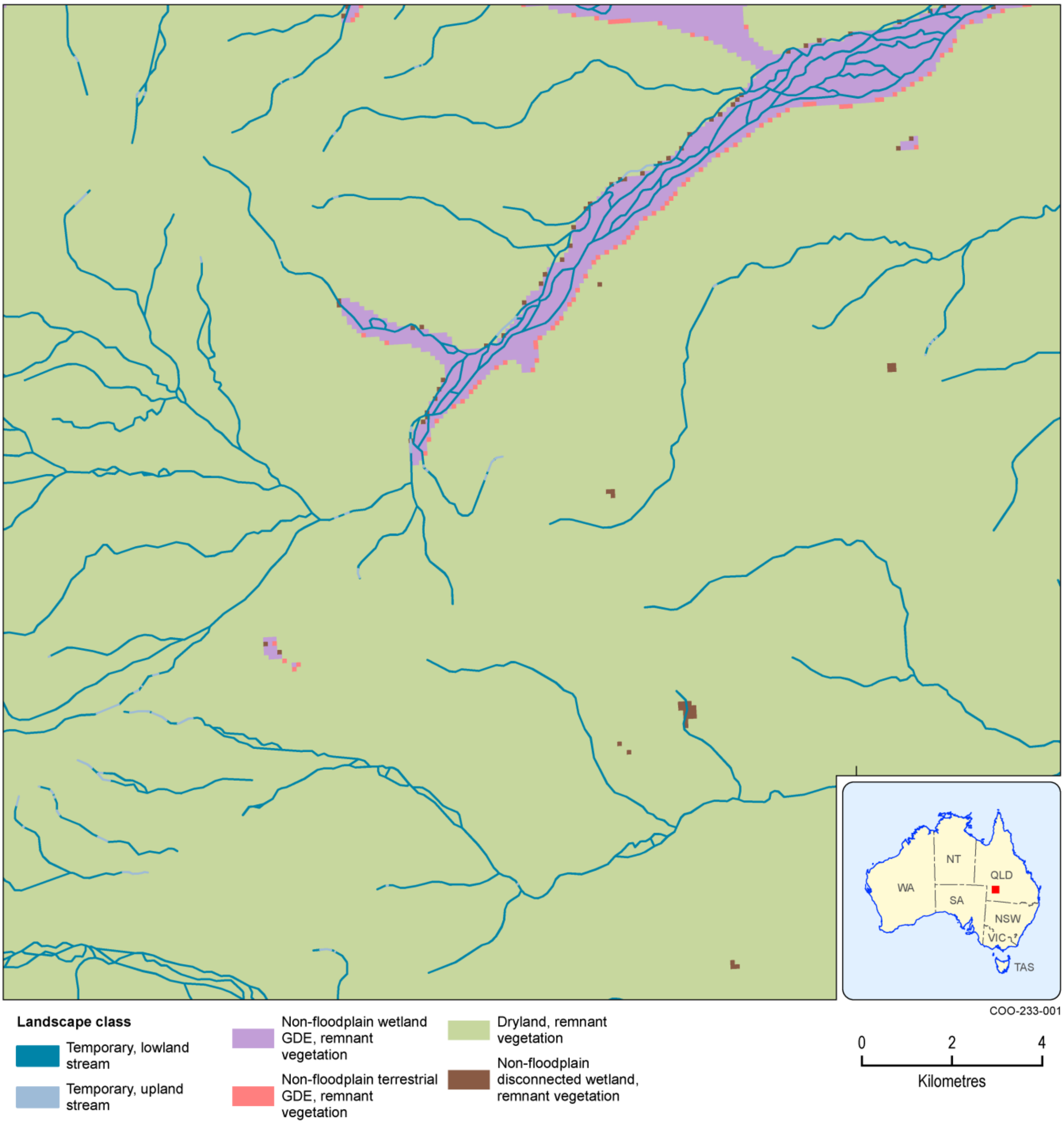

Figure 20 Landscape classes in the extreme north-east portion of the Cooper PAE, south-west Queensland

Data: CSIRO (Dataset 7)
The location of this map is identified by box #1 in Figure 19.
GDE = groundwater-dependent ecosystem

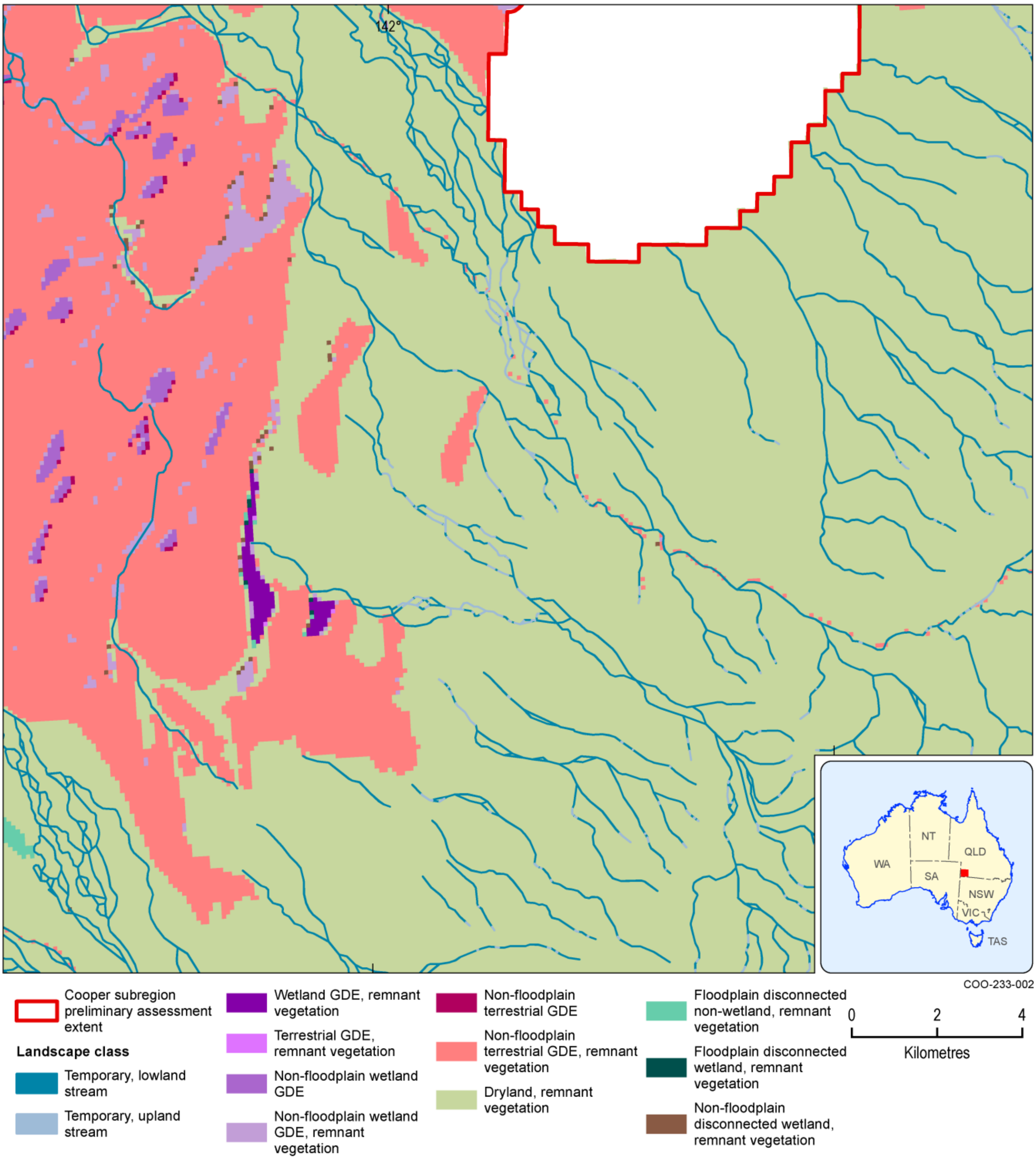

Figure 21 Landscape classes in an area between Warri Warri Creek and the Grey Range, south-west Queensland

Data: CSIRO (Dataset 7)
The location of this map is identified by box #2 in Figure 19.
GDE = groundwater-dependent ecosystem

'Floodplain or lowland riverine wetland GDE' landscape group

Wetland GDEs occupy 8.82% of the PAE (Table 5). This landscape group includes palustrine and lacustrine wetlands that are groundwater dependent. Extensive areas of the Cooper Creek floodplain in south-west Queensland and west of Innamincka, SA, are in the 'Wetland GDE, remnant vegetation' landscape class (Figure 19).

Discharge spring wetlands are a well-known type of wetland that depend on groundwater and are of high importance in terms of biodiversity values. Two discharge springs occur within the Cooper PAE, at Lake Blanche in the extreme south-west. The springs form part of the Lake Frome spring supergroup. This spring supergroup is part of a threatened ecological community that is listed in the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), 'The community of native species dependent on natural discharge of groundwater from the Great Artesian Basin'. The community occurs in parts of NSW, Queensland and SA (Fensham et al., 2010). It is listed as endangered.

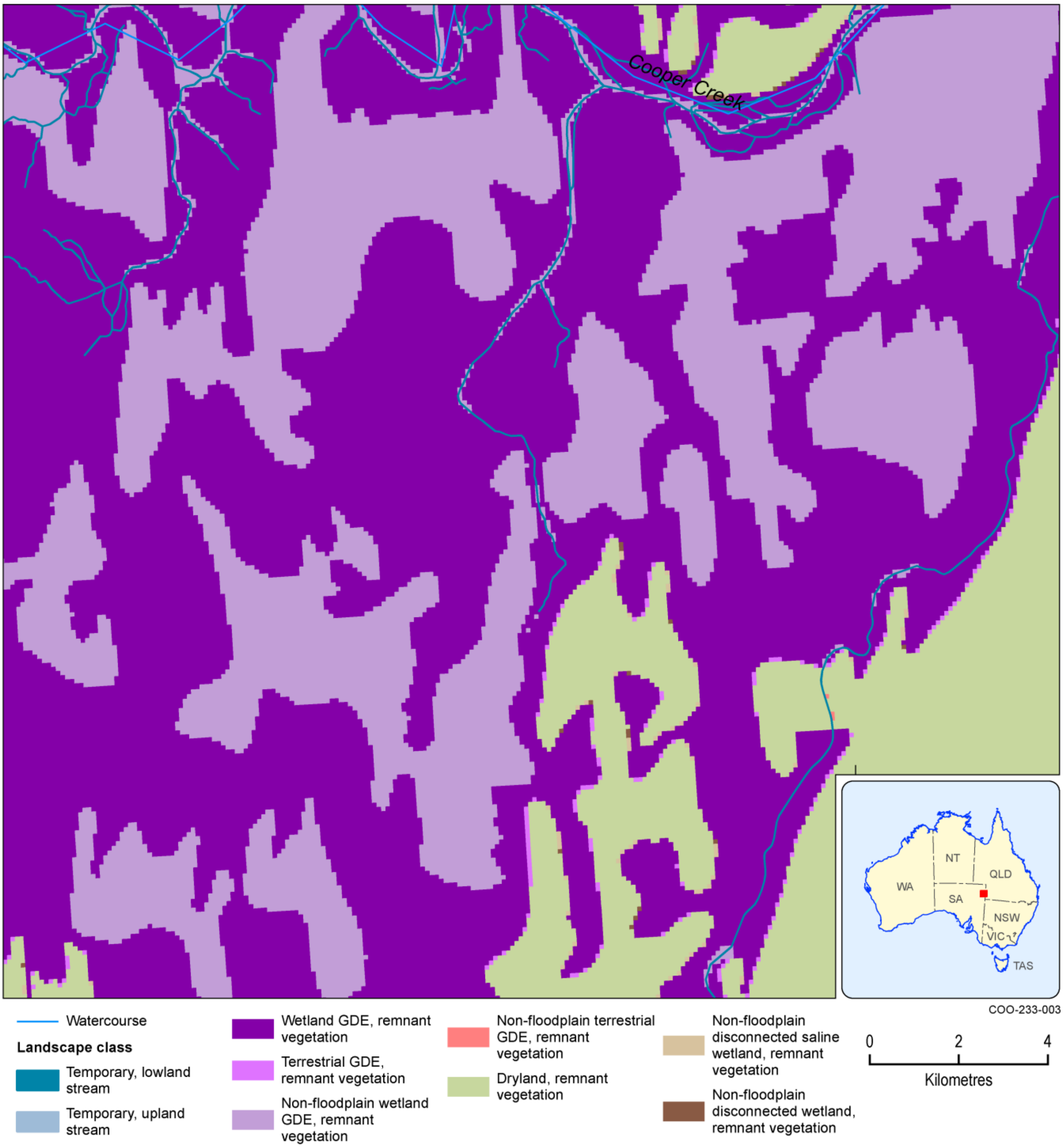

Figure 22 Landscape classes in the vicinity of Cooper Creek, north-east South Australia

Data: CSIRO (Dataset 7)
The location of this map is identified by box #3 in Figure 19.

'Floodplain, terrestrial GDE' landscape group

The 'Floodplain, terrestrial GDE' landscape group contains landscape classes that have a subsurface reliance on groundwater sources. Floodplain, terrestrial GDEs occupy 3.58% of the Cooper PAE (Figure 19 and Table 5). The landscape matrix between the Grey Range and Warri Warri Creek in south-west Queensland has several areas of landscape in the 'Terrestrial GDE, remnant vegetation' landscape class (Figure 21).

Terrestrial GDEs typically consist of terrestrial vegetation of various types (open-forest, woodland, shrubland, grassland) that require access to groundwater on a permanent or intermittent basis to meet all or some of their water requirements. These landscapes are dependent on the subsurface presence of groundwater, which is accessed via their roots at depth. Examples of terrestrial GDEs in the PAE include riparian vegetation such as river red gum (*Eucalyptus camaldulensis*) open forest and coolibah (*Eucalyptus coolabah*) woodland.

'Floodplain or lowland riverine disconnected wetland' landscape group

The 'Floodplain or lowland riverine disconnected wetland' landscape group includes all floodplain landscape classes that depend predominantly on surface water such as flood flows from rainfall events, direct precipitation and local runoff. These wetlands are usually separated from the underlying groundwater system by an unsaturated zone; if groundwater seepage does occur it is not the main source of water.

Three landscape classes in this group occur in the Cooper PAE: 'Floodplain disconnected wetland, remnant vegetation', 'Near-permanent, lowland stream' and 'Temporary, lowland stream'. The landscape group makes up less than 1% of the PAE based on the area of polygons. In contrast, the 'Temporary, lowland stream' landscape class makes up 94.59% of the stream network and is visible in all the landscapes mapped in this product (Figure 19 to Figure 24).

Remnant vegetation associated with disconnected wetlands includes woodland of river red gum, coolibah or river cooba (*Acacia stenophylla*), and shrubland of lignum (*Muehlenbeckia florulenta*) and northern bluebush (*Chenopodium auricomum*).

Waterholes within river channels are included in this landscape group. Waterholes are of considerable importance in that they continue to hold water once flow in river channels ceases. Thus waterholes act as refuges for aquatic biota when natural fragmentation occurs during dry periods and play a key role in sustaining assemblage dynamics and ensuring persistence of populations (Arthington et al., 2010; Arthington and Balcombe, 2011; Kerezy et al., 2011). Populations in waterholes disperse widely once flooding occurs leading to cycles of expansion and contraction of aquatic biota such as fish (e.g. Kerezy et al., 2013).

Waterholes may or may not interact with groundwater depending on the level of substrate permeability and depth to groundwater. The majority of waterholes in Cooper Creek are not groundwater dependent (Fensham et al., 2011). Although surface water-dependent waterholes lose water through evaporation, suspended clays that settle out after flow events form a bottom seal that minimises seepage loss.

Non-floodplains

Drylands, as well as areas that are not on the floodplain and are not wetlands, are the major landscape groups in the Cooper PAE. A further three landscape groups are water dependent but do not occur on floodplains (Table 5): 'Non-floodplain (including upland riverine) wetland GDE', 'Non-floodplain (including upland riverine) disconnected wetland' and 'Non-floodplain, terrestrial GDE'. Most landscape classes within these landscape groups consist of GDEs.

'Dryland' landscape group

Drylands receive water from rainfall and local runoff. The majority of the Cooper PAE is arid or semi-arid, with a mean annual rainfall of less than 300 mm (see Figure 10 in Smith et al., 2015). Only a limited area along the eastern margin of the PAE receives greater than 300 mm of rainfall on average annually. Rainfall within the PAE and throughout arid and semi-arid northern and central Australia is highly unpredictable (van Etten, 2009) and occurs in discrete pulses. As a consequence, land systems such as drylands experience irruptive pulses in primary productivity and support a biota that undergoes boom-bust population dynamics. Boom-bust population dynamics are also a strong feature of wetland systems in the Cooper PAE (Arthington et al., 2010; Arthington and Balcombe, 2011).

Most of the Cooper PAE is dryland that supports remnant vegetation. Specifically, the 'Dryland, remnant vegetation' landscape class comprises 74.74% of the PAE (Figure 19). The predominance of this landscape class is apparent in the landscape classes in the extreme north-east of the PAE (Figure 20), where most of the area is in the 'Dryland, remnant vegetation' landscape class.

A wide range of vegetation types occur within the 'Dryland' landscape class. The major vegetation assemblage is chenopod shrubland – specifically saltbush and/or bluebush shrubland, which occupies 22.3% of the subregion by area. Other major vegetation types include Mitchell grass (*Astrebla*) tussock grassland, spinifex (*Triodia*) hummock grassland, and Mulga (*Acacia aneura*) open woodland and sparse shrubland.

'Non-floodplain (including upland riverine) wetland GDE' landscape group

Non-floodplain wetland GDEs occupy 5.0% of the Cooper PAE but are patchily distributed (Figure 19). An area that is dominated by this landscape group is Lake Blanche, a salt lake located on the south-west boundary of the Cooper PAE (Figure 19). The main landscape class is 'Non-floodplain wetland GDE' with small areas of 'Non-floodplain wetland GDE, remnant vegetation'. The northern shore of Lake Blanche is fringed by 'Dryland' then 'Dryland, remnant vegetation' landscape classes (Figure 23).

In the central parts of the Cooper PAE, sand dunefields (sand ridges) are an important source of groundwater, which supports non-floodplain wetland GDEs. These dunefields can store groundwater in local, intermediate or regional groundwater flow systems and also in perched aquifers formed by layers of relatively impermeable clay-dominated material. Palustrine, lacustrine and riverine wetlands on the edge of inland sand dunefields may be present because of the surface expression of this groundwater.

'Non-floodplain, terrestrial GDE' landscape group

The details of the 'Non-floodplain, terrestrial GDE' landscape group are similar to the 'Floodplain, terrestrial GDE' landscape group although the former landscape group occupies more of the PAE (6.28%). The 'Non-floodplain, terrestrial GDE' landscape group is particularly concentrated in the central and the extreme east of the PAE (Figure 19).

Terrestrial GDEs are typically terrestrial vegetation of various types (open-forest, woodland, shrubland, grassland) that require access to groundwater on a permanent or intermittent basis to meet all or some of their water requirements. In the case of non-floodplain environments, terrestrial GDEs tend to be on loamy or sandy plains or inland sand dunefields (sand ridges), which are composed largely of unconsolidated sand deposited by aeolian processes (wind). Landscape classes in the 'Non-floodplain, terrestrial GDE' landscape group are dependent on the subsurface presence of groundwater, which is accessed via their roots at depth. For inland sand dunefields, groundwater is available from unconsolidated sedimentary aquifers from which terrestrial vegetation typically accesses water through the capillary zone above the watertable.

