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BIOREGIONAL ASSESSMENTS

CSIRO

Geological and environmental baseline assessment for the Cooper GBA region

Geological and Bioregional Assessment: Stage 2 summary

2020

A scientific collaboration between the Department of Agriculture, Water and the Environment, Bureau of Meteorology, CSIRO and Geoscience Australia

The Geological and Bioregional Assessment Program

The Geological and Bioregional Assessment Program will provide independent scientific advice on the potential impacts from development of selected unconventional hydrocarbon plays on water and the environment. The geological and environmental data and tools produced by the Program will assist governments, industry, landowners and the community to help inform decision making and enhance the coordinated management of potential impacts.

The Program 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 geological and bioregional assessments. For more information, visit http://www.bioregionalassessments.gov.au.

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Authorship is listed alphabetically after first author.

On 1 February 2020 the Department of the Environment and Energy and the Department of Agriculture merged to form the Department of Agriculture, Water and the Environment. Work for this document was carried out under the then Department of the Environment and Energy. Therefore, references to both departments are retained in this report.

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Cover photograph

Cooper Creek in flood, 4 km east of Windorah, March 2018.
Credit: Geological and Bioregional Assessment Program, Russell Crosbie (CSIRO) Element: GBA-COO-2-343

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At a glance

The $35.4 million Geological and Bioregional Assessment (GBA) Program is assessing the potential environmental impacts of shale and tight gas development to inform regulatory frameworks and management approaches. The geological and environmental baseline assessment for the Cooper GBA region (Stage 2) integrates data, knowledge and conceptual models that are the building blocks for the Stage 3 impact analysis and management. The Cooper GBA region (Figure 1) is in south-west Queensland and in the north-east of SA. Although conventional production has been underway for over 50 years, the region continues to yield new onshore gas discoveries.

Geology and gas resources: Areas of higher prospectivity for shale, tight and deep coal gas plays include the Nappamerri, Patchawarra, Windorah troughs (Figure 1), which is consistent with the location of recent exploration activity.

Groundwater: Most (90%) of the 2137 registered bores that access the Eromanga and Lake Eyre basins are less than 300 m deep. The deeper Cooper Basin is not a groundwater source.

Surface water: Cooper Creek supports the Ramsar-listed Coongie Lakes and many waterholes and terminal lakes. Waterholes are sustained by localised freshwater lenses recharged by floods. There is no evidence of connectivity between deeper groundwaters, gas plays and waterholes.

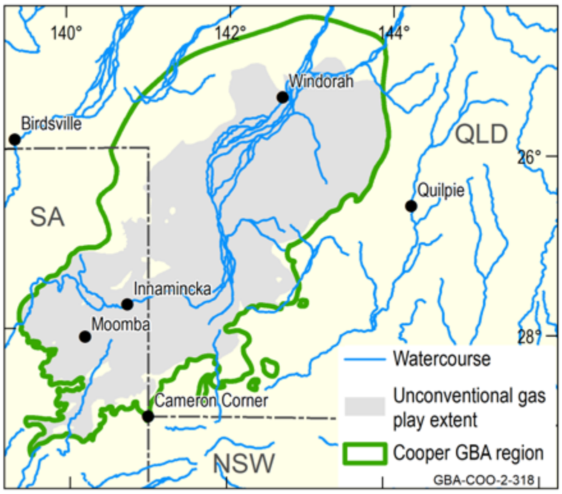

Figure 1 The Cooper GBA region

Element: GBA-COO-2-318

Water availability: Surface water is an unreliable potential water source for a future shale, tight and deep coal gas industry. Groundwater and produced water extracted during conventional oil and gas development are likely water sources.

Potential hydrological connections: Stage 3 will assess potential impacts from possible hydrological connections between deep unconventional gas plays or water source aquifers and environmental assets (including groundwater-dependent ecosystems).

Protected matters: Matters of national and state environmental significance include threatened species (plants, reptiles, birds and mammals) and ecological communities, wetlands, and heritage places.

Most of the Cooper GBA region is classified as floodplain and alluvium, inland dunefields or undulating country on fine-grained sedimentary rocks. Conceptual models for each landscape class will underpin assessments in Stage 3.

In Stage 3, 12 protected species and 18 protected areas will be assessed in greater detail (priority 1). This includes ten threatened species, one threatened ecological community and one Ramsar-listed wetland listed under the *Environment Protection and Biodiversity Conservation Act 1999* (Cth). A further nine protected areas will be assessed at a regional scale using landscape classes (priority 2). Further assessment is not warranted for the remaining 131 protected matters (priority 3).

Potential impacts: Over 200 individual hazards were systematically identified by considering all the possible ways an activity may impact ecological, economic and social values. Hazards were classified into 14 causal pathways – the logical chain of events that link unconventional gas resource development with potential impacts on water and the environment – and then aggregated in three groups.

Stage 3 will assess how each causal pathway might impact on the suite of endpoints – ecological, economic and/or social values to be protected. Seven causal pathways will be assessed in greater detail (priority 1). Important potential impacts to be assessed in Stage 3 are changes to groundwater quality; surface water flows; cultural heritage damage or loss; habitat fragmentation and loss; introduction of invasive species; and contamination of soil, groundwater and/or surface water.

The Geological and Bioregional Assessment Program

The GBA Program is undertaking independent scientific studies in three geological basins: the Cooper Basin in Queensland and SA, the Isa Superbasin in Queensland and the Beetaloo Sub-basin in NT. These scientific studies are being conducted by CSIRO and Geoscience Australia, supported by the Bureau of Meteorology and managed by the Department of Agriculture, Water and the Environment. They aim to provide baseline information that:

- identifies and evaluates areas of high potential for shale and tight gas for future development and any potential connections with water resources
- collates and summarises key information about geological structure, groundwater movement through geological layers, surface water systems and ecological systems
- evaluates possible ways that unconventional gas resource development might impact the things we value, such as the Cooper Creek floodplain, groundwaters, protected species, as well as culturally and ecologically important matters

User panels

Each assessment is informed by a user panel, where user needs and Program findings are discussed, and information is shared. The user panel for the Cooper GBA region includes people from local government, natural resource management bodies, Queensland and SA state governments, Traditional Owner groups, pastoralists, industry and other land user groups. The assessments will inform and support future regulatory frameworks and appropriate management approaches.

About this summary report

This report summarises knowledge about the geology and prospectivity of shale, tight and deep coal gas resources, water resources, protected matters (environmental and cultural) and risks to water (quantity and quality) and the environment in the Cooper GBA region and each section is colour coded to correspond with Figure 2.

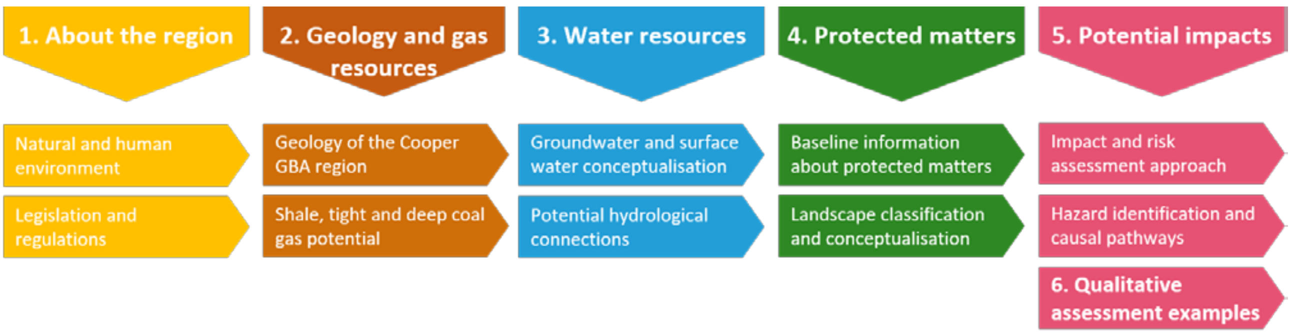

Figure 2 Geological and environmental baseline assessment report structure

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About the region

The Cooper GBA region (Figure 1) covers approximately 130,000 km^2 – 95,740 km^2 in Queensland, 34,310 km^2 in SA and 8 km^2 in NSW. It is defined by the surface projection of the outline of the Cooper Basin geological province.

Oil and gas resources were discovered in the region in 1963 and both the Cooper and overlying Eromanga geological basins have been producing conventional oil and gas for 50 years. The first gas flowed by pipeline into Adelaide in 1969, followed by Sydney in 1976 and Brisbane in 1996. Subsequent prospectivity assessments for selected unconventional plays have identified that the Cooper Basin has the potential to produce significant amounts of shale, tight and deep coal gas in the coming years.

The Cooper GBA region is generally flat and surface water availability is unpredictable. Rainfall in the region is highly variable and is supplemented by surface water flowing into the region from the north. Consequently, natural systems are driven by resource pulses and boom–bust ecological dynamics, shaping the high diversity of ecological communities and species (Figure 3). Native vegetation communities have been modified by grazing of sheep and cattle (Section 1.3 in baseline synthesis and gap analysis (Holland et al., 2020)). A hotter and drier climate is forecast by global climate models (Section 1.2 in baseline synthesis and gap analysis (Holland et al., 2020)).

The human population is sparse, with a large ‘fly-in–fly-out’ workforce servicing the oil and gas industry. More than 60% of the region is covered by Indigenous Land Use Agreements and is within the Eyre region for Indigenous language groups (Section 1.3 in baseline synthesis and gap analysis (Holland et al., 2020)).

The emerging shale, tight and deep coal gas industry is regulated at federal, state and local levels to ensure that industry development is sustainable and responsible and minimises impacts on environmental and social values. Commonwealth, intergovernmental, SA and Queensland regulations that are relevant to the development of shale, tight and deep coal gas resources are summarised (Section 1.4 in baseline synthesis and gap analysis (Holland et al., 2020)).

(a)

(b)

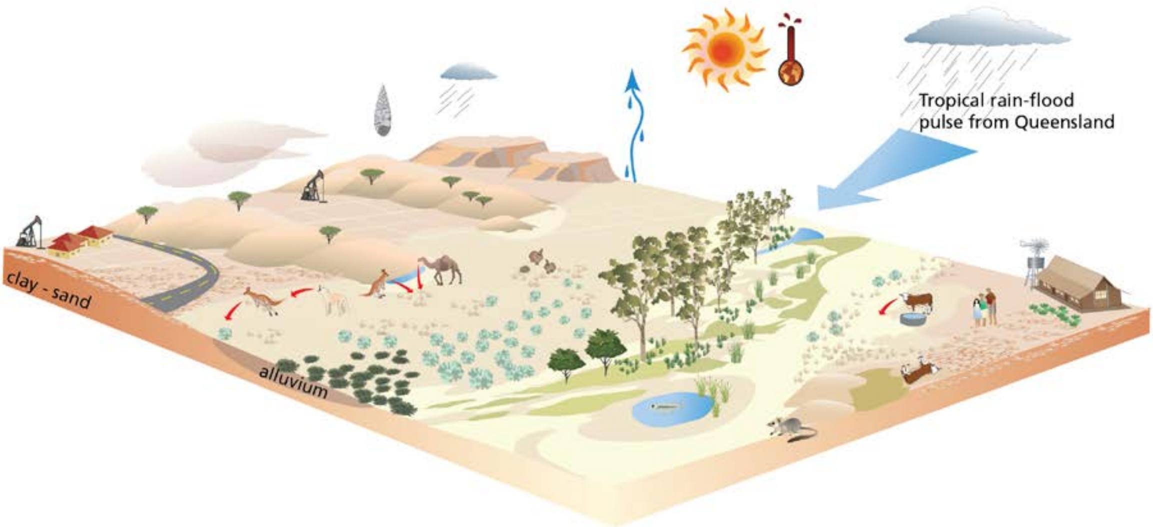

Figure 3 Channel Country characteristics during extreme (a) boom and (b) bust periods

The red arrows in the diagram represent grazing pressure and weed spread.
Source: Figure 4 in South Australian Arid Lands Natural Resources Management Board (2017)

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Geology and gas resources

The Cooper Basin is a Carboniferous to Triassic sedimentary basin that is up to 2500 m thick and occurs at depths between 1000 and 4500 m. It is overlain by the Jurassic–Cretaceous Eromanga and Cenozoic Lake Eyre sedimentary basins, both of which host major confined aquifer systems (Section 2.1 in baseline synthesis and gap analysis (Holland et al., 2020); geology technical appendix (Owens et al., 2020)).

The Cooper and Eromanga basins form Australia's most developed onshore hydrocarbon province. Although commercial production has been underway for over 50 years, the region continues to yield new discoveries. Between 1969 and 2014, the Cooper Basin and overlying Eromanga Basin produced 6.54 Tcf of gas (AERA, 2018) and contain 256 gas fields and 166 oil fields currently in production. This is a nationally significant provider of gas to the East Coast Gas Market (Section 2.2 in baseline synthesis and gap analysis (Holland et al., 2020)).

In the Cooper Basin, numerous resource development companies are pursuing a range of shale, tight and deep coal gas plays. Areas of higher prospectivity include the Nappamerri, Patchawarra, Windorah, Allunga and Wooloo troughs, which is consistent with recent exploration activity (Figure 4).

The mapped depth and extent of these shale, tight and deep coal gas plays inform where the plays are most likely to be present within the basin, which in turn aids assessment of potential connectivity to overlying surface water – groundwater systems and associated assets (Figure 5; Section 2.2.4 in baseline synthesis and gap analysis (Holland et al., 2020); petroleum prospectivity technical appendix (Lech et al., 2020)).