A landscape that has significant areas that are in the 'Non-floodplain, terrestrial GDE' landscape group is shown in Figure 21. Here, streams that are in both 'Temporary, lowland streams' and 'Temporary, upland streams' landscape classes flow from the Grey Range towards Warri Warri Creek. Extensive areas of 'Non-floodplain terrestrial GDE, remnant vegetation' occur in the west of the area (Figure 21). Similarly, the landscape in the vicinity of Cooper Creek and Coongie Lakes, SA, has patches of 'Non-floodplain terrestrial GDE' and 'Non-floodplain terrestrial GDE, remnant vegetation' along drainage lines (Figure 24).

'Non-floodplain (including upland riverine), disconnected wetland' landscape group

Landscape groups that contain 'non-floodplain disconnected wetland' include all non-floodplain landscape classes that depend on surface water such as flood flows from rainfall events. Landforms included are lacustrine, palustrine and riverine. Also included are riverine elements such as waterholes. The landscape groups include saline/brackish and freshwater wetlands with water availability being usually non-permanent or near-permanent. Non-floodplain disconnected wetlands make up a small area (0.26%) of the PAE based on polygons (Table 5) and 5.43% of the total stream network. A landscape that includes small patches of 'non-floodplain disconnected wetland, remnant vegetation' and 'non-floodplain disconnected saline wetland, remnant vegetation' is shown in Figure 22. Here the disconnected wetlands occur at the boundary of floodplain wetland GDEs and dryland, south-west of Innamincka.

Rockholes are a type of wetland only present in landscape groups that contain non-floodplain, disconnected wetlands. Rockholes are natural hollows in rocky landscapes that form by fracturing and weathering of rock and which store water from local runoff (Fensham et al., 2011). Typically, rockholes occur in sandstone and granite ranges. As with other wetlands in these landscape groups, most rockholes are non-permanent.

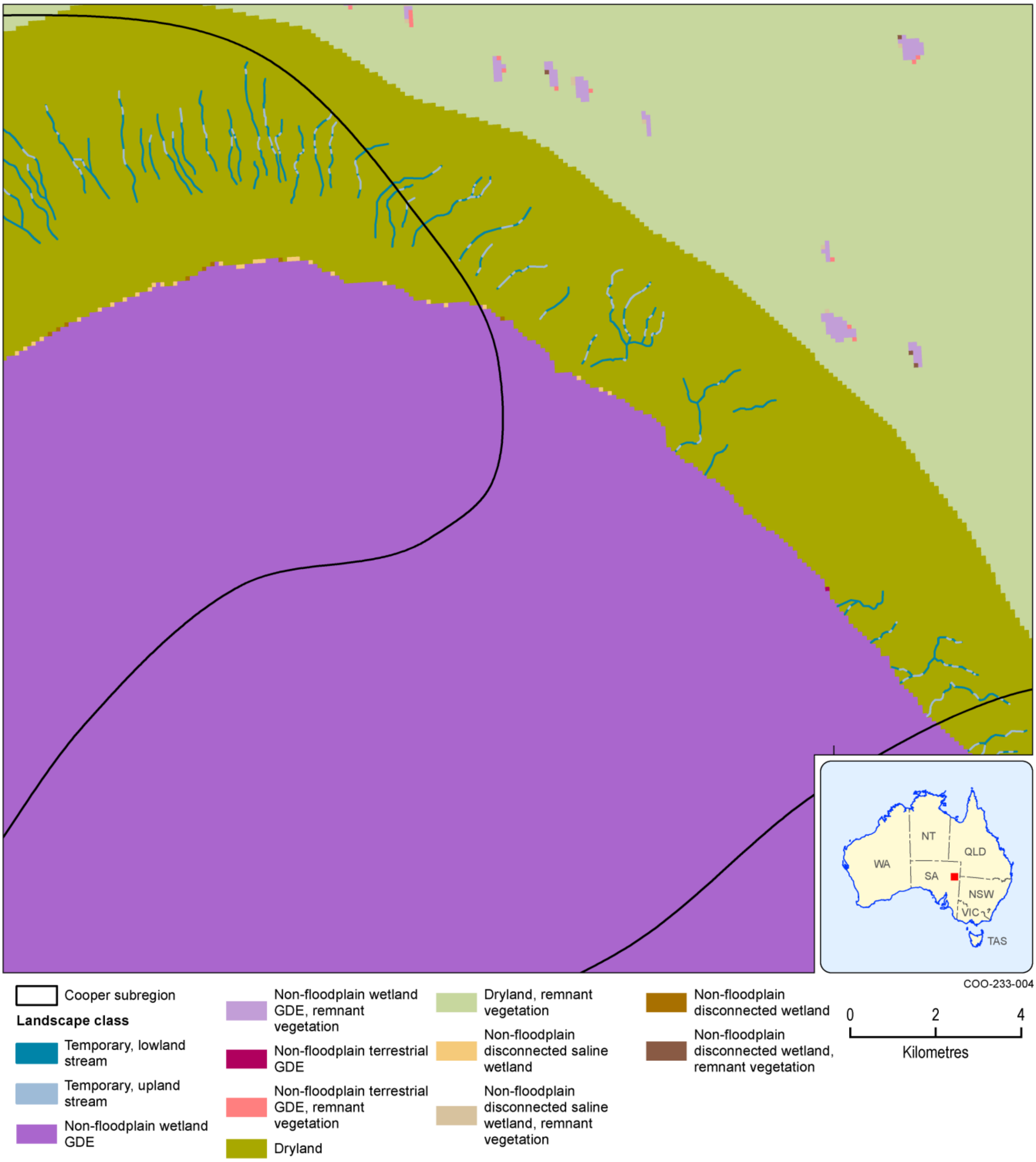

Figure 23 Landscape classes along the north portion of Lake Blanche, north-east South Australia

Data: CSIRO (Dataset 7)

The location of this map is identified by box #4 in Figure 19.

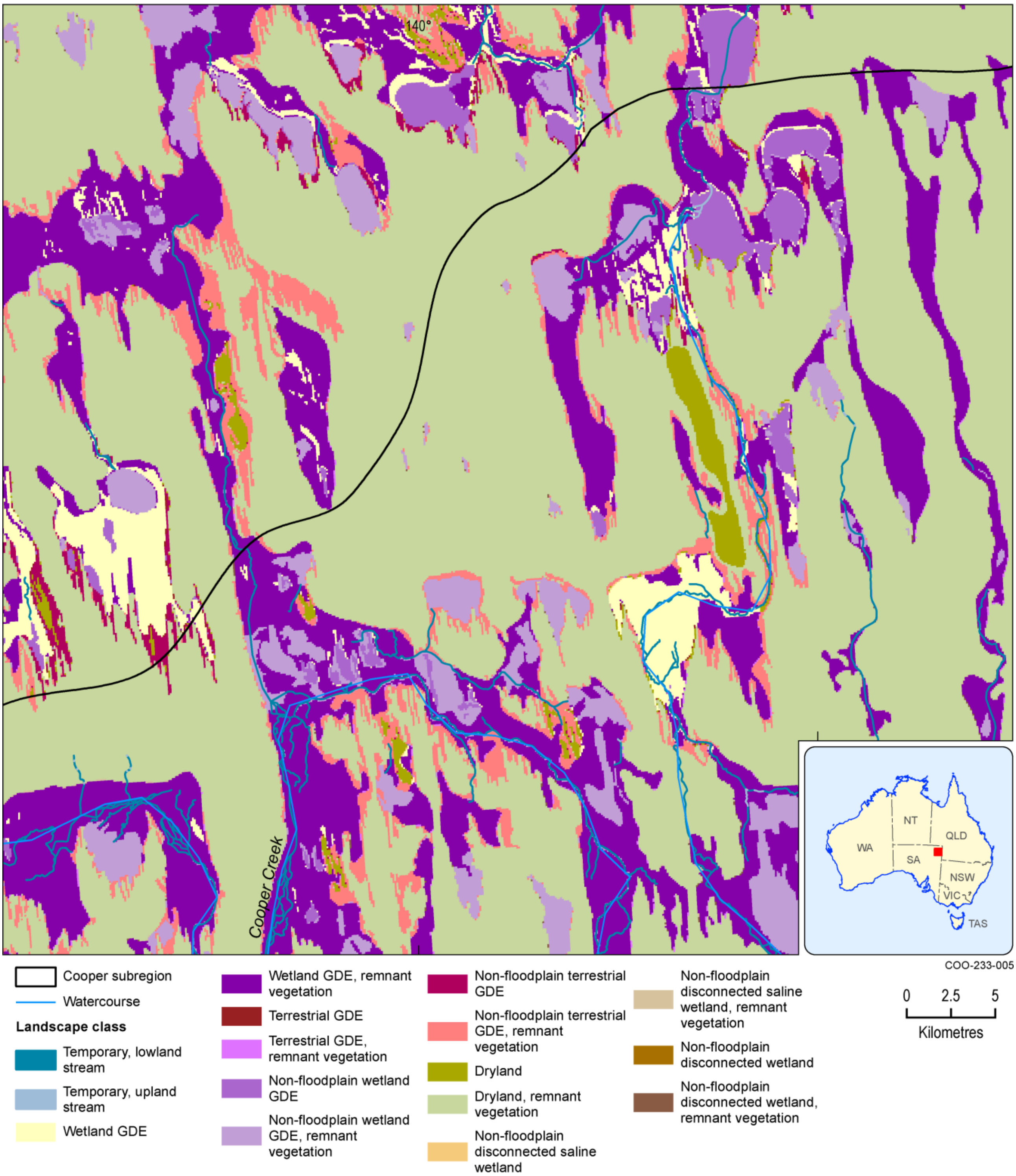

Figure 24 Landscape classes in the vicinity of Cooper Creek and Coongie Lakes, north-east, South Australia

Data: CSIRO (Dataset 7)
The location of this map is identified by box #5 in Figure 19.

Modified landscapes

As mentioned previously, very little of the Cooper PAE includes human-modified landscapes. The PAE does not include any dryland cropping or horticulture, irrigated cropping or horticulture, grazing of modified pastures or intensive horticulture or animal production. The main impact on water-dependent ecosystems from human activity is the placement of bores to provide water at the surface for livestock. Bores rely on groundwater and in the past have had a significant negative impact on springs adjacent to the PAE (Fensham and Fairfax, 2003; Fensham et al., 2011). Urban settlement is very limited in extent and the towns that do exist have small populations.

2.3.3.2 Gaps

Wetlands in large areas of the Cooper PAE are not adequately mapped. There is uncertainty about mapping in much of the PAE; the data have often not been validated by ground truthing to verify the accuracy of desktop-based assessments. The separation between groundwater-dependent and surface water-dependent wetlands may not always be accurate. There is also a likelihood of differences in understanding of GDEs across state borders. In many areas there is little knowledge of surface water – groundwater interactions.

Subsurface groundwater-dependent ecosystems (SGDEs) have not been adequately surveyed within the PAE and are not adequately represented in the landscape classification process. This is known to be a widespread issue (e.g. Tomlinson and Boulton, 2010). Specific landscape features are often not adequately mapped. An example of a gap in knowledge is the mapping of waterholes and rockholes within the Cooper PAE. Such gaps are likely to be widespread.

References

Aquatic Ecosystems Task Group (2012a) Aquatic Ecosystems Toolkit. Module 2. Interim Australian National Aquatic Ecosystem Classification Framework. Australian Government Department of Sustainability, Environment, Water, Population and Communities, Canberra.

Aquatic Ecosystems Task Group (2012b) Aquatic Ecosystems Toolkit. Case study 1: Lake Eyre Basin. Australian Government Department of Sustainability, Environment, Water, Population and Communities, Canberra.

Arthington AH, Olden JD, Balcombe SR and Thoms MC (2010) Multi-scale environmental factors explain fish losses and refuge quality in drying waterholes of Cooper Creek, an Australian arid-zone river. Marine and Freshwater Research 61, 842–856.

Arthington AH and Balcombe SR (2011) Extreme flow variability and the 'boom and bust' ecology of fish in arid-zone floodplain rivers: a case history with implications for environmental flows, conservation and management. Ecohydrology 4, 708–720.

Boulton A, Brock M, Robson B, Ryder D, Chambers J and Davis J (2014) Australian freshwater ecology: processes and management. John Wiley & Sons.

Brooks S, Cottingham P, Butcher R and Hale J (2014) Murray-Darling Basin aquatic ecosystem classification: Stage 2 report. Peter Cottingham & Associates report to the Commonwealth Environmental Water Office and Murray-Darling Basin Authority, Canberra.

Claus S, Imgraben S, Brennan K, Carthey A, Daly B, Blakey R, Turak E and Saintilan N (2011) Assessing the extent and condition of wetlands in NSW: supporting report A – conceptual framework. Monitoring, evaluation and reporting program, Technical report series, Office of Environment and Heritage, Sydney.

DERM (2015) Wetland (aquatic ecosystem) types, Wetland*Info*, Department of Environment and Heritage Protection, Queensland. Viewed 11 November 2015, http://wetlandinfo.ehp.qld.gov.au/wetlands/ecology/aquatic-ecosystems-natural/.

Fee B and Scholz G (2010) Draft South Australian Aquatic Ecosystems Program – stage two report. Development of a South Australian Aquatic Ecosystems classification and its potential applications. DWLBC Report 2010/XX, Government of South Australia through Department of Water, Adelaide.

Fensham RJ and Fairfax RJ (2003) Spring wetlands of the Great Artesian Basin, Queensland, Australia. Wetlands Ecology and Management 11, 343–362.

Fensham RJ, Ponder WF and Fairfax RJ (2010) Recovery plan for the Community of Native Species Dependent on Natural Discharge of Groundwater from the Great Artesian Basin. Report to Department of the Environment, Water, Heritage and the Arts, Canberra. Queensland Department of Environment and Resource Management, Brisbane.

Fensham RJ, Silcock JL, Kerezsy A and Ponder W (2011) Four desert waters: setting arid zone wetland conservation priorities through understanding patterns of endemism. Biological Conservation 144, 2459–2467.

Imgraben S and McNeil D (2015) Lake Eyre Basin Rivers Monitoring Project: preliminary conceptual models. DEWNR Technical Report 2013. Government of South Australia through Department of Environment, Water and Natural Resources, Adelaide.

Kerezy A, Balcombe SR, Arthington AH and Bunn SE (2011) Continuous recruitment underpins fish persistence in the arid rivers of far-western Queensland, Australia. Marine and Freshwater Research 62, 1178–1190.

Kerezy A, Balcombe SR, Tischler M and Arthington AH (2013) Fish movement strategies in an ephemeral river in the Simpson Desert, Australia. Austral Ecology 38, 798–808.

Miles C and Miles M W (2014) South Australian Lake Eyre Basin Aquatic Ecosystem Mapping and Classification. DEWNR technical report. Government of South Australia through Department of Environment, Water and Natural Resources, Adelaide.

Price A and Gawne B (2009) The development of wetland conceptual models for the semi-arid zone – final report. A report prepared for the Murray-Darling Basin Authority by the Murray-Darling Freshwater Research Centre. Viewed 11 November 2015, http://www.mdba.gov.au/sites/default/files/pubs/413-MDBA_Report1_46pp_lowres%20latest%20version%203.12.09.pdf.

Pringle CM (2001) Hydrologic connectivity and the management of biological reserves: a global perspective. Ecological Applications 11, 981–998.

Rogers K (2011) Vegetation. In: Rogers K and Ralph TJ (eds.) Floodplain wetland biota in the Murray-Darling basin: water and habitat requirements. CSIRO PUBLISHING, Collingwood, 17–73.

Smith M, Karim F, Sparrow A, Cassel R, and Hall L (2015) Context statement for the Cooper subregion. Product 1.1 for the Cooper subregion from the Lake Eyre Basin Bioregional Assessment. Department of the Environment, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia. Viewed 15 December 2015, http://data.bioregionalassessments.gov.au/product/LEB/COO/1.1.

Tomlinson M and Boulton AJ (2010) Ecology and management of subsurface groundwater dependent ecosystems in Australia – a review. Marine and Freshwater Research 61, 936–949.

van Etten EJB (2010) Inter-annual rainfall variability of arid Australia: greater than elsewhere? Australian Geographer 40, 109–120.

Datasets

Dataset 1 Queensland Herbarium, Department of Science, Information Technology, Innovation and the Arts (2013) Biodiversity status of pre-clearing and remnant regional ecosystems - South East Qld. Bioregional Assessment Source Dataset. Viewed 26 May 2016, http://data.bioregionalassessments.gov.au/dataset/9b7bcebf-8b7f-4fb4-bc91-d39f1bd960cb.

Dataset 2 Queensland Department of Science, Information Technology, Innovation and the Arts (2013) Queensland groundwater dependent ecosystems. Bioregional Assessment Source Dataset. Viewed 11 November 2016, http://data.bioregionalassessments.gov.au/dataset/10940dfa-d7ef-44fb-8ac2-15d75068fff8.

Dataset 3 Queensland Department of Science, Information Technology, Innovation and the Arts (2012) Queensland wetland data version 3 - wetland areas. Bioregional Assessment Source Dataset. Viewed 11 November 2016, http://data.bioregionalassessments.gov.au/dataset/2a187a00-b01e-4097-9ca4-c9683e7f4786.

Dataset 4 SA Department for Water (2010) South Australian Wetlands - Groundwater Dependent Ecosystems (GDE) Classification. Bioregional Assessment Source Dataset. Viewed 26 May 2016, http://data.bioregionalassessments.gov.au/dataset/fc35d75a-f12e-494b-a7d3-0f27e7159b05.

Dataset 5 Bureau of Meteorology (2011) Geofabric Surface Cartography, v2.1. Bioregional Assessment Source Dataset. Viewed 26 May 2016, http://data.bioregionalassessments.gov.au/dataset/5342c4ba-f094-4ac5-a65d-071ff5c642bc.

Dataset 6 CSIRO (2000) Multi-resolution Valley Bottom Flatness MrVBF at three second resolution CSIRO 20000211. Bioregional Assessment Source Dataset. Viewed 11 November 2016, http://data.bioregionalassessments.gov.au/dataset/7dfc93bb-62f3-40a1-8d39-0c0f27a83cb3.

Dataset 7 Bioregional Assessment Programme (2015) Landscape classification of the Cooper preliminary assessment extent. Bioregional Assessment Derived Dataset. Viewed 11 November 2016, http://data.bioregionalassessments.gov.au/dataset/883926c0-82a3-4e9e-89fc-99557fd0a371.

2.3.4 Baseline and coal resource development pathway

Summary

There was no coal or coal seam gas (CSG) (i.e. CSG-only, not associated with other hydrocarbon) production occurring in the Cooper subregion as of December 2012. As a result, the baseline coal resource development (baseline) for the subregion does not have any coal resource developments.

As of early 2016, the only potential coal resource considered likely to proceed to production is the Southern Cooper Basin Gas Project, in the Weena Trough. Coal seams in the Patchawarra Formation of the geological Cooper Basin at depths of around 1900 to 2100 m are production targets at this prospect. This potential CSG project is estimated to contain a prospective resource of 7375 petajoules (PJ), and is currently undergoing production testing.

It is anticipated that the project will enter full production sometime during 2020 or 2021, with a reported production life of 20 years.

The Southern Cooper Basin Gas Project is located within the Far North Prescribed Wells Area (FNPWA) in SA. Groundwater in the FNPWA is managed under a water allocation plan (the Far North Water Allocation Plan, FNWAP). In addition to the allocated volume for petroleum activities, the FNWAP also sets limits for drawdown effects at springs and at the SA border. Predicted drawdown must not exceed 1 m at the boundary of the Southwest Springs Zone, and must not exceed 0.5 m at a distance of 5 km from any individual spring.

In addition, drawdown in excess of 10% of the pressure head at a state border is a trigger for consultation with the potentially-affected state.

Full scale field development in the Southern Cooper Basin Gas Project will require a separate environmental assessment and approval under relevant legislation, additional to that which exists for the exploratory and testing operations. Water for drilling and stimulation activities for the Southern Cooper Basin Gas Project will be sourced from shallow bores adjacent to the well site, or trucked in. Produced water will be stored in lined ponds. Pond size is dependent on predicted water production rate, predicted total produced water volumes, evaporation rates and site constraints. Ponds will be constructed according to standard Cooper Basin construction methods. Excavation and bunding will be used to elevate pond walls above ground level. Ponds will be located on existing disturbed areas as far as practicable. Impermeable liners will be installed in ponds where required. Depending on operational parameters, these water management options may not be utilised.

At the completion of operations, after pond water has evaporated or been pumped out, the liner and any salt residue will be removed and disposed to an appropriately licensed facility, the ponds will be backfilled and re-profiled to match pre-existing surface contours, and the surface will be ripped to promote revegetation.

Data collected during production testing have shown that water production rates are in the order of 30 to 85 kL/day per well.

2.3.4.1 Developing the coal resource development pathway

The coal resource development pathway (CRDP) for the Cooper subregion has been defined based on the information provided in companion product 1.2 for the Cooper subregion (Smith et al., 2015). The approach used to define the CRDP is based on companion submethodology M04 (as listed in Table 1) for developing a CRDP (Lewis, 2014).

There is no coal mining or stand-alone CSG production occurring in the Cooper subregion as of December 2012. As a result, the baseline does not contain any coal resource developments, for the purposes of companion submethodology M05 (as listed in Table 1) for developing the conceptual model of causal pathways (Henderson et al., 2016).

As identified in companion product 1.2 for the Cooper subregion (Smith et al., 2015), the only potential coal resource development in the subregion is the Southern Cooper Basin Gas Project, situated in the Weena Trough (Figure 25, Table 8). Coal seams in the Patchawarra Formation of the geological Cooper Basin at depths of around 1900 to 2100 m are production targets at this prospect. This potential CSG project is estimated to contain a prospective resource of 7375 PJ[1] (Strike Energy Limited, 2014a) according to the *Guidelines for Application of the Petroleum Resources Management System* (PRMS; Society of Petroleum Engineers, 2011), and is currently undergoing production testing at the Klebb and Le Chiffre sites (Strike Energy Limited, 2015b) (shown in Figure 25). Production testing at Klebb-1, Klebb-2, Klebb-3 and Le Chiffre-1 has shown that commercial flows can be anticipated from the resource area. A 2C resource (classification according to the PRMS) has been estimated for Le Chiffre-1 and Klebb-1, for a combined 2C resource of 168.6 PJ and a 3C resource of 244.8 PJ:

- Le Chiffre-1 Patchawarra Vu Upper and Vu Lower zone 2C: 101.1 PJ
- Klebb-1 Patchawarra Vu Upper Zone 2C: 67.5 PJ (Strike Energy Limited, 2015a).

[1] Strike Energy Limited reported the resource estimate in units of trillion cubic feet (Tcf) and billion cubic feet (Bcf), which has been converted to PJ using the conversion factor of 1.0845 PJ/Bcf, which is the conversion factor for SA and NSW gas used in Geoscience Australia and BREE (2012).

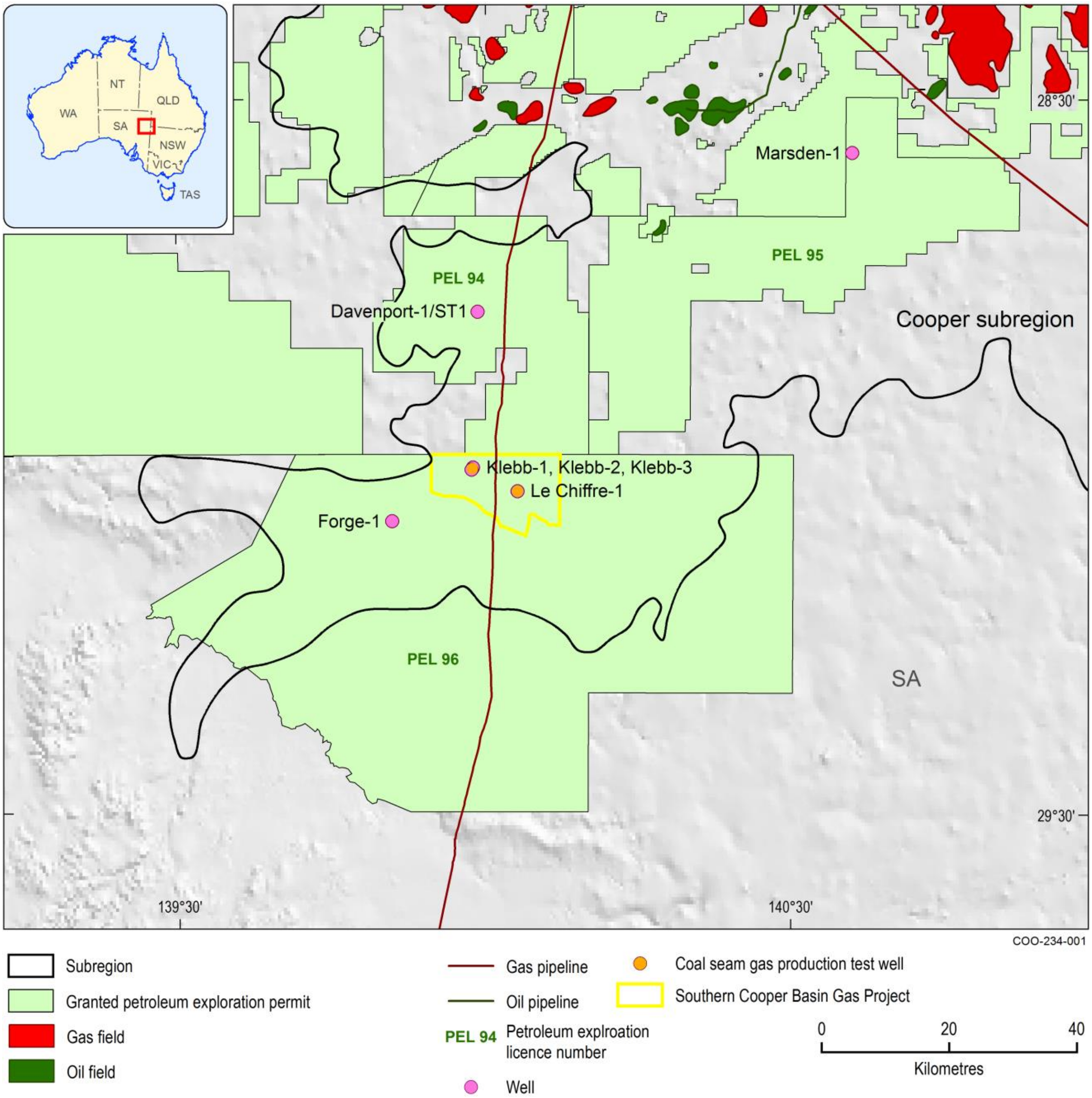

Figure 25 Location of Southern Cooper Basin Gas Project in the coal resource development pathway (CRDP) and current production test wells for the Cooper subregion

The extent of the coal resource developments in the CRDP is the union of the extents in the baseline and in the additional coal resource development. For the Cooper subregion, the extent of the additional coal resource development, Southern Cooper Basin Gas Project, is equal to the extent of the CRDP.
PEL = petroleum exploration licence
Data: Bioregional Assessment Programme (Dataset 1, Dataset 2), SA Department of State Development (Dataset 8, Dataset 9)
Southern Cooper Basin Gas Project location © Strike Energy

Table 8 Summary table for existing operations and proposed developments in the baseline and coal resource development pathway for the Cooper subregion

The primary activity in bioregional assessments (BAs) is the comparison of two potential futures: (i) the *baseline coal resource development (baseline)*, a future that includes all coal mines and coal seam gas (CSG) fields that are commercially producing as of December 2012; and (ii) *the coal resource development pathway (CRDP)*, a future that includes all coal mines and CSG fields that are in the baseline as well as those that are expected to begin commercial production after December 2012. The difference between CRDP and baseline is the change that is primarily reported in a BA. This change is due to the additional coal resource development (ACRD) – all coal mines and CSG fields, including expansions of baseline operations, that are expected to begin production after December 2012.

Name	Coal mine or coal seam gas (CSG) operation	Company	Included in baseline?	Included in the coal resource development pathway (CRDP) (modelled[a] or commentary[b])?	Start of mining operations or estimated project start	Projected mine life or estimated project life	Total defined coal (Mt) or coal seam gas resource (PJ)	Comments
Southern Cooper Basin Gas Project (PEL 96)	Coal seam gas field	Strike Energy Limited (JV with Australian Gasfields Ltd)	N	Y – Commentary (no modelling being undertaken in Cooper subregion)	2017[c]	20 years[e]	2C: 168.6 PJ 3C: 244.8 PJ[d] Prospective CSG resource: 7375 PJ[c]	Southern Cooper Basin Gas Project (PEL 96) is currently undergoing pilot production testing and has defined 2C and 3C contingent resources. This, combined with publicly available material from the company, suggests that future development of the field is likely. Production is planned to commence during 2020 or 2021.

[a]'Modelled' indicates those developments that are numerically modelled in this bioregional assessment.
[b]'Commentary' indicates those developments for which only commentary is provided because they cannot be modelled.
[c]Strike Energy Limited (2014a)
[d]Strike Energy Limited (2015a)
[e]Strike Energy Limited (2015b)
JV = joint venture, PEL = petroleum exploration licence
Strike Energy Limited reported the resource estimate in units of trillion cubic feet (Tcf) and billion cubic feet (Bcf), which has been converted to PJ using the conversion factor of 1.0845 PJ/Bcf, which is the conversion factor for SA and NSW gas used in Geoscience Australia and BREE (2012).

A development timeline is provided in Figure 26. It is anticipated that the project will enter production sometime during 2020 or 2021, after a period of development and a production demonstration facility, and will have a production life of 20 years (Strike Energy Limited, 2015d).

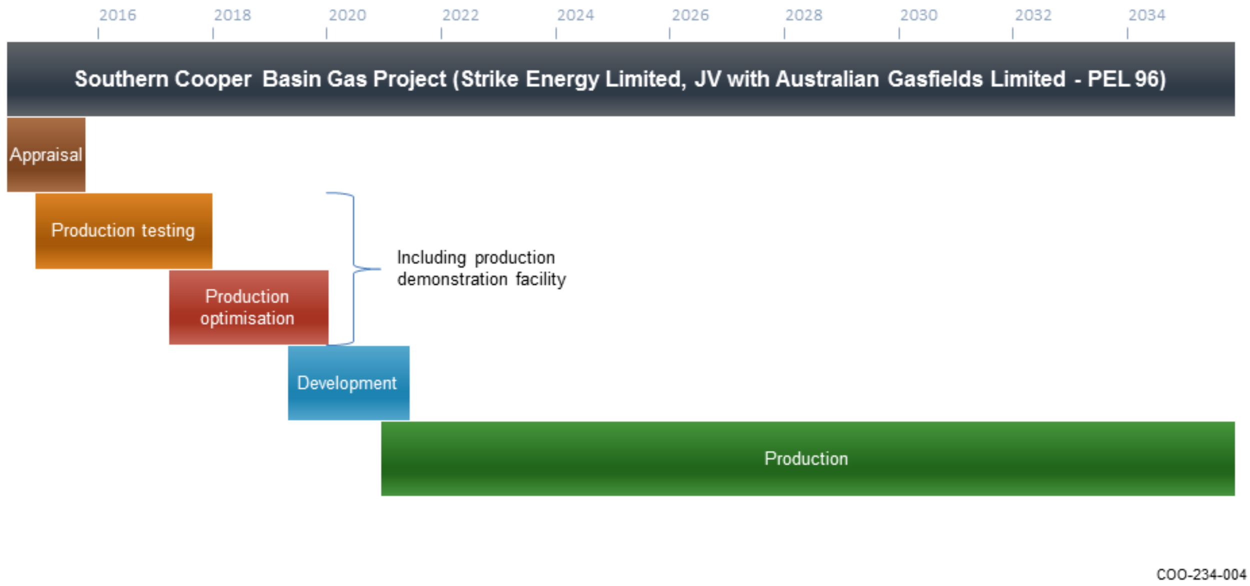

Figure 26 Timeline for Southern Cooper Basin Gas Project in the Cooper subregion

Source: Strike Energy Limited (2014b; 2014c; 2015d)

2.3.4.2 Water management for coal resource development

Water management for any future CSG production in the Cooper subregion will depend upon the results of current production testing. Indicative water management options are discussed by JBS&G Australia Pty Ltd and Strike Energy Limited (2014), and summarised in this section.

The CSG project in the CRDP is located within the Far North Prescribed Wells Area (FNPWA). Groundwater in the FNPWA is managed under a water allocation plan (the Far North Water Allocation Plan, FNWAP). General water management planning and obligations for the FNWAP are outlined in companion product 1.5 for the Cooper subregion (Karim et al., 2015). Under the FNWAP, 60 ML/day is allocated for water use as a by-product of petroleum production to the Minister for Mineral Resources and Energy. Extraction of groundwater within the FNPWA is generally licensed; drilling new water bores requires a permit and converting petroleum wells to water wells requires approval from the Department of Environment, Water and Natural Resources. An authorisation exists that allows for groundwater to be taken for use in drilling, construction and testing of petroleum (and other hydrocarbon) wells.

In addition to the allocated volume for petroleum activities, the FNWAP also sets limits for drawdown effects at springs and at the SA border. Predicted drawdown from the Cadna-owie – Hooray Aquifer must not exceed 1 m at the boundary of the Southwest Springs Zone, and must not exceed 0.5 m at a distance of 5 km from any individual spring (SA Arid Lands Natural Resources Management Board, 2009). The Southwest Springs Zone is shown in Figure 27. The pressure head in the Cadna-owie – Hooray aquifer is approximately 65 mAHD at the boundary of the Southwest Springs Zone (Bioregional Assessment Programme, Dataset 3). A 5 km buffer on identified springs is also shown in Figure 27. The pressure head in the Hooray equivalent aquifer is approximately 67 mAHD at a 5 km radius of the nearest spring.

In addition, drawdown in excess of 10% of the pressure head at a state border is a trigger for consultation with the potentially affected state. The pressure head of the Cadna-owie Aquifer at the SA–Queensland–NSW border is approximately 100 mAHD (Figure 27 and Figure 15 in 2.3.2).

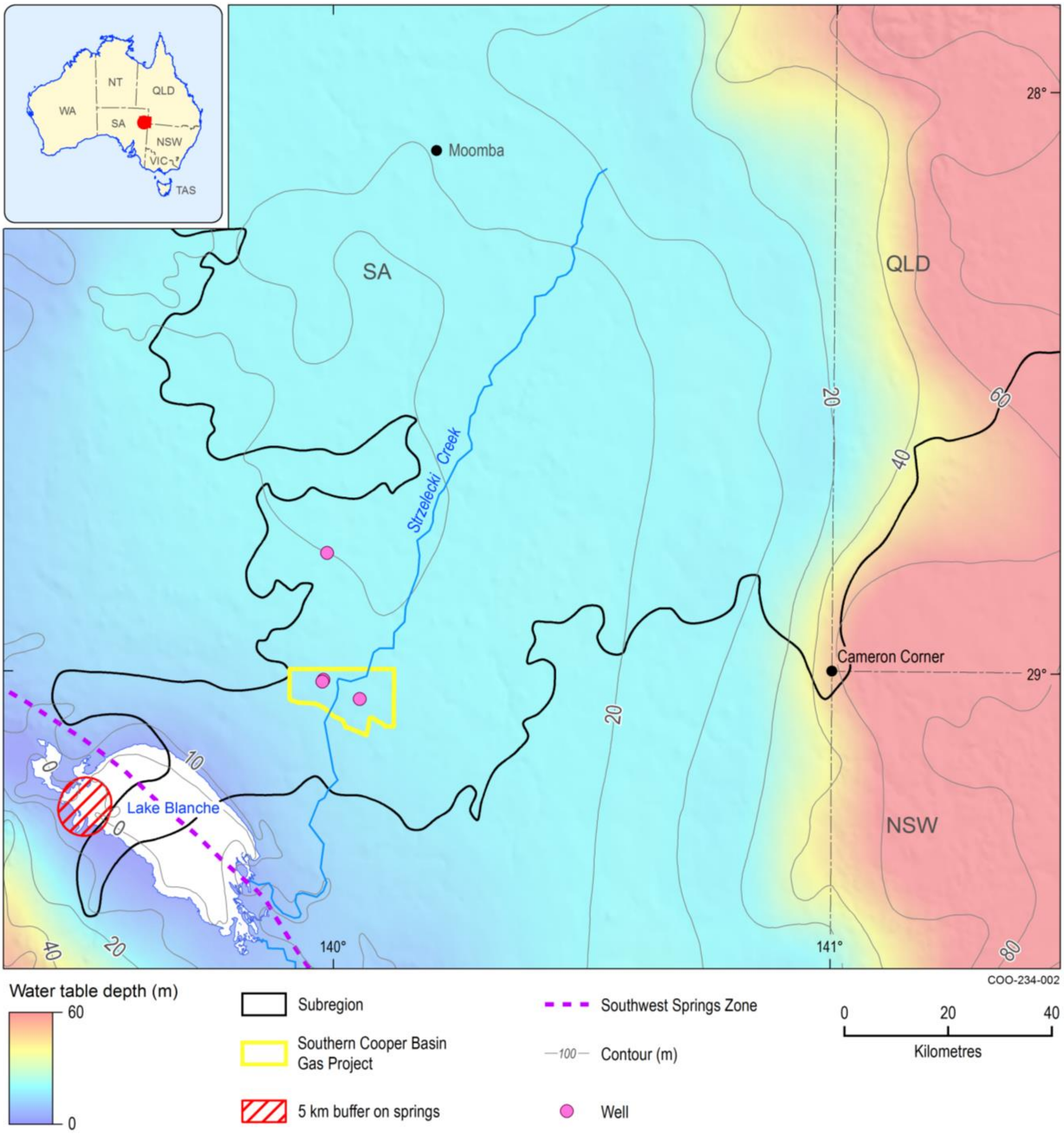

Figure 27 Watertable depth and contours with Southwest Spring Zone and 5 km buffer on spring locations

The extent of the coal resource developments in the CRDP is the union of the extents in the baseline and in the additional coal resource development. For the Cooper subregion, the extent of the additional coal resource development, Southern Cooper Basin Gas Project, is equal to the extent of the CRDP.
Data: Bioregional Assessment Programme (Dataset 1), Geoscience Australia (Dataset 4), Queensland Herbarium (Dataset 6), SA Department of Land Water and Biodiversity Conservation Knowledge and Information Division (Dataset 7)
Southern Cooper Basin Gas Project location © Strike Energy

Full scale field development in the Southern Cooper Basin Gas Project will require a separate environmental assessment and approval under relevant legislation, additional to that which exists for the exploratory and testing operations. The following water management process is based on the exploration and production testing operations.