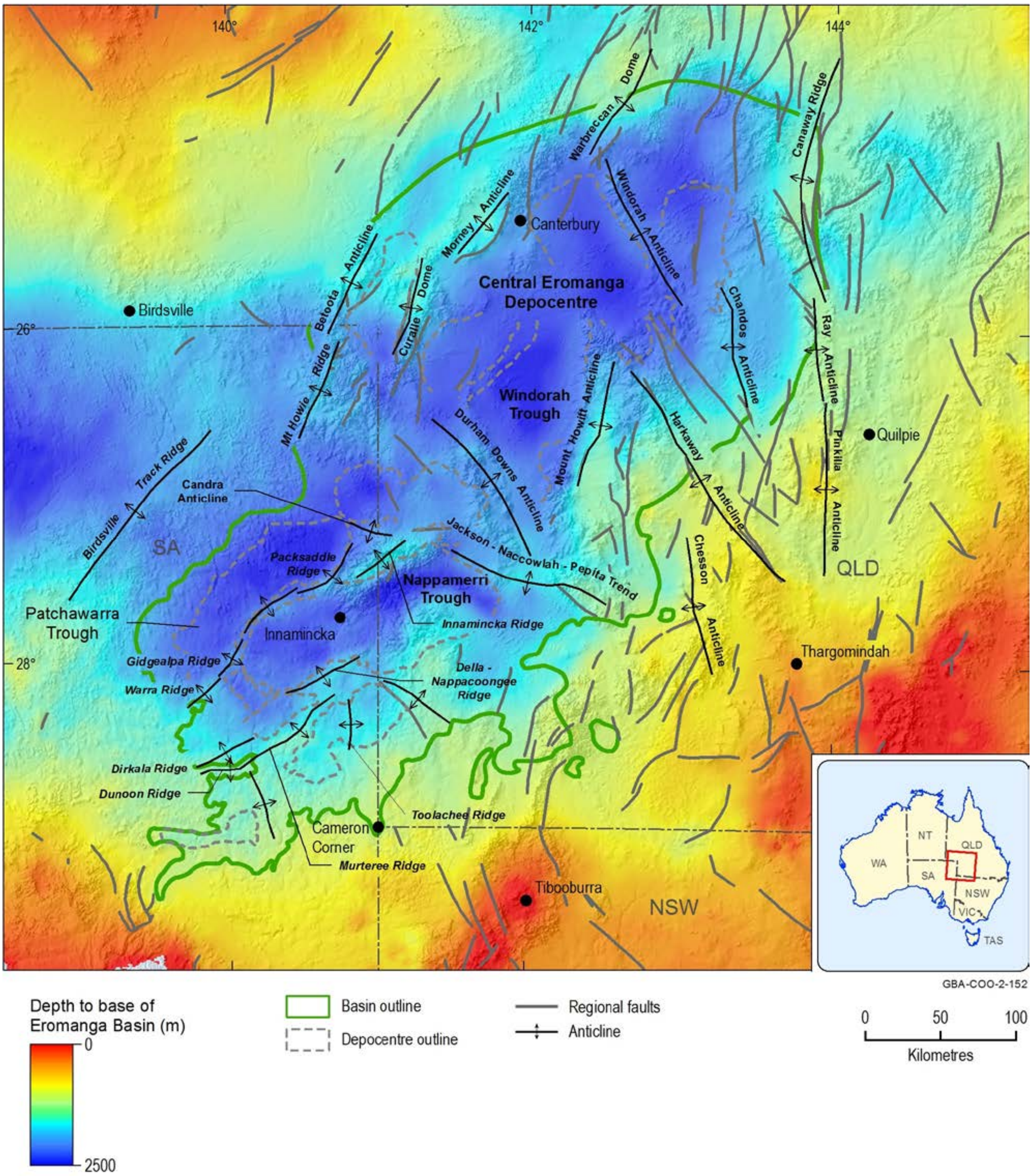

Figure 4 Structural elements map of the Eromanga Basin in the Cooper GBA region overlain on the depth to base Eromanga Basin

Anticlines depicted are regional trends and therefore to be used as a guide only.
Data: depth to base Eromanga Basin and regional faults from Smerdon et al. (2012). Anticlines from (Hall et al., 2015)
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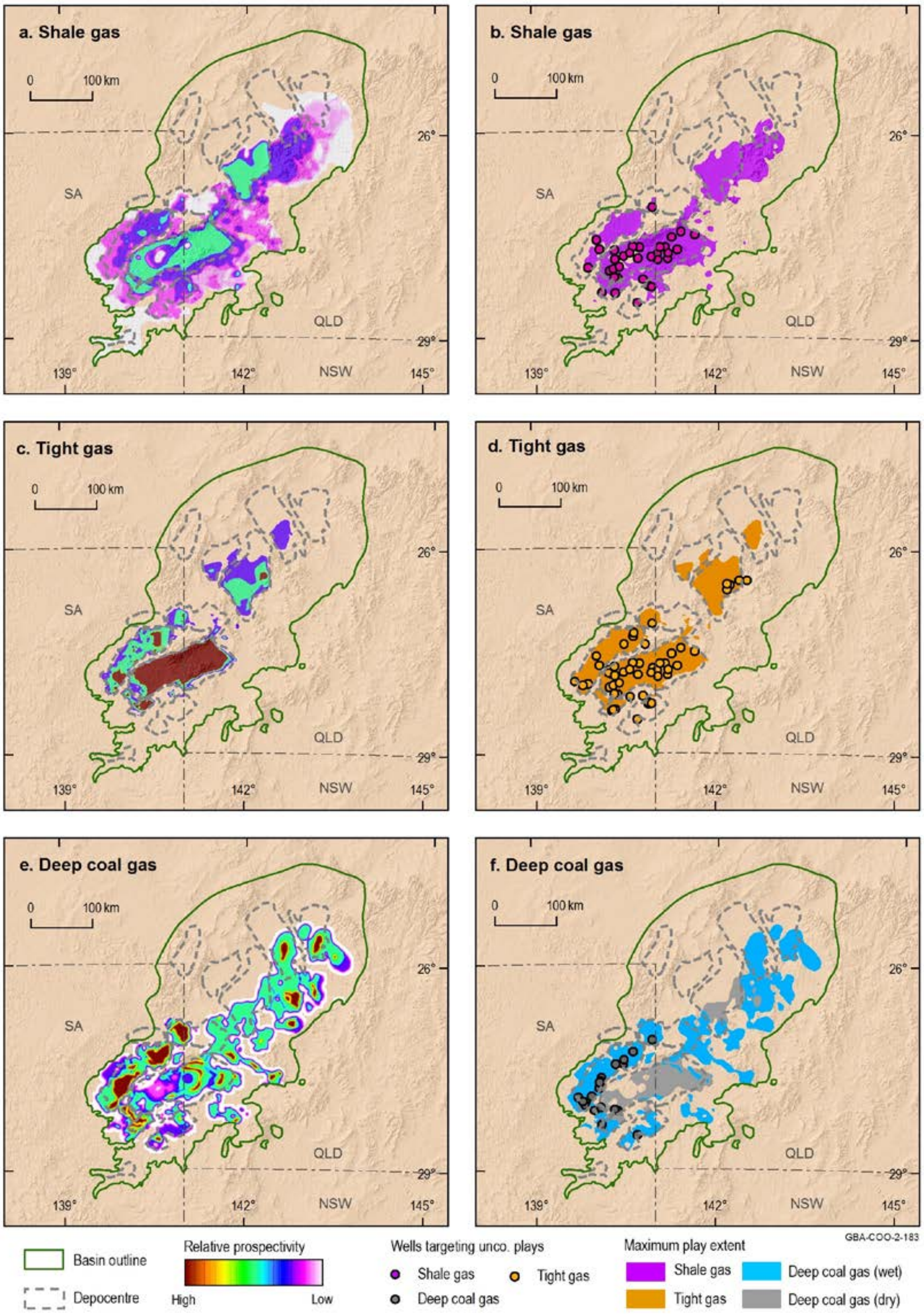