Water for drilling and stimulation activities is sourced from shallow bores adjacent to the well site, or trucked in and stored in lined ponds (storage for fracturing operations) or turkey nest dams (storage for drilling operations). Potential sources of water for any future development in the Southern Cooper Basin Gas Project are (Hydrogeologic Pty Ltd, 2014):

- *existing shallow bores adjacent to well sites*. Maslins, Klebb and Le Chiffre supply bores, and Strez bore, which are all extracting from the Cenozoic Eyre Formation

Management of produced water during production operations could be via (JBS&G Australia Pty Ltd and Strike Energy Limited, 2014):

- water directed to UV-stabilised, high-density polyethylene (HDPE)-lined ponds via surface-laid flowlines for concentration and evaporation
  - use existing disturbed ground to minimise need for vegetation removal
- chemically treated water directed to separate lined pond if required
- reusable water – will be reused when possible
  - possible uses include drilling and completions at other sites
  - investigations into possible beneficial reuse will be ongoing, but may include supply to other local operators or for stock watering.

The aim of produced water management is to reuse it for drilling and fracturing activities in preference to other water sources.

Pond size is dependent on predicted water production rate, predicted total produced water volumes, evaporation rates and site constraints. If water production rates require additional storage or disposal capacity, options such as the use of additional storage ponds may be needed (JBS&G Australia Pty Ltd and Strike Energy Limited, 2014). There is an accepted standard approach to the design and construction of ponds (e.g. Beach Energy, 2012), which are in line with the SA Environment Protection Authority (EPA) wastewater lagoon construction guidelines (Environment Protection Authority South Australia, 2014). These guidelines will be adhered to for ponds in the Southern Cooper Basin Gas Project.

Ponds will be constructed according to standard Cooper Basin construction methods (RPS Aquaterra Pty Ltd and Beach Energy, 2012; Santos, 2003). Excavation and bunding will be used to elevate pond walls above ground level. Ponds will be located on existing disturbed areas as far as practicable; however, it is likely that they will extend onto adjacent areas. Impermeable liners will be installed in ponds where required. If water quality is adequate to utilise ‘freeform’ evaporation areas, a low bund may be constructed to contain the water within a defined area. All ponds will be constructed in swales between dunes, which are expected to be disconnected from any receiving surface water features, such as Strzelecki Creek (JBS&G Australia Pty Ltd and Strike Energy Limited, 2014).

A camp would typically be designed to accommodate approximately 20 to 40 people. Camp wastewater is typically treated by a transportable aerobic wastewater treatment system and must be in accordance with the *South Australian Public Health (Wastewater) Regulations 2013*.

At the completion of operations, after pond water has evaporated or been pumped out, the liner and any salt residue will be removed and disposed to an appropriately licensed facility, the ponds will be backfilled and re-profiled to match pre-existing surface contours, and the surface will be ripped to promote revegetation (JBS&G Australia Pty Ltd and Strike Energy Limited, 2014).

Fuel, oils and chemicals are stored in accordance with applicable standards and guidelines, in approved containers in polythene-lined, bunded areas or on self-bunded pallets. Appropriate spill containment and clean-up equipment would be maintained on site, including chemical and hydrocarbon spill kits. Any spill that occurred would be contained, reported and cleaned up by treatment in situ where appropriate, or removal off-site for treatment or disposal (JBS&G Australia Pty Ltd and Strike Energy Limited, 2014).

Data collected during production testing have shown that water production rates are in the order of 30 to 85 kL/day per well. Typically, water is initially produced at higher rates, then tails off during production (Strike Energy Limited, 2015c).

2.3.4.3 Gaps

There are knowledge gaps surrounding water management for CSG production activities, as those presented are based on documents prepared prior to commencement of production testing operations.

There are knowledge gaps relating to the actual location of infill wells, and timing of drilling.

There is uncertainty around the project life based on production rates and resource estimates, and these will change with further production testing, infill drilling and production operations.

References

Beach Energy (2012) Environmental impact report – fracture stimulation of deep shale and tight gas targets in the Nappamerri Trough (Cooper Basin), South Australia. Beach Energy, Adelaide.

EPA (2014) Wastewater lagoon construction guidelines. EPA 509/14. Environment Protection Authority South Australia, Adelaide.

Geoscience Australia and BREE (2012) Australia Gas Resource Assessment 2012. Geoscience Australia and the Bureau of Resource and Energy Economics, Canberra.

Henderson BL, Hayes KR, Mount R, Schmidt RK, O'Grady A, Lewis S, Holland K, Dambacher J Barry S and Raiber M (2016) Developing the conceptual model for causal pathways. Submethodology M05 from the Technical Programme. Department of the Environment and Energy, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia. http://data.bioregionalassessments.gov.au/submethodology/M05.

Hydrogeologic Pty Ltd (2014) Hydrogeological assessment for multi-well exploration and appraisal production testing from deep coal in PEL 96 Southern Cooper Basin. Prepared for Strike Energy Limited. http://www.petroleum.dmitre.sa.gov.au/__data/assets/pdf_file/0003/231933/20141216_-_61.017.1e_PEL96_Multiwell_ProdTest_Groundwater_201412163.pdf

JBS&G Australia Pty Ltd and Strike Energy Limited (2014) Environmental impact report. Multi-well exploration and appraisal production testing from deep coals in PEL 96, Cooper Basin. December 2014. Viewed 9 September 2015, http://petroleum.dmitre.sa.gov.au/__data/assets/pdf_file/0020/231932/20141216_-_50114-EIR-PEL_96_Multi-well_Production_Test-Rev33.pdf.

Karim F, Smith M and Cassel R (2015) Current water accounts and water quality for the Cooper subregion. Product 1.5 for the Cooper subregion from the Lake Eyre Basin Bioregional Assessment. Department of the Environment, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia. Viewed 9 September 2015, http://data.bioregionalassessments.gov.au/product/LEB/COO/1.5.

Lewis S (2014) Developing a coal resource development pathway. A submethodology from the Technical Programme, part of the Bioregional Assessment Programme. Department of the Environment, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia. Viewed 9 September 2015, http://data.bioregionalassessments.gov.au/submethodology/M04

RPS Aquaterra Pty Ltd and Beach Energy (2012) Environmental Impact Report: Fracture Stimulation of Deep Shale Gas and Tight Gas Targets in the Nappamerri Trough (Cooper Basin), South Australia.

SA Arid Lands Natural Resources Management Board (2009) Water Allocation Plan for the Far North Prescribed Wells Area.

Santos (2003) South Australia Cooper Basin operators – environmental impact report: drilling and well operations.

Smith M, Cassel R and Evans T (2015) Coal and coal seam gas resource assessment for the Cooper subregion. Product 1.2 for the Cooper subregion from the Lake Eyre Basin Bioregional Assessment. Department of the Environment, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia. Viewed 9 September 2015, http://data.bioregionalassessments.gov.au/product/LEB/COO/1.2.

Society of Petroleum Engineers (2011) Guidelines for application of the petroleum resources management system. Sponsored by Society of Petroleum Engineers, American Association of Petroleum Geologists, World Petroleum Council, Society of Petroleum Evaluation Engineers and Society of Exploration Geophysicists. Viewed 24 February 2016, http://www.spe.org/industry/docs/PRMS_Guidelines_Nov2011.pdf.

Strike Energy Limited (2014a) Southern Cooper Basin resource upgrade. Viewed 13 March 2015, http://www.strikeenergy.com.au/wp-content/uploads/2015/01/20140219_Southern-Cooper-Basin-resource-upgrade.pdf.

Strike Energy Limited (2014b) Strike Energy Limited Energy Users Association of Australia - NSW Energy Forum. Viewed 9 September 2015, http://www.strikeenergy.com.au/wp-content/uploads/2015/01/20140604_Energy-Users-Association-of-Australia.pdf.

Strike Energy Limited (2014c) Strike Energy Limited Euroz Oil & Gas Explorers presentation. Viewed 9 September 2015, http://www.strikeenergy.com.au/wp-content/uploads/2015/01/20141127_Euroz-Oil-Gas-Explorers-Presentation.pdf.

Strike Energy Limited (2015a) Southern Cooper Basin Gas Project independent contingent resource certification. Viewed 21 May 2015, http://www.strikeenergy.com.au/wp-content/uploads/2015/04/20150427_Sthern-Cooper-Basin-Contingent-Resources.pdf.

Strike Energy Limited (2015b) Southern Cooper Basin Gas Project operations update. Viewed 24 September 2015, http://www.strikeenergy.com.au/wp-content/uploads/2015/09/20150924_Sthern-Cooper-Basin-Gas-Project-Operations-Update.pdf.

Strike Energy Limited (2015c) Southern Cooper Basin Gas Project operations update. Viewed 21 May 2015, http://www.strikeenergy.com.au/wp-content/uploads/2015/05/20150514_Sthern-Cooper-Basin-Gas-Project-Operations-Update.pdf.

Strike Energy Limited (2015d) Strike Energy Limited Investor Presentation June 2015. Viewed 9 September 2015, http://www.strikeenergy.com.au/wp-content/uploads/2015/06/20150626_Investor-Presentation-Update.pdf.

Datasets

Dataset 1 Bioregional Assessment Programme (2015) Strike Energy PEL 96 Phase One Area. Bioregional Assessment Derived Dataset. Viewed 9 September 2015, http://data.bioregionalassessments.gov.au/dataset/317dad8e-f6fb-4eea-bb33-f4da73a5023a.

Dataset 2 Bioregional Assessment Programme (2015) Coal Resource Development Pathway (CRDP) Locations for the Cooper Subregion. Bioregional Assessment Derived Dataset. Viewed 9 September 2015, http://data.bioregionalassessments.gov.au/dataset/d82a737c-89b8-4e50-8973-47311ddd070f.

Dataset 3 Bioregional Assessment Programme (2015) Potentiometric Surface Cadna-Owie Hooray grid v01. Bioregional Assessment Derived Dataset. Viewed 6 October 2015, http://data.bioregionalassessments.gov.au/dataset/25b78fbb-4e39-4c0a-9a39-d2c5e8abb124.

Dataset 4 Geoscience Australia (2013) Water table elevation of the Great Artesian Basin (GABWRA). Bioregional Assessment Source Dataset. Viewed 26 May 2016, http://data.bioregionalassessments.gov.au/dataset/08f01dba-ec93-4c00-8e29-2b25a1948a33.

Dataset 5 Geoscience Australia (2015) Potentiometric surface for the Cadna-owie-Hooray and equivalents Aquifer. Bioregional Assessment Source Dataset. Viewed 6 October 2015, http://data.bioregionalassessments.gov.au/dataset/bbf78bf8-9ef6-42c1-861d-b2f57afd9805.

Dataset 6 Queensland Herbarium, Environmental Protection Agency (2006) Springs of Queensland - Distribution and Assessment (Version 4.0). Bioregional Assessment Source Dataset. Viewed 26 May 2015, http://data.bioregionalassessments.gov.au/dataset/82749253-f555-47d9-ba76-7140c55b2a65.

Dataset 7 SA Department of Water, Land and Biodiversity Conservation" (1995) South Australia Prescribed Groundwater Areas. Bioregional Assessment Source Dataset. Viewed 26 May 2016, http://data.bioregionalassessments.gov.au/dataset/e1d9eb0f-5481-4c4b-99a9-7fadfc6dc11b.

Dataset 8 SA Department of State Development (2014) SA Petroleum Exploration Tenements, Expired Petroleum Exploration Licences. Bioregional Assessment Source Dataset. Viewed 26 May 2016, http://data.bioregionalassessments.gov.au/dataset/852b01ea-f195-40f9-8320-232b46eaf2da.

Dataset 9 SA Department of State Development (2015) Petroleum Wells. Bioregional Assessment Source Dataset. Viewed 9 September 2015, http://data.bioregionalassessments.gov.au/dataset/54a47829-05db-443c-83e2-5bf0f3b53a99.

2.3.5 Conceptual models of causal pathways

Summary

This section discusses the causal pathways by which impacts on water quantity and quality from proposed coal seam gas (CSG) operations may affect water-dependent assets for the Cooper subregion.

A hazard analysis is used to systematically identify activities that occur as part of coal resource development in the Cooper subregion and which may initiate *hazards*, defined as events, or chains of events, that might result in an effect (change in the quality and/or quantity of surface water or groundwater). A large number of hazards are identified; some of these are beyond the scope of bioregional assessments, such as accidents, and others are presumed to be adequately addressed by site-based risk management processes, standards and regulation. Hazards associated with CSG operations that are considered to be in scope for the Cooper coal resource development pathway (CRDP) are grouped into eight causal pathways: (i) depressurisation of coal seams and adjacent hydrostratigraphic units from CSG production; (ii) discharge of co-produced water to surface water; (iii) other extraction of surface water or groundwater during operations; (iv) fault-mediated propagation; (v) well construction: integrity, leakage, induced connectivity; (vi) hydraulic fracturing; (vii) unregulated or forced release of water from containment and (viii) disruption of natural surface drainage from infrastructure.

For the groundwater causal pathways, knowledge gaps include hydrogeological architecture around the CRDP; lack of detailed understanding of the three-dimensional distribution of faults and other geological structures; the hydraulic parameters of target and adjacent formations, and the inter-aquifer connectivity between the Cooper Basin and the Eromanga Basin.

Uncertainties around the well spacing, depth, production timeline and size of the CSG resource hamper the assessment of the impact of the CRDP, but do not significantly affect the identification of causal pathways and development of conceptual models for those pathways. Similar uncertainty exists around water production rates and water requirements for the CRDP.

Detailed surface water hydrology and geomorphological information would assist in refining the surface water causal pathway. This includes the hydrology of Strzelecki Creek and the interaction between proposed storage ponds and the surface water network.

2.3.5.1 Methodology

Conceptual models of causal pathways are a specific type of conceptual model which characterises the *causal pathways*, the logical chain of events – either planned or unplanned – that link coal resource development and potential impacts on water and water-dependent assets.

These conceptual models bring together the existing understanding and conceptual models of the key system components, processes and interactions for the geology, hydrogeology, surface water and surface ecosystems, and consider the most plausible and important impacts and their spatial and temporal context. The conceptual modelling draws heavily on companion products from Component 1: Contextual information which is summarised in Section 2.3.2, Section 2.3.3 and Section 2.3.4.

The causal pathways underpin the construction of groundwater and surface water models, and frame the assessment of the impacts on and risks to water and water-dependent assets. The approach taken in the Cooper subregion has leveraged existing state-based resources and knowledge of geological, surface water and groundwater conceptual models. The Assessment team summarised the key system components, processes and interactions for the geology, hydrogeology and surface water of the subregion at the 'Conceptual modelling of causal pathways' workshop held in Adelaide in November 2015. The focus of the workshop was to improve the landscape classification (described in Section 2.3.3) and description of the conceptual model of causal pathways. Discussion with representatives at the workshop focused on knowledge gaps and uncertainties identified by the Assessment team.

In a bioregional assessment (BA), the identification and definition of causal pathways are supported by a formal hazard analysis, known as Impact Modes and Effects Analysis (IMEA) as outlined in companion submethodology M11 (Ford et al., 2015) and in Figure 5. IMEA is a variant of the established hazard analysis tool, Failure Modes and Effects Analysis (FMEA). The causal pathways are based on the outcomes of this hazard analysis and current understanding of the way ecosystems and landscape classes in the subregion work and interact. The IMEA rigorously and systematically identifies potential *hazards*, defined as events, or chains of events, that might result in an *effect* (change in the quality and/or quantity of surface water or groundwater). Only hazards identified through the IMEA process are considered further in the BA. Additionally, the IMEA considers all the possible ways in which activities may lead to effects or impacts, before assessing the severity, likelihood and detectability of such impacts under current controls through structured scoring.

Key to an IMEA is identifying *activities*, planned events associated with a CSG operation or coal mine. Activities are grouped into *components*, which are grouped into *life-cycle stages*. It is important to assign activities to their appropriate life-cycle stage because the scale and duration of similar activities can be different for each life-cycle stage, which is reflected in the scores for severity and/or likelihood of the impacts resulting from these activities.

Activities for CSG operations are separated into five life-cycle stages and four components:

- life-cycle stages: (i) exploration and appraisal, (ii) construction, (iii) production, (iv) decommissioning, and (v) work-over
- components: (i) wells, (ii) processing facilities, (iii) pipelines, and (iv) roads and infrastructure.

An *impact cause* is an activity (or aspect of an activity) that initiates a hazardous chain of events. An activity can have undesirable effects (such as water and gas extraction that unintentionally reduces groundwater pressure to unacceptable levels) or a potentially beneficial effect (such as reinjection of co-produced water to restore groundwater pressure in a heavily utilised aquifer).

An *impact mode* is the manner in which a hazardous chain of events could result in an effect. There might be multiple impact modes for each activity or chain of events. The impact modes may arise through various mechanisms, including anthropogenic activities that are planned and expected to occur as part of operations; unplanned events due to human error or infrastructure failure; or through combination with external factors (e.g. heavy rainfall or floods).

Examples are illustrated in Figure 5 (Section 2.3.1):

- An example for open-cut coal mines (Figure 5(a)) is initiated with the activity 'dewatering down to coal seam for an open-cut mine', which is the impact cause. The impact mode ('intentional dewatering down to coal seam') leads to the effect ('change in groundwater quantity (drawdown)'), which in turn may result in an ecological impact, 'reduced groundwater availability for a groundwater-dependent ecosystem'.
- An example for CSG operations (Figure 5(b)) is initiated with the activity 'corridor or site vegetation removal for CSG operations or coal mine', which is the impact cause. Subsequent events ('rainfall event' and 'soil erosion') then combine to form the impact mode ('soil erosion following heavy rainfall') that leads to multiple effects ('change in surface water quantity and surface water quality') and associated stressors ('surface water flow' and 'total suspended solids (TSS)'). In turn, this may cause an ecological impact, 'change of condition of habitat for a given species'.

Participants in IMEA workshops were invited to identify all plausible hazards and impact modes on an activity-by-activity basis, together with the potential hydrological effects on groundwater and/or surface water. Each hazard is scored with respect to the severity, likelihood and time to detection. The IMEA elicits an interval (upper and lower score) for each hazard that all workshop participants agree upon:

- The *severity score* describes the magnitude of the impact resulting from a hazard, which is scored so that an increase (or decrease) in score indicates an increase (or decrease) in the magnitude of the impact.
- The *likelihood score* describes the annual probability of a hazard occurring, which is scored so that a one-unit increase (or decrease) in score indicates a ten-fold increase (or decrease) in the probability of occurrence.
- The *detection score* describes the expected time to discover a hazard, scored in such a way that a one-unit increase (or decrease) in score indicates a ten-fold increase (or decrease) in the expected time (measured in days) to discover it.

Two overarching hazard ranking scores are calculated:

- *hazard score*, the sum of the severity score and likelihood score
- *hazard priority number*, the sum of severity score, likelihood score and detection score.

It is important to emphasise that despite the use of severity scores and likelihood scores, the hazard ranking scores do not provide an absolute or even relative measure of risk. IMEA provides a relative rank of hazards. The value of this analysis lies in the systematic and thorough identification of hazards and in their ranking relative to each other. Hazards with higher scores do not imply that the risks associated with those potential hazards are in some way significant or apply equally across the Cooper subregion at all times, only that it is important that these hazards (along with many others) are considered for inclusion in the BA.

There is considerable structure and hierarchy within these lists of IMEA hazards (Bioregional Assessment Programme, Dataset 1) with the finer-level hazards aggregating to successively coarser resolutions. For example, there are a range of activities as part of CSG operations that may require the removal of site vegetation (the impact cause), including the creation of pipeline networks, storage ponds, site processing plants, water treatment plants, ground-based geophysics and the construction of access roads; these may all potentially result in changes to surface water quality from soil erosion following heavy rainfall (impact mode).

The hazards identified by the IMEA represent a conceptual model of the chain of events that begins with an activity and ends with a potential impact on groundwater or surface water; causal pathways include these chains of events and also extend to resulting ecological impacts (see Figure 5). Causal pathways are considered for CSG operations and open-cut coal mines separately, for both the baseline coal resource development (baseline) and the coal resource development pathway (CRDP). A full suite of generic causal pathways for hazards due to coal mines and CSG operations is presented in figures in an appendix in companion submethodology M05 (as listed in Table 1) for developing a conceptual model of causal pathways (Henderson et al., 2016). These figures identify activities, impact causes and impact modes as well as those aspects of surface water and groundwater that might be affected. The causal pathways in the submethodology are generally applicable to all subregions or bioregions; this section presents specific results for the Cooper subregion.

Hazards are grouped for the Cooper subregion if they have the same causal pathways, even if those hazards occur because of different activities, at different life-cycle stages or at different intensities. This smaller set of causal pathway groups provides a useful starting point for summarising and representing the causal pathways associated with coal resource development (e.g. through influence diagrams) and focusing on those causal pathways that are in scope for BA.

The spatial footprint for the identified hazards and identified causal pathways is a core focus of the conceptual modelling, and is arrived at on the basis of existing knowledge, scientific logic and preliminary hydrological modelling results. An important aspect of this is using those same sources to identify which landscape classes and assets may be affected by a potential hydrological change that arises from those causal pathways, and (equally importantly) which landscape classes and assets will *not* be affected. Throughout the BA, areas of the preliminary assessment extent (PAE) that will not be affected are progressively ruled out in order to focus efforts of the Assessment team and ultimately the impact and risk analysis. In this product, the discussion of causal pathways is focused on the area of the PAE subject to the CRDP.

In addition to the methods utilised across the Bioregional Assessment Technical Programme, work reported by Commonwealth of Australia (2015) addresses the use of conceptual modelling to link water-related ecological responses to CSG extraction and coal mining, which should be considered in further assessments of potential impacts in the Cooper subregion.

2.3.5.2 Hazard analysis

Hazard analysis is a critical part of the BA as it rigorously and systematically identifies the potential impacts (hazards) on water-dependent assets arising from whole-of-life-cycle CSG and coal mining activities. Only hazards identified through this process are considered further in a BA.

A hazard analysis was conducted for the Cooper subregion based on the identified potential CSG development outlined in Section 2.3.4.1. The hazard analysis for the Cooper subregion was undertaken during a one-day workshop in March 2015 with experts from CSIRO, Geoscience Australia and the Department of the Environment.

The findings for the Cooper subregion (Bioregional Assessment Programme, Dataset 1) are:

- A total of 226 activities were identified for CSG operations.
- These were all activities identified during the IMEA. However, the results are based on a subset of activities with complete scores.
- All decisions were recorded. However, some activities were left unscored if there was incomplete information, or if they were considered not applicable to the Cooper subregion.

2.3.5.2.1 Coal seam gas operations

A range of generic causal pathways for hazards due to CSG operations are presented in companion submethodology M05 for developing a conceptual model of causal pathways (Henderson et al., 2015). Activities, impact causes and impact modes are identified, as well as those aspects of surface water and groundwater that might be affected. The causal pathways in the submethodology are generally applicable to all subregions or bioregions; this section presents results specific to the Cooper subregion.

The highest ranked hazards, ranked by the mid-point of the hazard priority number are displayed in Figure 28. The figure highlights that aquifer depressurisation, occurring through the activity of water and gas extraction during the production life-cycle, was the top ranked hazard. It occurred five times in the top 30, through various impact modes for: the coal seam; non-target, non-reservoir aquifers; when an aquitard is absent; and fault-mediated aquifer depressurisation.

The most frequently cited impact causes in the Cooper subregion IMEA are:

- litter and spills associated with ground support operations – a potential source of hazards in many contexts, but these were ranked as very low priority and are well managed given current controls
- inevitable, deliberate or accidental incidents – a good proportion of the hazards associated with CSG operations were attributed this impact cause. These include hydraulic fracturing and depressurisation of the target coal seam to enable gas extraction

- removal of vegetation and diversion of site drain lines – cited relatively frequently in the list of potential impact causes. Their potential impacts are not deemed negligible (due to the potential habitat fragmentation and soil erosion) but neither do they rank in the top hazards (see below). By virtue of their frequency these types of impacts may warrant additional attention in relation to the potential for cumulative effects.

Figure 28 shows the 30 highest ranked activities and impact modes, ranked by midpoint of the hazard priority number. This shows the range of hazard score and hazard priority number for each of these hazards. Figure 28 shows a representation of the IMEA results for the Cooper subregion.

The hazard priority number or hazard score indicates the relative importance of the hazard. Hazards with low scores are of lower priority.

When ranked by hazard score, the analysis identifies disruption of natural surface drainage as the most frequent hazard associated with CSG operations in the Cooper subregion, occurring eight times in the top 30. This impact mode may occur through multiple activities during gas field construction. The top three associated activities were: constructing gas and water gathering pipeline networks; brine storage ponds, pumps and water disposal pipelines; and hypersaline brine ponds. Discharge into river following heavy rainfall and imbalance of mud pressure between well and aquifer appeared twice in the top 30. Disruption of natural surface drainage was the top-ranked hazard when ranked by hazard priority number. Following this was two impact modes with high detection scores (difficult to detect): incomplete compromised cementing/casing (linking aquifers) and leaking (from brine storage ponds, pumps and water disposal pipelines and from hypersaline brine ponds).

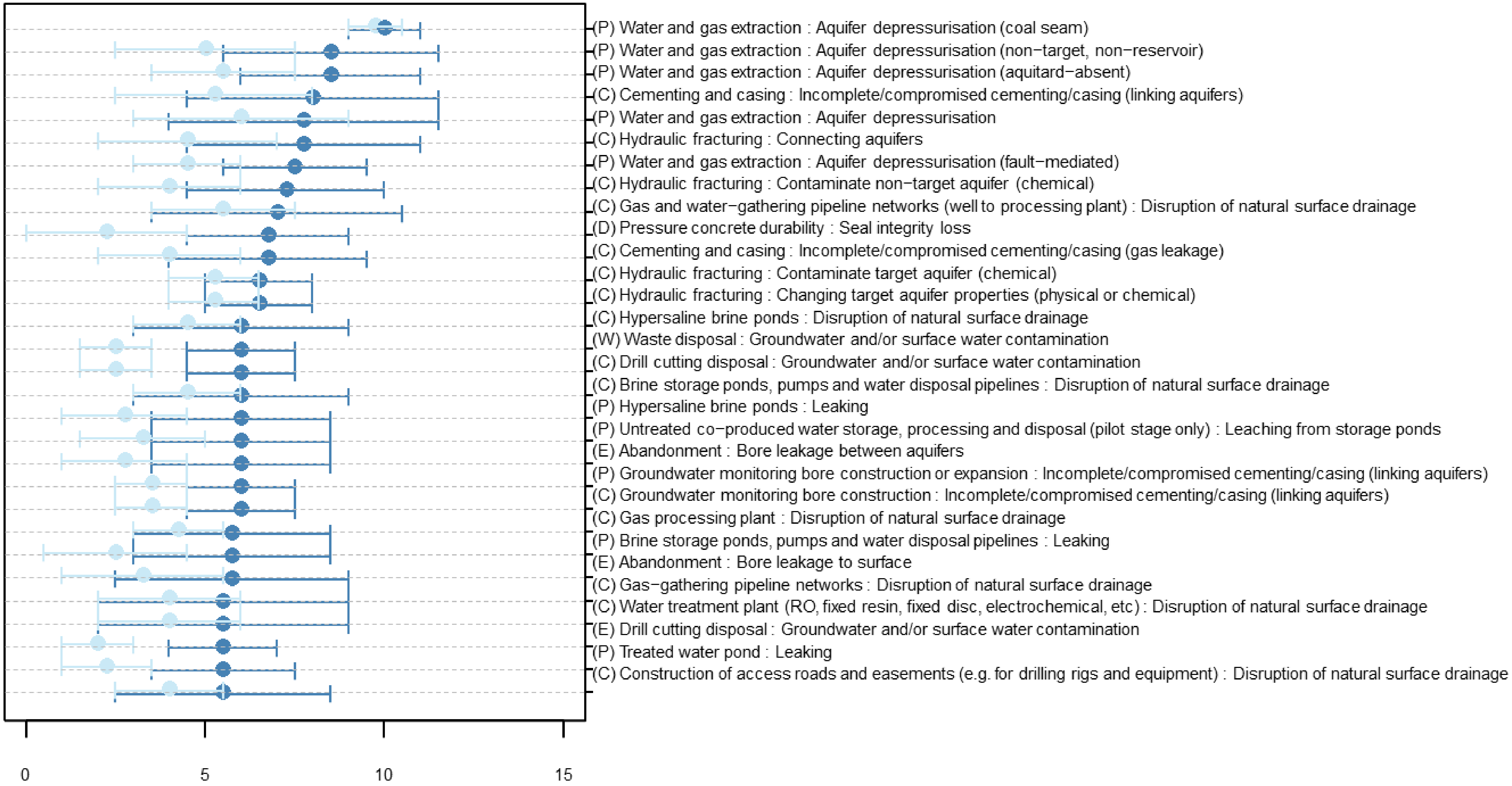

Figure 28 Highest ranked hazards (and their associated activities and impact models) for coal seam gas operations ranked by midpoint of hazard priority number for the Cooper subregion

The x-axis shows the hazard priority number and hazard score for potential hazards. The intervals between the highest and lowest hazard priority number are shown in dark blue; the intervals for hazard score are shown in light blue. The same hazard may appear multiple times, as it may arise from a number of different life cycles and activities. Hazards are listed with the syntax [Life-cycle stage][Activity]:[Impact mode], where life-cycle stages are indicated by (E) for exploration and appraisal, (C) for construction, (P) for production, (W) for work-over and (D) for decommissioning.
Data: Bioregional Assessment Programme (Dataset 1)

This figure has been optimised for printing on A3 paper (420 mm x 297 mm).

2.3.5.2.2 Hazard handling and scope

A long list of hazards has been generated for CSG operations. The primary focus for the Assessment for the Cooper subregion are those hazards that extend beyond the development site and that may have cumulative impacts, as these are consistent with the regional focus of the Bioregional Assessment Programme, and are where the work will add value beyond site-specific environmental impact statements (EIS). EIS are required under SA regulatory approvals process.

Development of causal pathways and the hazard identification work undertaken for BAs only consider impacts that can happen via water, and so hazards such as dust, fire or noise are deemed out of scope and are addressed by site-based risk management strategies required as part of development approval conditions, unless there is a water-mediated pathway.

For BA purposes best practice and design and construction specifications to appropriate levels are assumed for all site-based operations. Accidents are deemed to be covered adequately by site-based risk management procedures and are beyond the scope of BAs; for example, the failure of a pipeline and any impacts that this may cause are covered by site-based risk management.

Hazards that pertain to the development site and with no off-site impacts are important to acknowledge but will typically be addressed by site-based risk management procedures.

For CSG operations, the following hazards were identified as being out of scope in the Cooper subregion, because they are deemed to be covered by site-based risk management and regulation:

- equipment/infrastructure failure (e.g. pipeline failures)
- leaching/leaking from storage ponds and stockpiles
- containment failure due to construction or design
- spillages and disposals (diesel, mud, cuttings, fluid recovery)
- vegetation clearance and subsequent soil erosion following heavy rainfall
- abandonment practice.

2.3.5.3 Causal pathways

Hazards associated with CSG operations considered to be in scope for BA purposes were grouped for the Cooper subregion according to their hydrological pathway to impact. These causal pathway groups represent models linking an activity with a potential impact on the groundwater or surface water. The identified causal pathways are shown in Table 9, and discussed in the following sections. They are a subset of the causal pathways described in companion submethodology M05 for developing a conceptual model of causal pathways (Henderson et al., 2015). The causal pathways were discussed and refined during the external conceptual models of causal pathways workshop held in Adelaide on 11 and 12 November 2015.

Table 9 Causal pathway groups identified for the coal resource development pathway for the Cooper subregion

CSG = coal seam gas
Only causal pathways identified for the coal resource development pathway (CRDP) are included as there are no coal resource developments in the baseline for the Cooper subregion

Causal pathway group	Causal pathway	Comments
Subsurface depressurisation and dewatering	Groundwater pumping enabling CSG extraction	Intentional depressurisation of coal seams to reduce hydrostatic pressure and enable production of CSG (and co-produced water)
	Unplanned groundwater changes in non-target aquifers	Groundwater extraction for resource development may unintentionally affect groundwater variables and parameters such as pressure, flow paths and water quality in non-target layers, in situations where direct hydraulic connections exist. Such hydraulic connections may occur preferentially via geological structures such as faults, or more diffusely where direct stratigraphic contact exists between layers.
	Groundwater pumping of target aquifer	Intentional extraction undertaken to supply water from a target aquifer, which is required for on-site development and production usage in the coal resource development operations (see also the ‘operational water management’ causal pathway group).
Subsurface physical flow paths	Failure of well integrity	May create a direct fluid pathway between target formation and overlying aquifers, between the target formation and the surface, or between non-target formations. Additional to CSG wells (main operation where this occurs), it can also include other types of boreholes, such as those drilled for coal exploration or groundwater extraction (though these are generally have much smaller impacts compared to CSG extraction).
	Hydraulic fracturing	Intentional activity undertaken to change properties of target coal seams (such as permeability) to enhance gas production. Will create additional lateral flow paths within the coal seam. Depending on in situ rock properties and stress regime, poorly managed hydraulic fracturing can also potentially create fracture pathways linking target coal seams with adjacent hydrostratigraphic units which, in some cases, may be aquifers. There is potential for affecting groundwater flow gradients and changing various water quality parameters, for example, through injecting hydraulic fracturing fluids.
Surface water drainage	Altering surface water system	Diverting or realigning the pre-development surface water drainage, thereby changing the course and nature of the affected river and stream. Also includes other activities that can disrupt surface topography or structure, which may subsequently lead to enhanced erosion and impacts on surface water quality.
Operational water management	Storing extracted water	Storing water in large holding dams and ponds may create a point source for leakage (unintentional outflow) which may reach surface water or groundwater systems.
	Discharging extracted water into surface water system	This may be a regulated activity governed by specific conditions and rules, or (less commonly) may be unregulated, for example, due to severe flood inundation or dam engineering failure. May increase surface water flow volumes, or affect water quality.
	Processing and using extracted water	Main impacts may relate to offsite use of treated co-produced CSG water, for example, for irrigation of crops. Extracted water may be reused on-site for various purposes, for example dust suppression, but will mostly be retained within area of operations.

Proposed CSG development in the Cooper subregion targets the Patchawarra Formation at depths of 1900 to 2100 m. The main Eromanga Basin aquifers in the southern Cooper subregion are the Winton and Mackunda formations, the Coorikiana Sandstone (collectively referred to as the K-aquifer), the Cadna-owie – Hooray Aquifer and equivalents (including the Algebuckina Sandstone) and the Hutton Sandstone (collectively referred to as the J-K aquifer). The Patchawarra Formation is considered as a partial aquifer or leaky aquitard in the subregion, and is in direct connection with the Hutton Sandstone and Algebuckina Sandstone. These aquifers are more porous and permeable (Kellet et al., 2012), and hence have greater capacity to store and transmit groundwater, than the Patchawarra Formation. The main aquitards in the southern Cooper subregion are the Bulldog Shale and Oodnadatta Formation and the Allaru Mudstone, Toolebuc Formation and Wallumbilla Formation of the Rolling Downs Group. There is a potential aquitard section in the intra-Patchawarra shale unit identified in the recent stratigraphic reinterpretation (Morton, in review); however, the hydraulic character of this unit is undefined at this stage. The target coal seams in the Patchawarra Formation occur below this intra-Patchawarra unit. The lithology of the Patchawarra Formation in the Weena Trough (Section 2.3.2 and Morton, in review), and hydraulic parameters of the Patchawarra Formation in the Cooper Basin more broadly (Dubsky and Macphail, 2001), are such that it represents a leaky aquitard or aquitard hydrostratigraphy. The geological character of the rocks, and their associated hydraulic parameters, in conjunction with the separation of the CSG target within the Patchawarra Formation limits the amount of hydraulic connection with the overlying hydrostratigraphic units.

The geology and hydrogeology of the southern Cooper subregion are discussed in Section 2.3.2, and can be represented conceptually in terms of potential and demonstrated linkages as shown in Figure 29. This conceptualisation forms the basis for narrative relating to the groundwater causal pathways in Table 9. The hydrostratigraphic framework incorporates the revised stratigraphy for the Weena Trough, which was provided and discussed at the external conceptual models of causal pathways workshop, and is adopted as the working framework for the southern Cooper subregion.

Known hydrological links are established based on geological contact between units, or demonstrated hydrogeological linkages. For example, the Coorikiana Sandstone aquifer hydrological link with the Lake Blanche springs is demonstrated by hydrogeochemical data provided by the Lake Eyre Basin Springs Assessment (LEBSA) Lake Blanche springs hydrogeology and springs conceptualisation update (Keppel et al., 2016), and discussions at the external conceptual models of causal pathways workshop. The links between the Cenozoic Lake Eyre Basin and Quaternary hydrogeological units with Lake Blanche are demonstrated by the lake representing the discharge area for the watertable, and these units hosting the watertable. Similarly, local discharge from perched watertables, or recharge to such, is considered to occur around the stream network (Strzelecki Creek). Geological cross-sections in Figure 8 and Figure 9 in Section 2.3.2 illustrate the nature of the propagation pathway from proposed CSG operations activities to the surface. It is important to consider the potential groundwater causal pathways both vertically and laterally.