Figure 5 Combined relative prospectivity maps by play type

(a) Shale gas relative prospectivity map; (b) maximum extent of shale gas plays with location of key wells targeting shale gas; (c) basin-centred tight gas relative prospectivity map; (d) maximum extent of basin-centred tight gas plays with location of key wells targeting tight gas; (e) deep coal gas (dry and wet) relative prospectivity map; and (f) maximum extent of deep coal gas play with location of key wells targeting deep coal gas play. The maximum area in which each play type may be present was derived from the relative prospectivity maps using a cut-off value of 0.2.
Well coverage is not exhaustive, as there are inconsistencies in how wells have been classified depending on the information source. Only key wells used in shale, tight and deep coal gas characterisation are shown.
This figure has been optimised for printing on A3 paper (420 mm x 297 mm).
Data: Geological and Bioregional Assessment Program (2019a)
Source: petroleum prospectivity technical appendix (Lech et al., 2020)
Element: GBA-COO-2-183

Understanding conventional and unconventional gas

Conventional natural gas (and oil) occurs in discrete accumulations trapped by a geological structure and/or stratigraphic feature, typically bounded by a down-dip contact with water and capped by impermeable rock.

Conventional petroleum was not formed in-situ; it migrated from the deeper source rocks into a trap containing porous and permeable reservoir rocks (Schmoker, 2002; Schmoker et al., 1995) (Figure 6).

Unconventional gas is found in a range of geological settings and includes shale gas, tight gas and deep coal gas. Unlike conventional reservoirs, unconventional reservoirs have low permeabilities and require innovative technological solutions to move the trapped hydrocarbons to the surface (Figure 6).

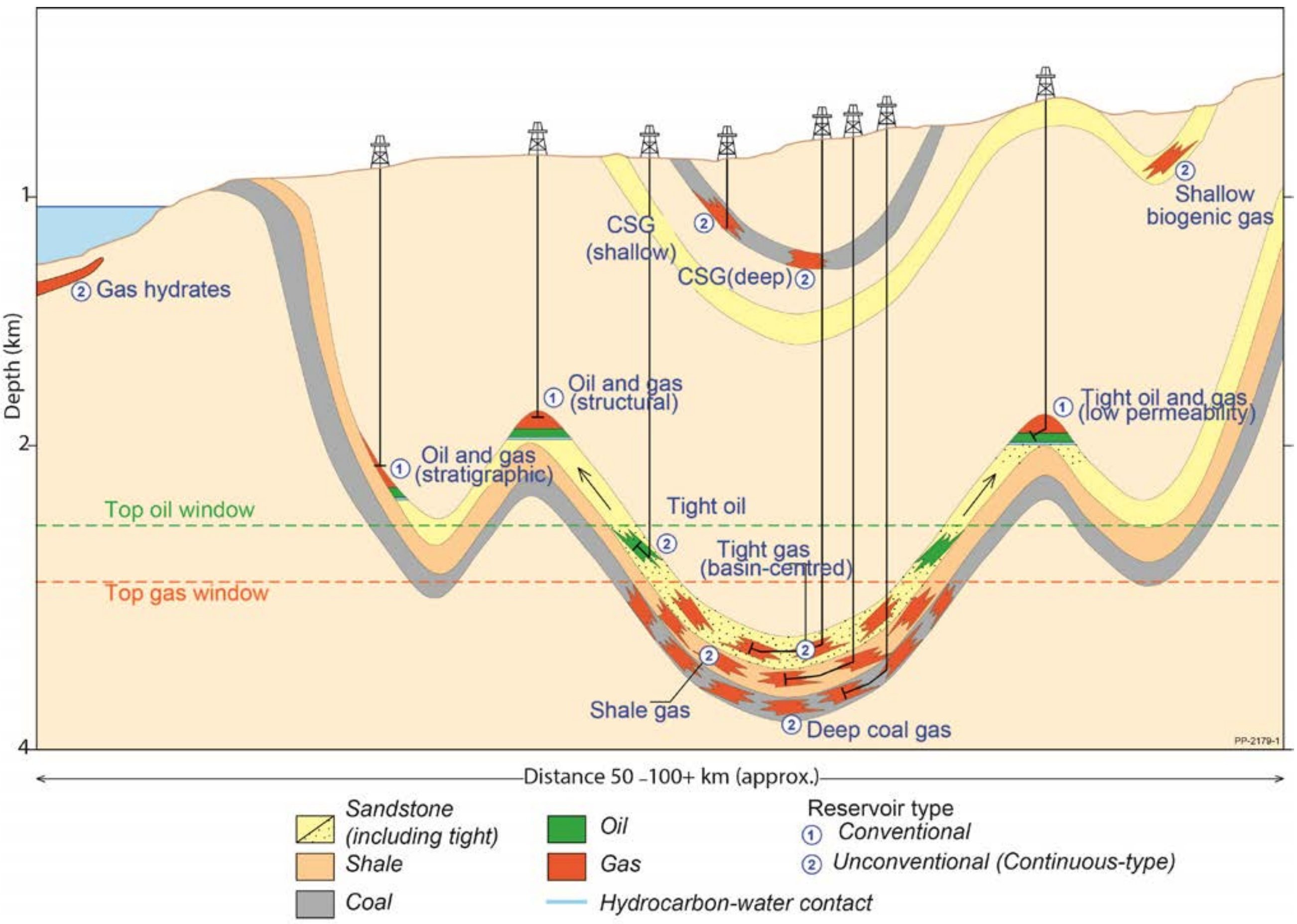

Figure 6 Schematic showing some of the typical types of oil and gas accumulations

Except for gas hydrates, which are located below the sea floor in deep water, these are common conventional and unconventional hydrocarbon accumulations observed in the Cooper Basin. The 'oil window' refers to the maturity range in which oil is generated from oil-prone organic matter. Below is the 'gas window', which refers to the maturity range in which gas is generated from organic matter.
Source: after Schenk and Pollastro (2002); Cook et al. (2013); Schmoker et al. (1995)
Element: GBA-COO-2-172

Water resources – groundwater

There are three major hydrostratigraphic sequences in the Cooper GBA region: the Cooper Basin, the Eromanga Basin and Cenozoic sediments of the Lake Eyre Basin (Figure 7). In the Cooper Basin, the Permian Gidgealpa Group hosts the shale, tight and deep coal gas resources and is overlain by the Nappamerri Group, which is considered a regional seal to petroleum systems in the Gidgealpa Group. Due to depth of burial (generally greater than 1500 m), the Cooper Basin is not directly used as a groundwater source (Section 3.1 in baseline synthesis and gap analysis (Holland et al., 2020); hydrogeology technical appendix (Evans et al., 2020)).