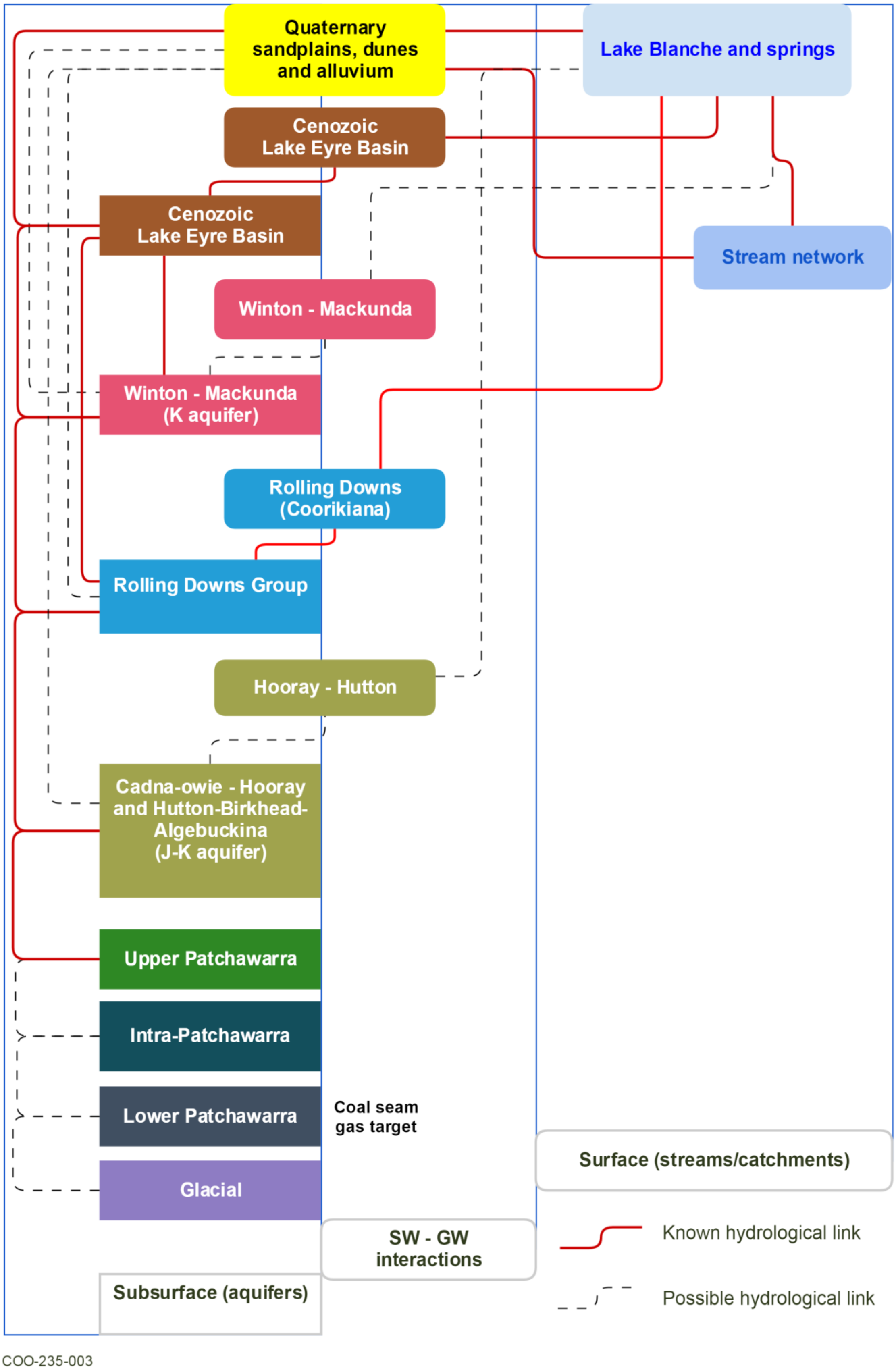

Figure 29 Conceptual representation of the linkages between geology, hydrogeology and surface water in the southern Cooper subregion

LEB refers to the geological Lake Eyre Basin, consisting broadly of the Eyre and Namba formations. SW-GW refers to surface water – groundwater. J-K and K aquifer refer to alternative aquifer names used in the region.

2.3.5.3.1 Subsurface depressurisation and dewatering

This group of causal pathways arises when CSG operations intentionally dewater and depressurise subsurface hydrostratigraphic units (such as coal seams and aquifers) to permit coal resource extraction. Pumping groundwater to enable coal resource extraction modifies pre-existing groundwater gradients, for example, changes groundwater levels, pressures or chemistry of aquifers. A number of activities may affect the pressure gradients that control the direction and rate of groundwater transmission within different hydrostratigraphic layers, for example: depressurising a water-saturated target coal seam to induce desorption and subsequent extraction of CSG ('Groundwater pumping enabling coal seam gas extraction' causal pathway). Groundwater level or pressure is most commonly altered as a direct result of depressurisation, but other gradients can also be changed via this process, such as temperature, density or chemical composition (water quality). This causal pathway group also includes conventional groundwater extraction from aquifers ('Groundwater pumping of target aquifer' causal pathway), which may be undertaken to supply water resources to support development and production activities associated with CSG operations. However, the scale of these effects is typically much less than those associated with CSG extraction. The 'Unplanned groundwater changes in non-target aquifers' causal pathway is also included in this group. This pathway includes impacts outside the target aquifer as a result of direct connections with other hydrostratigraphic units allowing propagation. This can occur as a result of geological structures, or where the target unit is in direct stratigraphic connection with another hydrostratigraphic unit.

Groundwater pumping enabling coal seam gas extraction causal pathway

Depressurisation is necessary to facilitate desorption of gas from the target coal seams in CSG production. This is achieved by pumping formation water out of the target zone. This depressurisation may propagate into adjacent, connected hydrostratigraphic units, and thus to the watertable. Depressurisation reduces the potentiometric head (pressure) in the target CSG formation and connected hydrostratigraphic units. This pressure reduction usually extends radially from the pumping zone, producing a drawdown cone. Impacts include changes in groundwater flow, pressure and level. The causal pathway for propagation of depressurisation is shown in Figure 30. Landscape classes identified as being groundwater dependent may be susceptible to this causal pathway.

The areal extent of depressurisation in the target formation in the Southern Cooper Basin Gas Project has been analytically modelled for initial production testing activities (Hydrogeologic Pty Ltd, 2014) according to the requirements of the Far North Water Allocation Plan (SA Arid Lands NRM Board, 2009). The Far North Water Allocation Plan (FNWAP) specifies that drawdown must not exceed 0.5 m at 5 km from an identified spring, 1 m at the boundary of the Southwest Springs Zone, and 10% of the head at a state border (10 m in this case). This analytical model identified that the maximum expected drawdown in the Patchawarra Formation would be 0.5 m at a distance of 40 km from the centre of pumping. The Hydrogeologic Pty Ltd (2014) analytical model used a conservative steady-state approach, including overestimation of hydraulic parameters and overestimation of water production rates. The water production rates were estimated at 240 kL/day per well, for ten wells (Hydrogeologic Pty Ltd, 2014), whereas actual pumping rates recorded during production testing are between 30 and 85 kL/day per well, for four wells.

Hydraulic parameters from the Cadna-owie – Hooray Aquifer were assumed to apply to the production zone, as opposed to lower values from the actual target formations (Hydrogeologic Pty Ltd, 2014). A similar approach was undertaken for this Assessment (Bioregional Assessment Programme, Dataset 3), using a pumping rate of 3.375 ML/day over 15 years centred at the Klebb wells, and applying the same hydraulic properties as the Hydrogeologic Pty Ltd (2014) estimation. The resulting drawdown extent and magnitude is shown in Figure 31. Given the depth of the target production zone, and the stratigraphy presented in preceding sections, it is unlikely that the drawdown impact would extend beyond the Cadna-owie and equivalent hydrostratigraphic units, and that any propagated drawdown would be significantly less than that presented for the Patchawarra Formation.

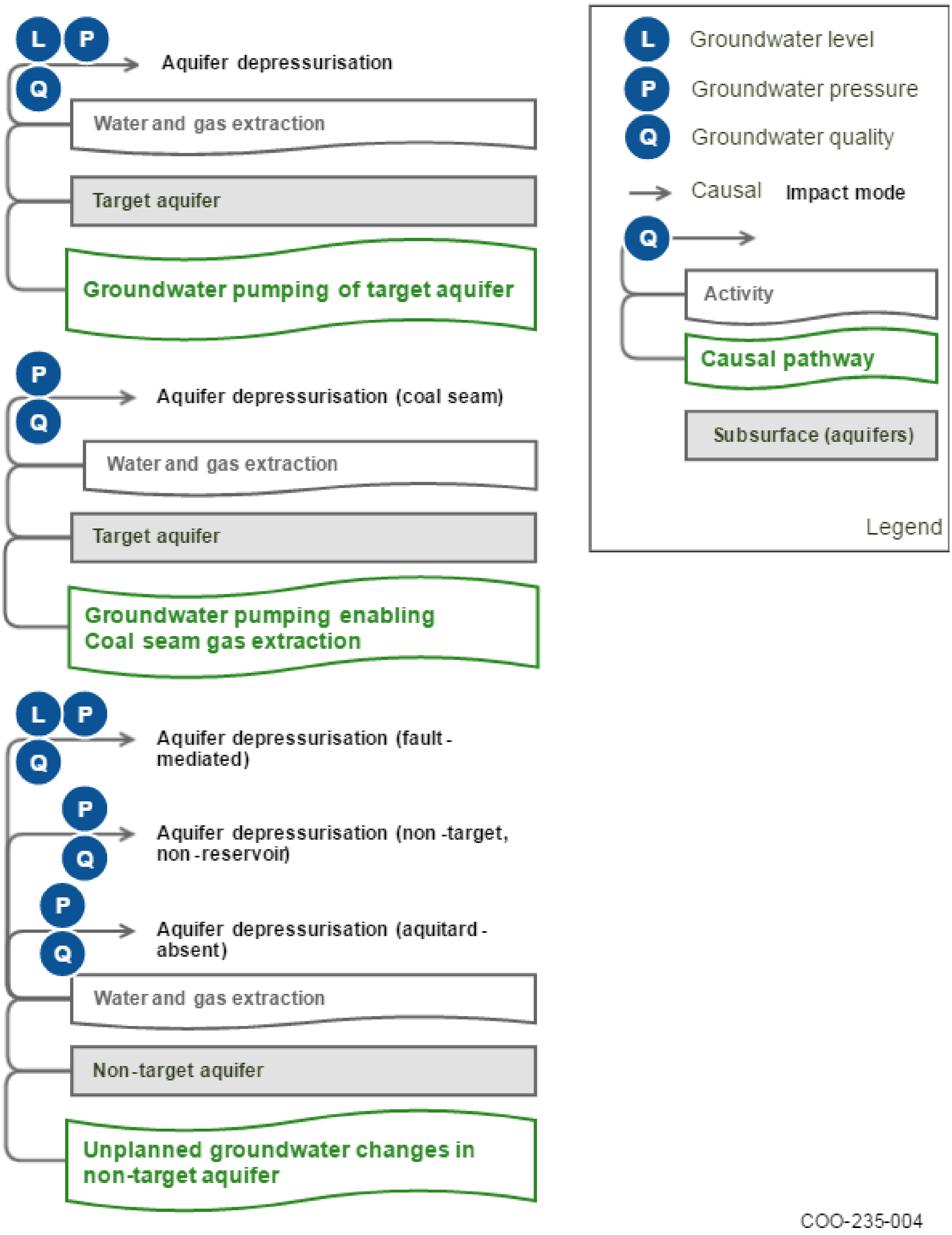

Figure 30 Conceptual model of the 'Subsurface depressurisation and dewatering' causal pathway group linking the causal pathway group to the IMEA

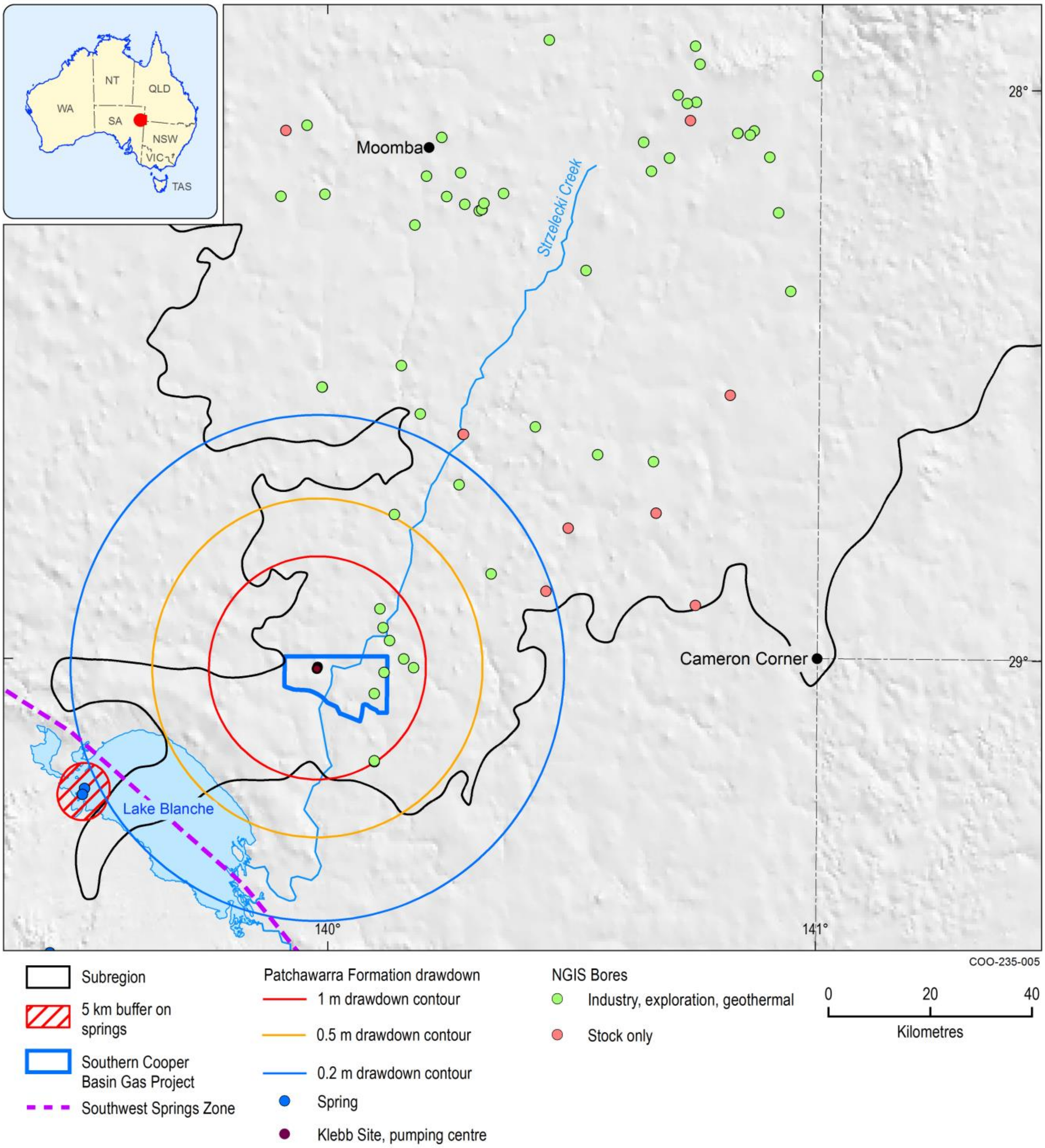

Figure 31 Spatial extent of drawdown in the Patchawarra Formation estimated using the de Glee steady-state leaky aquifer equation for the coal resource development pathway (CRDP) in the Cooper subregion

Data: Bioregional Assessment Programme (Dataset 2, Dataset 3, Dataset 7), Queensland Herbarium (Dataset 4), SA Department of Land Water and Biodiversity Conservation Knowledge and Information Division (Dataset 5) and SA Department of State Development (Dataset 6)
The extent of the coal resource developments in CRDP is the union of the extents for baseline and additional coal resource development.
Southern Cooper Basin Gas Project location © Strike Energy Limited

Groundwater pumping of target aquifer causal pathway

Water is required for drilling, hydraulic fracturing, dust suppression, accommodation and other support activities. As discussed in JBS&G Australia Pty Ltd and Strike Energy Limited (2014) the most likely source of water for operations is groundwater. This may be extracted from existing bores, as well as from specifically constructed bores. Other sources may include water reuse, water being trucked in from off-site, or opportunistic harvesting of surface water. Information provided at the external workshop for conceptual models of causal pathways indicated that produced water from CSG wells is the most likely source of water for drilling and fracturing during operations. The potential pathways for impact for groundwater extraction are similar to the 'Depressurisation for gas extraction' causal pathway (Figure 30) and the 'Well integrity' causal pathway (Figure 32). Landscape classes identified as being groundwater dependent may be susceptible to this causal pathway.

Groundwater extraction is most likely to be from the Eromanga Basin and Cenozoic Lake Eyre Basin aquifers, as well as Cooper Basin formation water from converted petroleum bores, or from co-produced water. These aquifers are currently subject to extraction by other users in the southern part of the Cooper subregion, either for stock purposes, or for industry and exploration activity. Additional extraction from these resources will be managed according to relevant state-based regulation, which will consider potential impacts on these other users.

Unplanned groundwater changes in non-target aquifers causal pathway

A significant body of work has been developed investigating the hydrogeological characteristics of geological structures, in particular faults. Fault zones may act as hydraulic conduits, connecting shallow and deep geological environments, but simultaneously the fault cores of many faults often form effective barriers to flow (e.g. Bense et al., 2013; Bense and Person, 2006; Bredehoeft, 1997; Caine et al., 1996). More broadly, geological structures may act as barriers or preferential pathways to fluid flow. Within and across lithological units, preferential flow paths can exist through fractures and faults (Commonwealth of Australia, 2014a). They may:

- compartmentalise the hydrogeological system, effectively isolating areas
- connect different hydrostratigraphic units, effectively connecting distinct aquifers or juxtaposing aquifers against aquitards
- facilitate linkage with the surface water system, as is the case for some springs
- have no effect on the flow of groundwater.

Faults may also be intraformational (i.e. not extending beyond one geological unit into another). This is discussed with reference to the Cooper subregion in Section 2.3.2.2.4.

Landscape classes identified as being groundwater dependent may be susceptible to this causal pathway.

The role of geological structures in this causal pathway is related to the possibility for structures to connect parts of the groundwater system with other parts, or with surface water. To that end, they may propagate impacts. In the southern Cooper subregion, the geometry and geological history of the Weena Trough may be partly influenced by faulting. This is uncertain, due to the lack of data that can be used to interpret geological structures in the region. It is possible that the glacial valley that became the Weena Trough may have developed by exploiting a pre-existing (fault-controlled) structural weakness in basement (Morton, in review). In addition, the presence of intraformational faulting in the aquitard units of the Rolling Downs Group in the Cooper subregion provides a potential pathway for propagation of impact. While evidence for intraformational faulting in the Weena Trough has not been found to date, discussion of the role of intraformational faulting acting as potential inter-aquifer connections is unlikely, as discussed in Section 2.3.2.2.4.

2.3.5.3.2 Subsurface physical flow paths

This group of causal pathways involves physical modification of the rock mass or geological architecture by creating new physical paths that water may potentially infiltrate and flow along. Just because a new physical path is created does not necessarily mean that water will start flowing along it in preference to how it flowed before – it will still follow the path of least resistance, and be governed by pressure gradients. This causal pathway group can, however, potentially lead to direct hydraulic connection between the target strata and other hydrostratigraphic units (such as regional aquifers), by creating new zones of deformation in the rock mass. This may occur when the integrity of wells drilled for groundwater or gas extraction is compromised, or may occur due to hydraulic fracturing of coal seams.

Failure of well integrity causal pathway

Well construction may lead to enhanced connection between layers. The causal pathway for this hazard arises from drilling a well for CSG operations or drilling a water bore for groundwater supply (Figure 32). A well that is not completely sealed with the surrounding material may provide a direct conduit for water to any other unit the well or bore penetrates, or to the land surface. This may be as a result of well construction, degradation of the well sealing materials over time, or changes in the aquifer material or structure over time. Well construction may increase local connectivity (Commonwealth of Australia, 2014a; Stuckey and Mulvey, 2013), and allow the mixing of waters from previously disconnected units of different quality and chemical properties, or of any fluid introduced down the well with groundwater. More information on well integrity and well failure in the Australian context can be found in Commonwealth of Australia (2014b). Landscape classes identified as being groundwater dependent may be susceptible to this causal pathway.