The Eromanga Basin covers the entirety of the Cooper Basin and contains a sequence of aquifers and aquitards that comprise part of the Great Artesian Basin (GAB). Most of the existing groundwater bores (779 of 1566) in the region access the shallower Cenozoic Lake Eyre Basin aquifers from a mean depth of 55 m (Figure 8). Groundwater in the aquifers of the Eromanga and Lake Eyre basins in the Cooper GBA region is generally suitable for stock and domestic use.

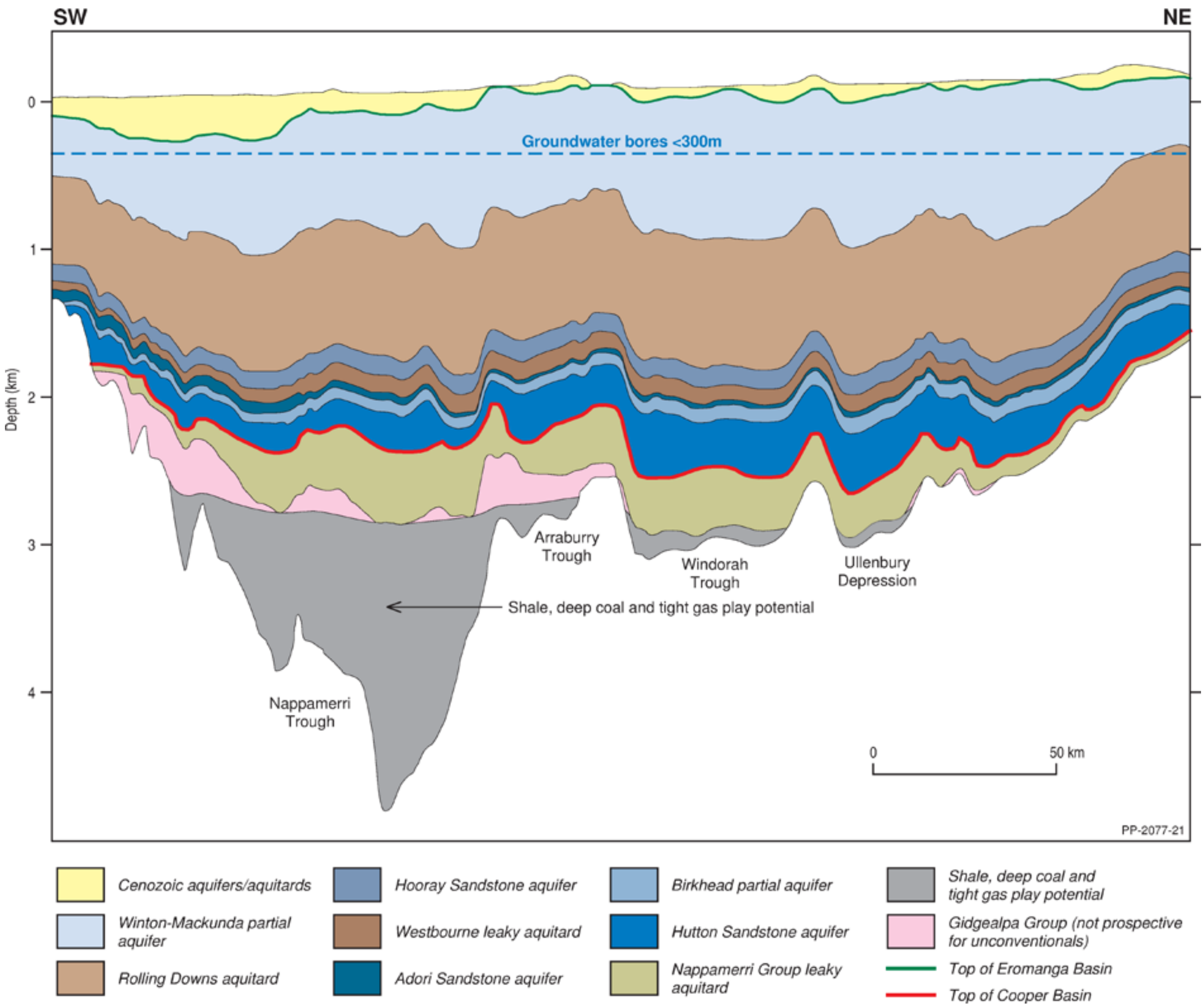

Figure 7 Hydrostratigraphic cross-section for the Cooper GBA region

Location of the cross-section line is shown in Figure 14 in baseline synthesis and gap analysis (Holland et al., 2020). Dashed blue line represents depth of most groundwater bores in the region (i.e. 90% of bores are less than 300 m deep (Evans et al., 2020)).
Source: Geoscience Australia (2016)
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Groundwater (from the GAB and aquifers above the GAB) and produced water extracted during conventional oil and gas development are both potential water sources for a future shale, tight and deep coal gas industry in the Cooper GBA region. Existing allocations under water-sharing plans, potential competition with existing water users (e.g. stock and domestic users; conventional oil and gas industry) and proximity to produced water supplies are likely to affect the future availability (Section 3.1.4 in baseline synthesis and gap analysis (Holland et al., 2020)).

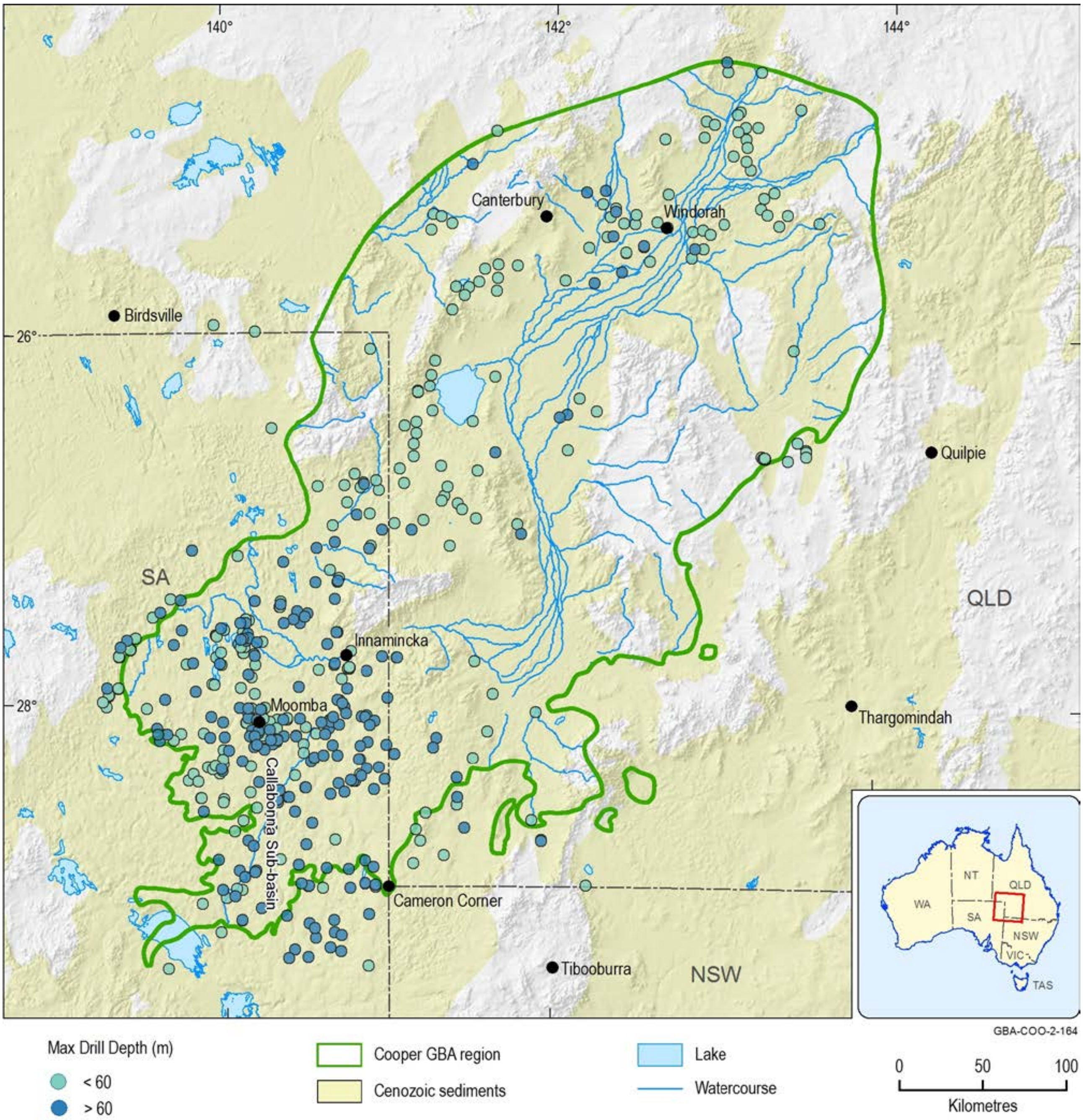

Figure 8 Potential distribution of the 'deeper' aquifer in Lake Eyre Basin using maximum groundwater bore depth as an analogue

Source: Geological and Bioregional Assessment Program (2018a)
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Water resources – potential hydrological connections

Between 600 and 2000 m of sedimentary rock typically separates aquifers, such as those in the Cenozoic and Winton-Mackunda formations or deeper GAB aquifers, from shale, tight and deep coal gas plays in the Cooper Basin.

The nature of the hydrological connection (if any) between deeper groundwaters (Cooper, Eromanga and Lake Eyre basins), shallow aquifers and surface waters is poorly understood. Five potential hydrological connections are postulated for the Cooper GBA region (Table 1; Section 3.4 in baseline synthesis and gap analysis (Holland et al., 2020); hydrogeology technical appendix (Evans et al., 2020)). Investigations in Stage 3 will focus on potential hydrological connections relevant to risks from future shale, tight and deep coal gas development.

Hydrochemistry and dissolved gas concentrations provide some evidence of potential connectivity between deep and shallow system components. However, the assessment also highlights that considerable data and knowledge gaps exist and leads to several hypotheses to be tested during Stage 3 or in future studies to better estimate the likelihood of hydrological connections between stressors and assets.

Table 1 Summary of potential hydrological connections and potential impacts on water and the environment in the Cooper GBA region

Potential hydrological connections	Potential impacts on water and the environment
① Vertical migration via deep-seated dilational faults connecting unconventional gas plays to overlying aquifers	Water bores and springs that access artesian GAB aquifers.
② Lateral migration through porous GAB aquifers and Winton-Mackunda partial aquifer	Water bores tapping the GAB aquifers and Winton-Mackunda partial aquifer.
③a) Lateral migration through the Rolling Downs Group aquitard via polygonal fault system (PFS)	Not directly.
③b) Vertical migration through the Rolling Downs Group aquitard via PFS reaching permeable intervals of the Winton-Mackunda partial aquifer	Water bores in the Winton-Mackunda partial aquifer.
④ Migration due to contact between gas plays and overlying aquifers near the basin margin (due to the top of the Nappamerri Group pinching out and/or through inferred fault zones associated with basement highs).	Springs fed by GAB aquifers in the south (Lake Blanche Springs) and GDEs associated with lakes in the south (e.g. Lake Blanche). Impacts from shale, tight and deep coal developments would be quite indirect, as these types of plays occur in the Copper Basin, and not the Eromanga Basin.
⑤ Vertical migration at catchment constrictions where steep hydraulic gradients exist between alluvial aquifers and underlying GAB formations.	Impacts due to extracting water, particularly from Winton-Mackunda partial aquifer and Lake Eyre Basin.

GAB = Great Artesian Basin; GDE = groundwater-dependent ecosystem; PFS = polygonal fault system

Water resources – surface water – groundwater conceptualisation

Cooper Creek supports the Ramsar-listed Coongie Lakes and many waterholes and terminal lakes and has one of the most variable flow regimes of all rivers worldwide. When flooded, the floodplain becomes a huge inland 'sea' broken only by a few ridges and stunted trees; it eventually contracts to channels, lagoons and claypans.

Runoff is generated in the upper reaches (outside the Cooper GBA region) and flows through the Barcoo and Thomson river systems before becoming Cooper Creek, which flows over large areas (typically 20,000 to 50,000 km^2, depending on the flood conditions) of floodplain below Windorah. High evapotranspiration rates reduce streamflow by about half between the confluence of the Thomson and Barcoo rivers and the Nappa Merrie gauge near the SA border (Figure 9; Section 3.2 in baseline synthesis and gap analysis (Holland et al., 2020)).

Seven large waterholes make up half the estimated volume of waterhole capacity on the Cooper Creek floodplain. Potential water sources for a future shale, tight and deep coal gas industry in the Cooper GBA region are unlikely to include surface water sources.