Data were provided at the external workshop for conceptual models of causal pathways (SA Department of State Development, 2015, pers. comm.) for petroleum well failures in the Cooper Basin in SA. This shows that there have been four instances of petroleum well failure observed out of 2288 petroleum wells drilled. 'Failure' is an event in a well that has caused either:

- fluid crossflow between two formations or
- fluid flow from a formation to the surface (not including wellhead leaks).

These failures were in wells (drilled into the Patchawarra and Nappamerri troughs):

- Big Lake-2 (2500 m total depth; blowout), drilled in 1963

- Della-1 (2179 m total depth; blowout), drilled in 1970
- Tirrawarra-3 (2019 m total depth; low rate flow to surface), drilled in 1971
- Della-20 (3018 m total depth; crossflow between formations behind casing), drilled in 2000.

In addition, there has also been one failure (blowout) in the Habanero-3 geothermal well (4221 m total depth) drilled in 2004, out of the seven geothermal wells in the South Australian Cooper Basin.

Information relating to water bores indicated that the average time before casing failure in PVC bores was 25 years for SA (SA DEWNR, 2015, pers. comm.).

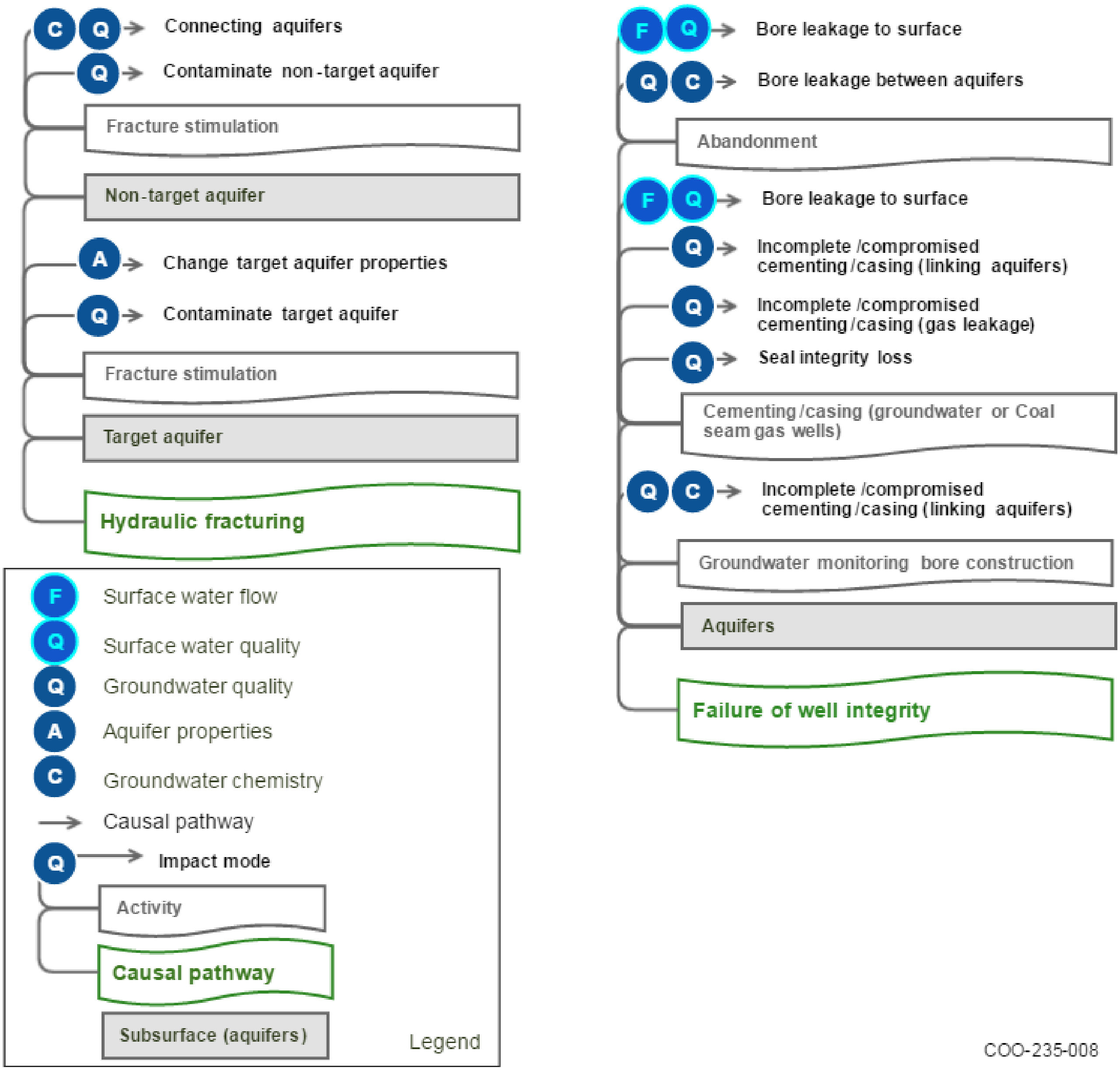

Figure 32 Conceptual model of the 'Subsurface physical flow paths' causal pathway group linking the causal pathway group to the IMEA

Hydraulic fracturing causal pathway

Hydraulic fracturing is required to assist with depressurisation of the target coal seam, which in turn facilitates desorption. Hydraulic fracturing is a highly targeted and controlled process. Co-produced water is recovered and directed to storage ponds, and flowback fluid is pumped and recovered according to approved site management practices. The hydraulic fracturing causal pathway will result in changes to groundwater pressures and flow in the target formation, and could result in possible contamination and depressurisation of adjacent, connected units as a result of induced connectivity (Figure 32).

The extent of hydraulic fracturing and its associated effects is highly dependent on the nature of the resource being extracted. It varies with the density and number of wells, the rate, duration, staging and intensity of fracturing, the orientation and strength of the geological stress field, the geological complexity of the target seam and adjacent rock mass, and the hydraulic properties of the target seam and adjacent rock mass. Landscape classes identified as being groundwater dependent may be susceptible to this causal pathway.

In the CRDP for the Cooper subregion, hydraulic fracturing will be necessary to liberate gas from the Patchawarra Formation coals. Strike Energy has undertaken hydraulic fracturing as part of their production testing activities at all four wells (JBS&G Australia Pty Ltd and Strike Energy Limited, 2014; Strike Energy Limited, 2015). Data obtained from hydraulic fracturing of wells Klebb-1 and Le Chiffre-1 show that the fractures did not propagate beyond the target zone (JBS&G Australia Pty Ltd and Strike Energy Limited, 2014). Information provided at the external conceptual modelling for causal pathways workshop indicated that subsequent hydraulic fracturing stages did not extend beyond the target zones, and that this is supported by data from tilt-meter and pressure monitoring. Fracturing operations in the Weena Trough require pumping of the hydraulic fracturing fluids at approximately 27,500 kPa, which is much lower than fracturing in deeper parts of the Cooper Basin in the order of 69,000 to 103,000 kPa, to initiate fracture development. In addition, the soft nature of the coal and contrasting strong adjacent rock mass act to contain fracture propagation to the coal seams. The available evidence from initial CSG well testing by Strike Energy Limited has shown that hydraulic fractures are contained within target coal seams and do not propagate beyond into adjacent hydrostratigraphic units. Thus, at this stage, there is no evidence that hydraulic fracturing activity in Cooper CSG fields will create new subsurface flow paths. In addition, any fluids injected during hydraulic fracturing operations will be contained within the target unit within the Patchawarra Formation. The Patchawarra Formation is not utilised as a groundwater source in the Cooper subregion.

2.3.5.3.3 Operational water management

Water produced from CSG extraction wells is recovered and stored at the surface in lined and bunded ponds. There is no provision for release to surface water or reinjection in the CRDP for the Cooper subregion. Storage ponds will be designed and constructed according to relevant standards and regulations. The potential causal pathway for co-produced water is via containment failure, which is illustrated by the ‘Discharging extracted water to surface water’ causal pathway. Another pathway is for impacts to groundwater quality via seepage from the storage ponds.

The ‘Sourcing water for on-site operations’ causal pathway is covered by the ‘Groundwater pumping of target aquifer’ causal pathway, as the Southern Cooper Basin Gas Project will be sourcing all its water for operational requirements from groundwater sources (JBS&G Australia and Strike Energy Limited, 2014). The ‘Reinjecting co-produced water into aquifer’ causal pathway is not considered in the Cooper subregion, as it is not part of the proposed operational water management regime.

The discharge of extracted water into surface water systems in the Cooper subregion can only occur via unregulated or forced release of water from containment. This may lead to changes in the surface water flow regime, resulting from changes to the distribution of surface materials redirecting surface water flow. Another change to the surface water regime is surface water quality change as a result of a release of contaminants. These events are 'one-off', or discrete, and can be thought of as similar to a high-flow or flood event. The impact will vary with the configuration of containment facilities, configuration and flow character of the surface water network and the magnitude of the release.

Within the southern Cooper subregion, the surface water feature that could potentially be affected by a loss of containment is the ephemeral, low-gradient Strzelecki Creek. Downstream effects could propagate to Lake Blanche. Strzelecki Creek experiences large variations in discharge and flow duration, from periods of no flow to flooding. Information provided in JBS&G and Strike Energy Limited (2014), and discussion at the external of causal pathways workshop identified that water containment facilities are currently constructed to specified standards, including lining and bunding. Site-specific high resolution digital elevation models discussed at the external conceptual models of causal pathways workshop show that water containment structures are situated in locations that are disconnected from Strzelecki Creek (Strike Energy Limited, 2015, pers comm).

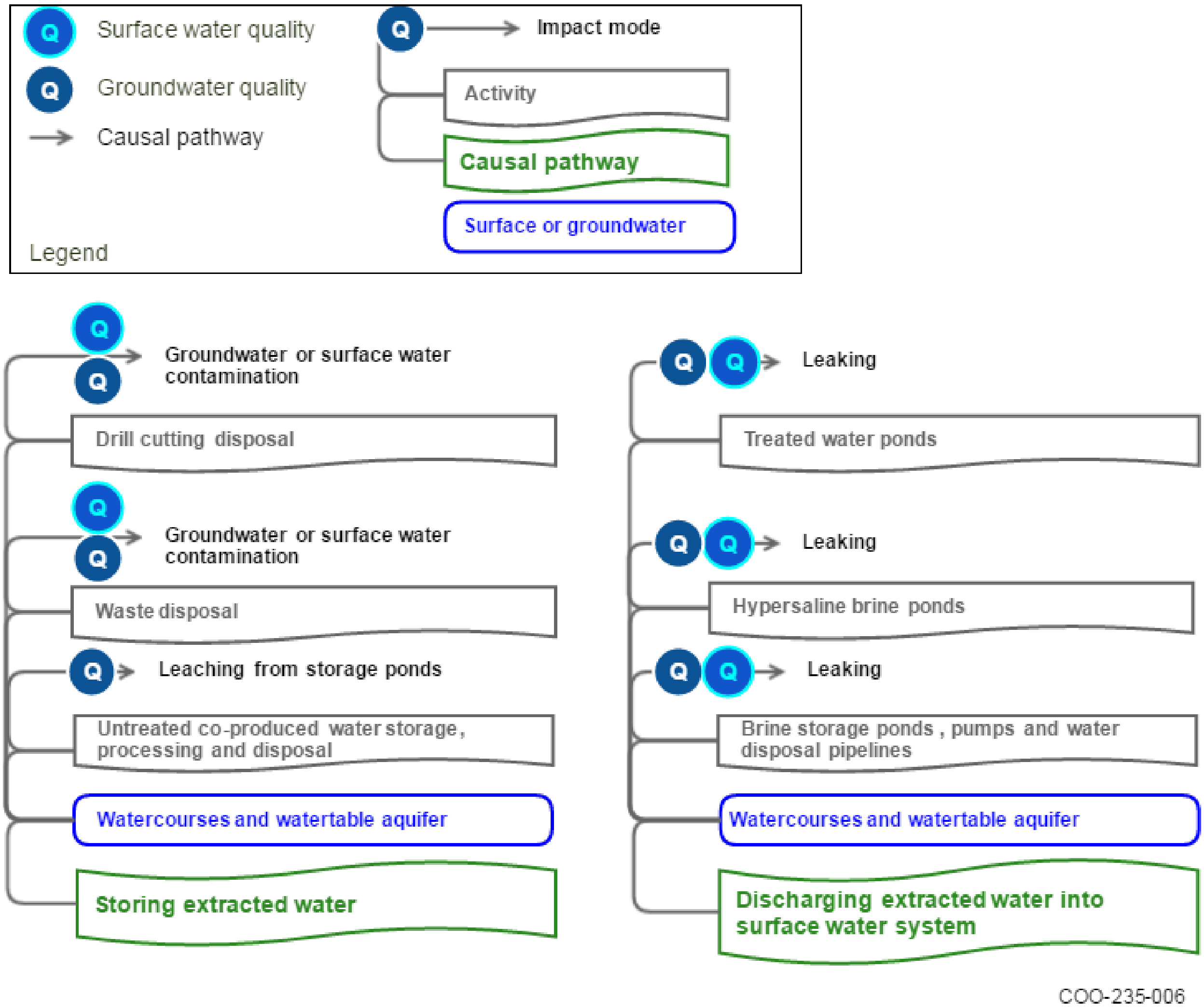

Figure 33 Conceptual model for the 'Operational water management' causal pathway group linking the causal pathway group to the IMEA

2.3.5.3.4 Surface water drainage

This group of causal pathways involves the physical disruption and disturbance of surface topography and near-surface materials (vegetation, topsoil, weathered rock). Such landscape changes can alter parameters such as the direction, volume and quality of surface flow over the landscape within the mine lease, and may reduce runoff to the stream network. Surface disturbance can also lead to enhanced soil erosion rates, which can then affect surface water quality, for example, through increased stream sediment loads. This group of causal pathways typically starts with activities associated with development of the CSG well network and related infrastructure. It can include activities such as diverting water around operations areas with drains or walls, realigning part of a stream network to permit mining to occur, or clearing vegetation and soil to construct a drilling pad. For the Cooper subregion, the 'Intercepting surface water runoff' causal pathway is considered to be covered by site-based management practices, while the 'Altering surface water system' causal pathway is considered to be a potential causal pathway and warrants further discussion. Landscape classes associated with floodplains, streams, lakes and springs may be susceptible to this causal pathway group.

Altering surface water system causal pathway

Altering the surface water system may lead to a loss, or redirection, of runoff that can have long-term cumulative effects on downstream watercourses. The physical infrastructure of CSG operations, including land clearing, land levelling, the construction of hard packed areas such as roads and tracks, pipelines and plant for collection and transport of gas can disrupt natural drainage systems by redirecting and concentrating flows. Water flow and landscape topography co-evolve in natural systems such that the areas of most concentrated flow are the most resistant to erosion. Changes in flow regime and catastrophic events can alter flows and pathways either temporarily before returning to the previous state, or semi-permanently until the next event. In the same way, human-made structures and earth works associated with CSG exploration and production may divert and concentrate surface flow. This may lead to erosion of the land surface, stream banks or streambeds, and alter water quality in streams if new material is mobilised and washed into them. Given the low-topographic gradient across the southern Cooper subregion, minor changes that could result from infrastructure development could have an impact on surface water flow. This is reflected in the hazard scoring, with a higher severity score given for drainage disruption modes relative to other subregions (Bioregional Assessment Programme, Dataset 1). The impact of any disruption to surface water drainage will vary with the configuration of the surface water network and the flow character of the receiving surface water system. The conceptual model of this causal pathway is shown in Figure 34.

Within the southern Cooper subregion, the surface water feature that could potentially be disrupted due to infrastructure for CSG operations is the ephemeral, low-gradient Strzelecki Creek. Downstream effects could propagate to Lake Blanche. The Southern Cooper Basin Gas Project is located adjacent to existing roads and gas pipelines, so the requirement for major infrastructure development will be small. However, this will depend upon the final layout of the CSG operations including well spacing and number of wells, and location and type of support infrastructure such as accommodation, roads, gas flowlines, water management infrastructure and processing infrastructure.

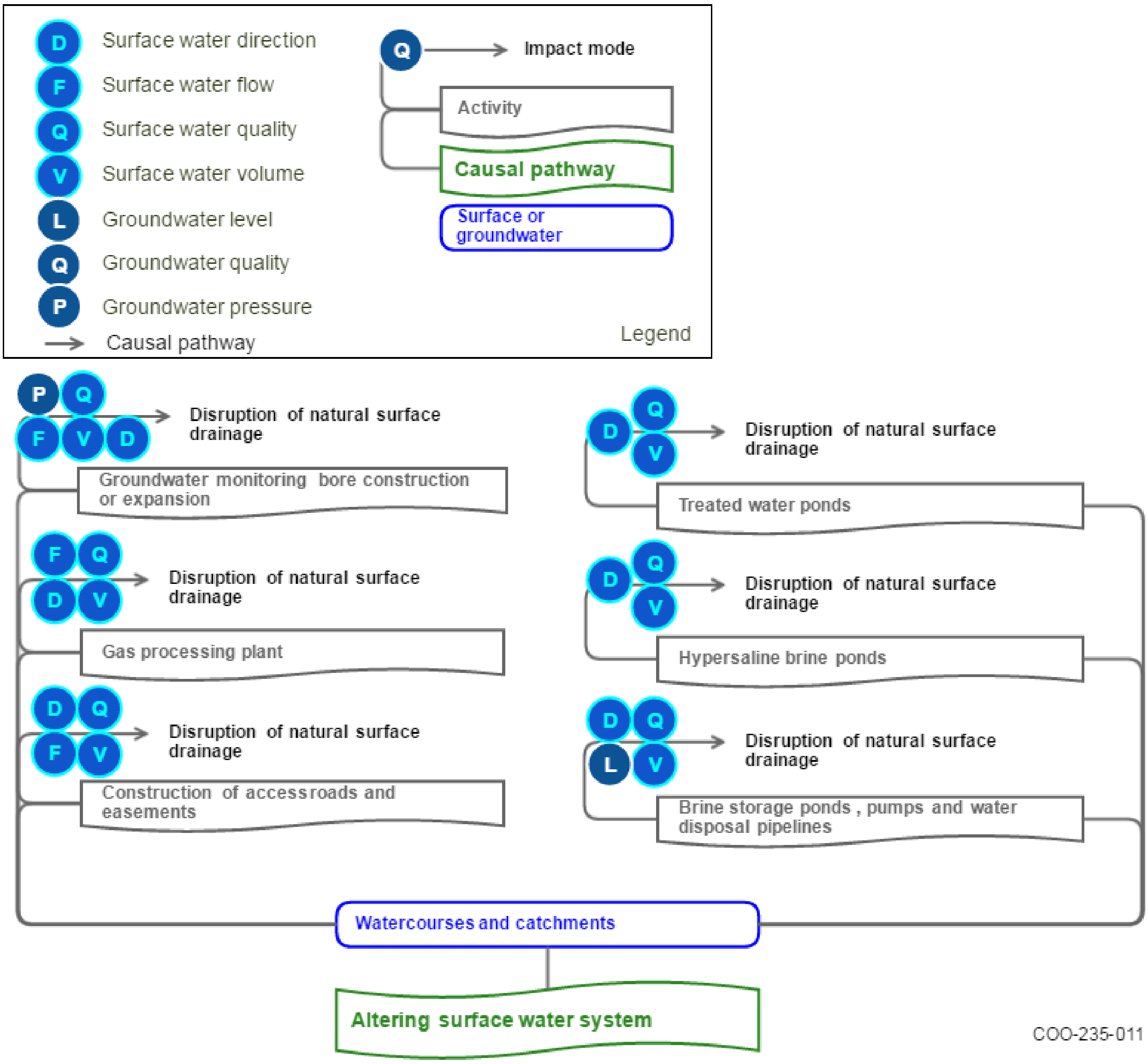

Figure 34 Conceptual model for the 'Surface water drainage' causal pathway group linking the causal pathway group to the IMEA

2.3.5.4 Gaps

This product is the final product to be released under this iteration of the Bioregional Assessment Programme for the Cooper subregion. The causal pathways conceptualised here provide a guide for future BA-type studies in the subregion. In addition, the gaps identified below should serve to provide an initial starting point for more detailed assessment of potential impacts from CSG development in the subregion.