Surface water quality is variable in space and over time, with floodwaters in the upper reaches having low salinity and the terminal lakes tending to be saline. Median salinity recorded at three stream gauges on the Cooper, Barcoo and Thomson rivers is approximately 100 mg/L total dissolved solids (TDS), which is suitable for drinking water and for stock watering (Section 3.2.2 in baseline synthesis and gap analysis (Holland et al., 2020)).

Surface water – groundwater interactions are more likely to occur where water sits in the landscape, which in the Cooper GBA region is primarily the Cooper Creek floodplain. From a small study, the occurrence of freshwater lenses overlying more saline groundwater was noted in the vicinity of some waterholes on the floodplain. This was attributed to recharge during floods, with water leaking through the base of the waterholes. It is not known, though, whether all waterholes act as points of recharge to shallow aquifers. Also, the degree of separation between waterhole and watertable could change depending on where the waterhole sits in the landscape (e.g. near the margins or in the centre of the flood plain).

Lakes can act as points of recharge or discharge for shallow aquifers. Discharge can occur through evaporation during dry periods, with concentration of salts in the lake floor.

Springs are unlikely to be directly impacted by future developments of shale, tight and deep coal gas plays, as springs in the Cooper GBA region are distant from future development areas (Section 3.3 in baseline synthesis and gap analysis (Holland et al., 2020)). However, cumulative impacts from multiple types of petroleum plays (e.g. conventional oil and gas; coal seam gas (CSG); shale, tight and deep coal gas) to GAB springs near Lake Blanche are difficult to predict at this point in time. This could be considered further once there is a clearer understanding of how resources will be developed in the south-western corner of the Cooper GBA region in the future.

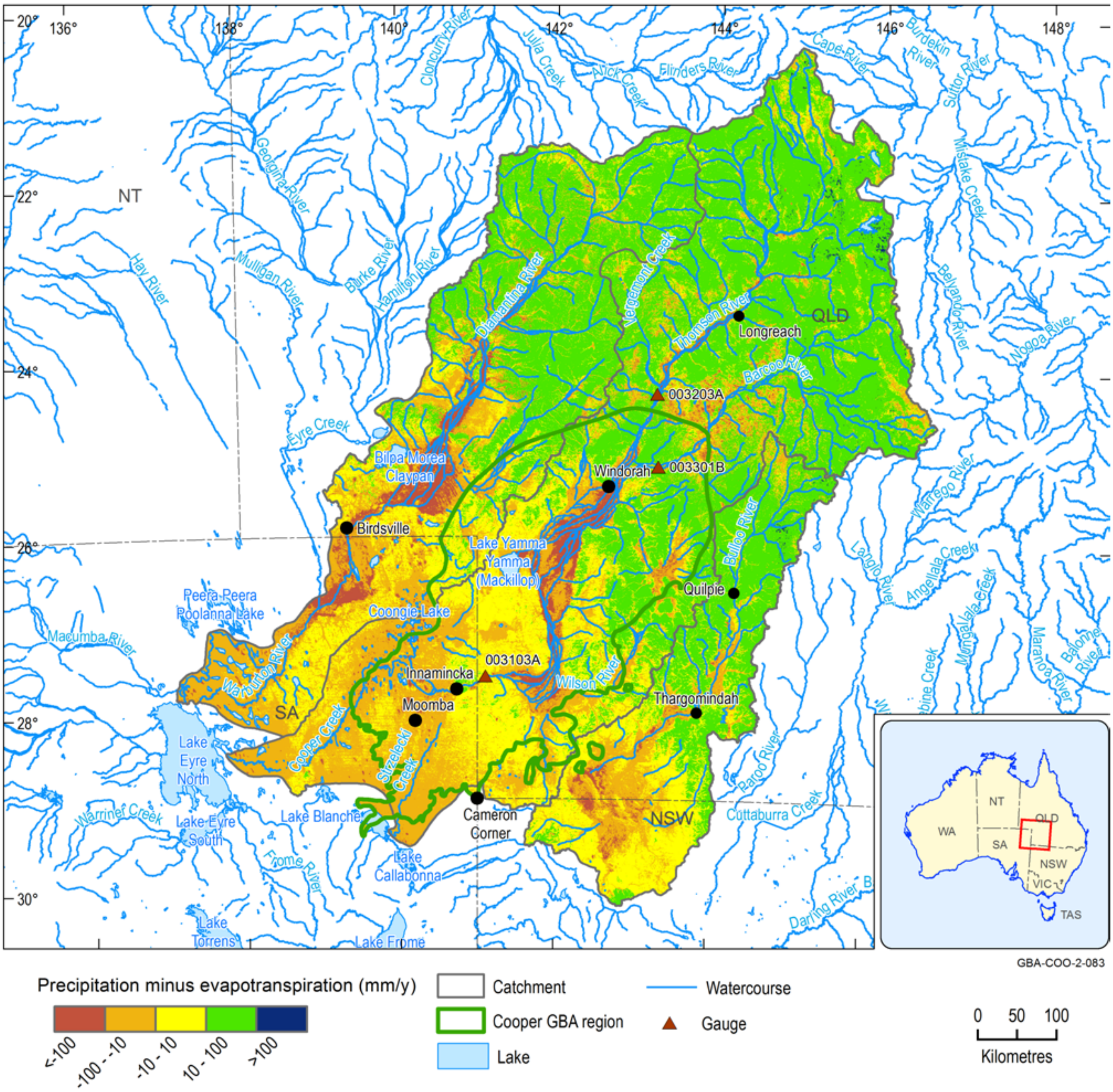

Figure 9 Precipitation minus evapotranspiration (P–ET) for 2001 to 2010 showing areas exporting water (headwaters are mostly green) and areas of lateral inflows (floodplains are mostly red)

Data: CSIRO (2014)

Element: GBA-COO-2-083

Protected matters – environmental and cultural assets

Matters of National Environmental Significance (MNES) in the Cooper GBA region include a Ramsar-listed wetland (Coongie Lakes; Figure 10), eight nationally important wetlands ((i) Bulloo Lake; (ii) Coongie Lakes; (iii) Cooper Creek – Wilson River Junction; (iv) Cooper Creek Overflow swamps – Nappa Merrie; (v) Cooper Creek Overflow swamps – Windorah; (vi) Lake Cuddapan; (vii) Lake Yamma Yamma; and (viii) the Strzelecki Creek Wetland system) (Figure 11) and 26 taxa (plants, reptiles, birds and mammals) listed as threatened (critically endangered, endangered or vulnerable) (Table 2, Section 4.1.1 in baseline synthesis and gap analysis (Holland et al., 2020); protected matters technical appendix (O'Grady et al., 2020)).