The greatest knowledge gap in assessing the potential impact from CSG development in the Cooper subregion relates to the hydrogeological architecture around the Southern Cooper Basin Gas Project. Contributing to this is a lack of detailed understanding of the three-dimensional distribution of faults and other geological structures. Another key knowledge gap relates to the hydraulic parameters of Patchawarra Formation coal, intra-Patchawarra shale and upper Patchawarra Formation, and the hydraulic relationship with the abutting Hutton Sandstone, which will directly influence the inter-aquifer connectivity between the Cooper Basin and the Eromanga Basin.

This product presents a framework within which assessment of potential hazards from coal resource development in the CRDP identified for the Cooper subregion may be refined. Uncertainties around the well spacing, depth, production timeline and size of the CSG resource hamper the assessment of the impact of the CRDP, but do not significantly affect the identification of causal pathways and development of conceptual models for those pathways. Similar uncertainty exists around water production rates and water requirements for the CRDP.

Detailed surface water hydrology and geomorphological information would assist in refining the surface water causal pathway conceptual models. This includes the hydrology of Strzelecki Creek and the interaction between proposed storage ponds and the surface water network.

In order to progress the bioregional assessment work in the Cooper subregion, receptor impact modelling should be undertaken. This would be informed by work in the Galilee subregion, which shares some commonalities and overlaps with the Cooper subregion. This work would follow from the work reported in this product, and build upon increased knowledge specific to the Cooper CRDP. Receptor impact modelling for the Galilee subregion will be reported in companion product 2.7 for the Galilee subregion.

References

Bense VF, Gleeson T, Loveless SE, Bour O and Scibek J (2013) Fault zone hydrogeology. Earth-Science Reviews 127, 171-192. DOI: 10.1016/j.earscirev.2013.09.008.

Bense VF and Person MA (2006) Faults as conduit-barrier systems to fluid flow in siliciclastic sedimentary aquifers. Water Resources Research 42(5) W05421. DOI: 10.1029/2005wr004480.

Bredehoeft JD (1997) Fault permeability near Yucca Mountain. Water Resources Research 33(11), 2459-2463. DOI: 10.1029/97wr01710.

Caine JS, Evans JP and Forster CB (1996) Fault zone architecture and permeability structure. Geology 24(11), 1025-1028.

Commonwealth of Australia (2014a) Aquifer connectivity within the Great Artesian Basin, and the Surat, Bowen and Galilee Basins, Background review. Prepared for the Department of the Environment, Commonwealth of Australia. Viewed 11 February 2016, http://www.environment.gov.au/system/files/resources/004450a8-cf4f-4666-96b2-7be88a10add3/files/background-review-aquifer-connectivity_0.pdf.

Commonwealth of Australia (2014b) Bore integrity, Background review. prepared by Jacobs SKM for the Department of the Environment, Commonwealth of Australia. Viewed 11 February 2016, http://www.environment.gov.au/system/files/resources/00f77463-2481-4fe8-934b-9a496dbf3a06/files/background-review-bore-integrity.pdf.

Commonwealth of Australia (2015) Modelling water-related ecological responses to coal seam gas extraction and coal mining. Prepared by Auricht Projects and the Commonwealth Scientiifc and Industrial Research Organisation (CSIRO) for the Department of the Environment, Commonwealth of Australia. Viewed 16 May 2016, http://www.environment.gov.au/system/files/resources/83770681-a40b-4fa2-bf6e-8d41022873bd/files/modelling-water-related-ecological-responses-csg-extraction.pdf.

Dubsky M and McPhail A (2001) Environmental Impact Research Report (EIR) SA Cooper Basin well operations statement of environmental objectives (SEO) water pressure and salinity module report. SA Chamber of Mines and Energy.

Ford JH, Hayes KR, Henderson BL, Lewis S Baker PA and Schmidt RK (2016) Systematic analysis of water-related hazards associated with coal and coal seam gas development. Submethodology M11 from the Bioregional Assessment Technical Programme. Department of the Environment and Energy, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia. http://data.bioregionalassessments.gov.au/submethodology/M11.

Henderson BL, Hayes KR, Mount R, Schmidt RK, O'Grady A, Lewis S, Holland K, Dambacher J, Barry S and Raiber M (2016) Developing the conceptual model for causal pathways. Submethodology M05 from the Bioregional Assessment Technical Programme. Department of the Environment and Energy, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia. http://data.bioregionalassessments.gov.au/submethodology/M05.

Hydrogeologic Pty Ltd (2014) Hydrogeological assessment for multi-well exploration and appraisal production testing from deep coal in PEL 96 Southern Cooper Basin. Prepared for Strike Energy Limited. Viewed 11 December 2015, https://sarigbasis.pir.sa.gov.au/WebtopEw/ws/samref/sarig1/image/DDD/PGER00039PRODUCTION%20AND%20PROCESSING%20OPER.pdf

JBS&G Australia Pty Ltd and Strike Energy Limited (2014) Environmental impact report. Multi-well exploration and appraisal production testing from deep coals in PEL 96, Cooper Basin. December 2014. Viewed 11 December 2015, https://sarigbasis.pir.sa.gov.au/WebtopEw/ws/samref/sarig1/image/DDD/PGER00037EIR%20PRODUCTION%20AND%20PROCESSING.pdf

Kellett JR, Radke BM, Ransley TR, Bell JG and Stewart GA (2012) Chapter 5: Hydrogeological Framework. In: Smerdon BD and Ransley TR (eds) Water Resource Assessment for the Central Eromanga Region. A Report to the Australian Government from the CSIRO Great Artesian Basin Water Resource Assessment. CSIRO Water for a Healthy Country Flagship, 63–90.

Keppel M, Gotch T, Inverarity K Niejalke, Dand Wohling D (2016) A hydrogeological and ecological characterisation of springs in near Lake Blanche, Lake Eyre Basin, South Australia. DEWNR Technical report 2016/03. Government of South Australia, through the Department of Environment, Water and Natural Resources, Adelaide. 122

Morton JGG (in review) Weena Trough stratigraphic review study: summary report, report book 2016/00002. Department of State Development, South Australia, Adelaide.

SA Arid Lands NRM Board (2009) Explanation of the Water Allocation Plan for the Far North Prescribed Wells Area. Viewed 29 February 2016, https://admin.environment.sa.gov.au/files/7ba7ae4c-951e-4000-a82d-a2c8007a4ea1/far-north-water-allocation-plan-explanation.pdf.

Strike Energy Limited (2015) Southern Cooper Basin Gas Project operations update. Viewed 24 September 2015, http://www.strikeenergy.com.au/wp-content/uploads/2015/09/20150924_Sthern-Cooper-Basin-Gas-Project-Operations-Update.pdf.

Stuckey M and Mulvey P (2013) Looking for fractures – integrating geochemistry with hydrogeology to find inter-aquifer leakage above dewatered or collapsed coal seams. Water in Mining 2013, Brisbane, Queensland, 26 to 28 November. Australasian Institute of Mining and Metallurgy, Carlton, Victoria.

Datasets

Dataset 1 Bioregional Assessment Programme (2015) Impact Modes and Effects Analysis for the Cooper subregion. Bioregional Assessment Source Dataset. Viewed 02 March 2016, http://data.bioregionalassessments.gov.au/dataset/dec0acbe-52cf-4317-9f75-0aeecb784c63.

Dataset 2 Bioregional Assessment Programme (2015) Cooper subregion NGIS bores. Bioregional Assessment Derived Dataset. Viewed 10 October 2015, http://data.bioregionalassessments.gov.au/dataset/8f813643-f70f-476d-a561-484e4251c271.

Dataset 3 Bioregional Assessment Programme (2015) Cooper Basin Drawdown Calculations – De Glee method. Bioregional Assessment Derived Dataset. Viewed 10 October 2015, http://data.bioregionalassessments.gov.au/dataset/51323ab4-3613-47eb-acf3-3d89e8b9c062.

Dataset 4 Queensland Herbarium, Environmental Protection Agency (2006) Springs of Queensland - Distribution and Assessment (Version 4.0). Bioregional Assessment Source Dataset. Viewed 26 May 2016, http://data.bioregionalassessments.gov.au/dataset/82749253-f555-47d9-ba76-7140c55b2a65.

Dataset 5 SA Department of Water, Land and Biodiversity Conservation (1995) South Australia Prescribed Groundwater Areas. Bioregional Assessment Source Dataset. Viewed 26 May 2016, http://data.bioregionalassessments.gov.au/dataset/e1d9eb0f-5481-4c4b-99a9-7fadfc6dc11b.

Dataset 6 SA Department of State Development (2015) Petroleum Wells. Bioregional Assessment Source Dataset. Viewed 10 October 2015, http://data.bioregionalassessments.gov.au/dataset/54a47829-05db-443c-83e2-5bf0f3b53a99.

Dataset 7 Bioregional Assessment Programme (2015) Strike Energy PEL 96 Phase One Area. Bioregional Assessment Derived Dataset. Viewed 9 September 2015, http://data.bioregionalassessments.gov.au/dataset/317dad8e-f6fb-4eea-bb33-f4da73a5023a.

Glossary

The register of terms and definitions used in the Bioregional Assessment Programme is available online at http://environment.data.gov.au/def/ba/glossary (note that terms and definitions are respectively listed under the 'Name' and 'Description' columns in this register). This register is a list of terms, which are the preferred descriptors for concepts. Other properties are included for each term, including licence information, source of definition and date of approval. Semantic relationships (such as hierarchical relationships) are formalised for some terms, as well as linkages to other terms in related vocabularies.

activity: for the purposes of Impact Modes and Effects Analysis (IMEA), a planned event associated with a coal seam gas (CSG) operation or coal mine. For example, activities during the production life-cycle stage in a CSG operation include drilling and coring, ground-based geophysics and surface core testing. Activities are grouped into components, which are grouped into life-cycle stages.

aquifer: rock or sediment in a formation, group of formations, or part of a formation that is saturated and sufficiently permeable to transmit quantities of water to wells and springs

aquitard: a saturated geological unit that is less permeable than an aquifer, and incapable of transmitting useful quantities of water. Aquitards often form a confining layer over an artesian aquifer.

asset: an entity that has value to the community and, for bioregional assessment purposes, is associated with a subregion or bioregion. Technically, an asset is a store of value and may be managed and/or used to maintain and/or produce further value. Each asset will have many values associated with it and they can be measured from a range of perspectives; for example, the values of a wetland can be measured from ecological, sociocultural and economic perspectives.

baseline coal resource development: a future that includes all coal mines and coal seam gas (CSG) fields that are commercially producing as of December 2012

bioregion: a geographic land area within which coal seam gas (CSG) and/or coal mining developments are taking place, or could take place, and for which bioregional assessments (BAs) are conducted

bioregional assessment: 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 coal mining development on water resources. The central purpose of bioregional assessments is to analyse the impacts and risks associated with changes to water-dependent assets that arise in response to current and future pathways of coal seam gas and coal mining development.

bore: a narrow, artificially constructed hole or cavity used to intercept, collect or store water from an aquifer, or to passively observe or collect groundwater information. Also known as a borehole or piezometer.

causal pathway: for the purposes of bioregional assessments, the logical chain of events either planned or unplanned that link coal resource development and potential impacts on water resources and water-dependent assets

coal resource development pathway: a future that includes all coal mines and coal seam gas (CSG) fields that are in the baseline as well as those that are expected to begin commercial production after December 2012

component: for the purposes of Impact Modes and Effects Analysis (IMEA), a group of activities associated with a coal seam gas (CSG) operation or coal mine. For example, components during the development life-cycle stage of a coal mine include developing the mine infrastructure, the open pit, surface facilities and underground facilities. Components are grouped into life-cycle stages.

conceptual model: abstraction or simplification of reality

connectivity: a descriptive measure of the interaction between water bodies (groundwater and/or surface water)

context: the circumstances that form the setting for an event, statement or idea

cumulative impact: for the purposes of bioregional assessments, the total change in water resources and water-dependent assets resulting from coal seam gas and coal mining developments when all past, present and reasonably foreseeable actions that are likely to impact on water resources are considered

current controls: the methods or actions currently planned, or in place, to detect hazards when they occur or to reduce the likelihood and/or consequences of these hazards should they occur

dataset: a collection of data in files, databases or delivered by services that comprise a related set of information. Datasets may be spatial (e.g. a shape file or geodatabase or a Web Feature Service) or aspatial (e.g. an Access database, a list of people or a model configuration file). In the BA Repository, datasets are guaranteed to have a metadata record in the Metadata Catalogue and to have their components (files, database interface) delivered via the Data Store. In semantic web terms, a BA dataset is defined as a subclass of DCAT Dataset and PROMS Entity and is described in the BA Ontology as a scope note in term record.

detection score: for the purposes of Impact Modes and Effects Analysis (IMEA), the expected time to discover a hazard, scored in such a way that a one-unit increase (or decrease) in score indicates a ten-fold increase (or decrease) in the expected time (measured in days) to discover it

discharge: water that moves from a groundwater body to the ground surface or surface water body (e.g. a river or lake)

diversion: see extraction

ecosystem: a dynamic complex of plant, animal, and micro-organism communities and their non-living environment interacting as a functional unit. Note: ecosystems include those that are human-influenced such as rural and urban ecosystems.

effect: for the purposes of Impact Modes and Effects Analysis (IMEA), change in the quantity and/or quality of surface water or groundwater. An effect is a specific type of an impact (any change resulting from prior events).

extraction: the removal of water for use from waterways or aquifers (including storages) by pumping or gravity channels

formation: rock layers that have common physical characteristics (lithology) deposited during a specific period of geological time

groundwater: water occurring naturally below ground level (whether in an aquifer or other low permeability material), or water occurring at a place below ground that has been pumped, diverted or released to that place for storage there. This does not include water held in underground tanks, pipes or other works.

groundwater-dependent ecosystem: ecosystems that rely on groundwater - typically the natural discharge of groundwater - for their existence and health

groundwater recharge: recharge occurs where rainfall or surface water drains downward and is added to groundwater (the zone of saturation)

groundwater system: see water system

hazard: an event, or chain of events, that might result in an effect (change in the quality and/or quantity of surface water or groundwater)

hazard priority number: for the purposes of Impact Modes and Effects Analysis (IMEA), one of two ranking systems that indicate the relative importance of a hazard. It is the sum of severity score, likelihood score and detection score.

hazard score: for the purposes of Impact Modes and Effects Analysis (IMEA), one of two ranking systems that indicate the relative importance of a hazard. It is the sum of the severity score and likelihood score.

hydrogeology: the study of groundwater, including flow in aquifers, groundwater resource evaluation, and the chemistry of interactions between water and rock

impact: a change resulting from prior events, at any stage in a chain of events or a causal pathway. An impact might be equivalent to an effect (change in the quality and/or quantity of surface water or groundwater), or it might be a change resulting from those effects (for example, ecological changes that result from hydrological changes).

impact cause: an activity (or aspect of an activity) that initiates a hazardous chain of events

impact mode: the manner in which a hazardous chain of events (initiated by an impact cause) could result in an effect (change in the quality and/or quantity of surface water or groundwater). There might be multiple impact modes for each activity or chain of events.

Impact Modes and Effects Analysis: a systematic hazard identification and prioritisation technique based on Failure Modes and Effects Analysis

landscape class: for bioregional assessment (BA) purposes, an ecosystem with characteristics that are expected to respond similarly to changes in groundwater and/or surface water due to coal resource development. Note that there is expected to be less heterogeneity in the response within a landscape class than between landscape classes. They are present on the landscape across the entire BA subregion or bioregion and their spatial coverage is exhaustive and non-overlapping. Conceptually, landscape classes can be considered as types of ecosystem assets.

life-cycle stage: one of five stages of operations in coal resource development considered as part of the Impact Modes and Effects Analysis (IMEA). For coal seam gas (CSG) operations these are exploration and appraisal, construction, production, work-over and decommissioning. For coal mines these are exploration and appraisal, development, production, closure and rehabilitation. Each life-cycle stage is further divided into components, which are further divided into activities.

likelihood: probability that something might happen

likelihood score: for the purposes of Impact Modes and Effects Analysis (IMEA), the annual probability of a hazard occurring, which is scored so that a one-unit increase (or decrease) in score indicates a ten-fold increase (or decrease) in the probability of occurrence

material: pertinent or relevant

preliminary assessment extent: the geographic area associated with a subregion or bioregion in which the potential water-related impact of coal resource development on assets is assessed

receptor: a point in the landscape where water-related impacts on assets are assessed

recharge: see groundwater recharge

risk: the effect of uncertainty on objectives

runoff: rainfall that does not infiltrate the ground or evaporate to the atmosphere. This water flows down a slope and enters surface water systems.

severity: magnitude of an impact

severity score: for the purposes of Impact Modes and Effects Analysis (IMEA), the magnitude of the impact resulting from a hazard, which is scored so that an increase (or decrease) in score indicates an increase (or decrease) in the magnitude of the impact

source dataset: a pre-existing dataset sourced from outside the Bioregional Assessment Programme. This includes data sourced from the Programme partner organisations.

spring: a naturally occurring discharge of groundwater flowing out of the ground, often forming a small stream or pool of water. Typically, it represents the point at which the watertable intersects ground level.

stratigraphy: stratified (layered) rocks

stressor: chemical or biological agent, environmental condition or external stimulus that might contribute to an impact mode

subregion: an identified area wholly contained within a bioregion that enables convenient presentation of outputs of a bioregional assessment (BA)

surface water: water that flows over land and in watercourses or artificial channels and can be captured, stored and supplemented from dams and reservoirs

uncertainty: the state, even partial, of deficiency of information related to understanding or knowledge of an event, its consequence, or likelihood. For the purposes of bioregional assessments, uncertainty includes: the variation caused by natural fluctuations or heterogeneity; the incomplete knowledge or understanding of the system under consideration; and the simplification or abstraction of the system in the conceptual and numerical models.

water allocation: the specific volume of water allocated to water access entitlements in a given season, defined according to rules established in the relevant water plan

water-dependent asset: an asset potentially impacted, either positively or negatively, by changes in the groundwater and/or surface water regime due to coal resource development

water system: a system that is hydrologically connected and described at the level desired for management purposes (e.g. subcatchment, catchment, basin or drainage division, or groundwater management unit, subaquifer, aquifer, groundwater basin)

watertable: the upper surface of a body of groundwater occurring in an unconfined aquifer. At the watertable, pore water pressure equals atmospheric pressure.

well: typically a narrow diameter hole drilled into the earth for the purposes of exploring, evaluating or recovering various natural resources, such as hydrocarbons (oil and gas) or water. As part of the drilling and construction process the well can be encased by materials such as steel and cement, or it may be uncased. Wells are sometimes known as a ‘wellbore’.

www.bioregionalassessments.gov.au

Australian Government

Department of the Environment and Energy

Bureau of Meteorology

Geoscience Australia

CSIRO