In addition, Matters of State Environmental Significance (MSES) (Section 4.1.2 in baseline synthesis and gap analysis (Holland et al., 2020); protected matters technical appendix (O'Grady et al., 2020)) in Queensland include 28 species listed as endangered, near threatened, vulnerable or special least concern. The region also contains areas of significant environmental value, including protected areas, High Ecological Value Aquatic Ecosystems (HEVAE) and regional ecosystems listed as ‘of concern’ in Queensland. In SA, 17 species are listed as endangered or vulnerable. Both states contain areas reserved for the region’s iconic landforms and biota, important wetlands and groundwater-dependent ecosystems.

Due to its historical significance, the Burke, Wills, King and Yandruwandha National Heritage Place located along the course of Cooper Creek is the one national heritage place listed as a protected matter. The Register of the National Estate also lists nine Indigenous sites, 12 heritage sites and two recreational areas. Cooper Creek and associated waterholes have a long and enduring cultural significance as part of traditional trade routes (Section 4.2 in baseline synthesis and gap analysis (Holland et al., 2020); protected matters technical appendix (O'Grady et al., 2020)).

To focus assessment in Stage 3, protected matters are prioritised based on the importance of the region to the matter (Table 2). The prioritisation identified 30 assets (including MNES and MSES) to be assessed in greater detail (priority 1) and 20 assets (regional ecosystems and protected areas) to be assessed at a regional scale using landscape classes (priority 2). The remaining 131 assets do not warrant further assessment in Stage 3 (priority 3) based on listed conservation status and/or expected occurrence in the region (Section 4.4 in baseline synthesis and gap analysis (Holland et al., 2020)).

Table 2 Prioritisation of protected matters that occur, or potentially occur, in the Cooper GBA region

Priority 1 – Importance of the region to the matter warrants a detailed level of assessment. Priority 2 – Importance of the region to the matter warrants a high-level assessment. Priority 3 – Importance of the region to the matter does not warrant further assessment.

Listing	Category	Priority 1	Priority 2	Priority 3
Protected species	Bird	4	0	35
	Mammal	3	0	7
	Plant	5	0	10
	Fish	0	0	2
	Reptile	0	0	4
Protected areas	Threatened ecological communities	1	0	0
	Regional ecosystems	0	8	73
	Wetland (national)[a]	8	0	0
	Wetland (international)	1	0	0
	Other protected areas	9	1	0
	Heritage sites	0	11	0
Total		**30**	**20**	**131**

[a] Coongie Lakes is listed twice: as a Ramsar-listed wetland (international) and as a DIWA wetland (national).
Source: Asset dataset (Geological and Bioregional Assessment Program, 2019b)

Figure 10 Coongie Lakes, looking south

Credit: Geological and Bioregional Assessment Program, Alex Tomlinson (Department of Energy and the Environment), September 2018
Element: GBA-COO-2-225

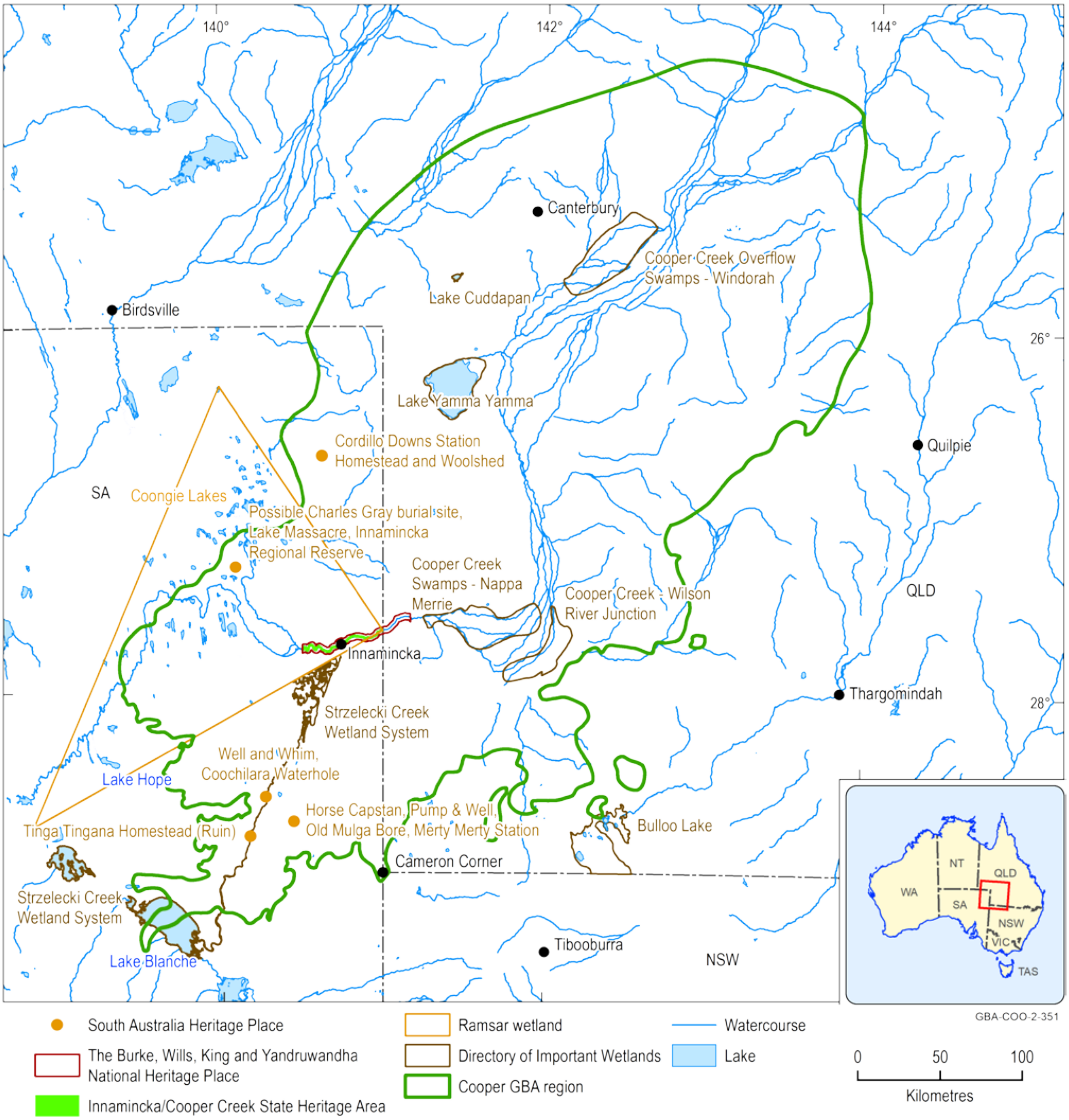

Figure 11 Location of environmental and cultural protected matters in the Cooper GBA region

Data: Department of the Environment and Energy (2008, 2010, 2018); Department for Environment and Water (SA) (2019); Department of Planning, Transport and Infrastructure (SA) (2019)
Element: GBA-COO-2-351

Protected matters – landscape classes

The Stage 3 assessment is underpinned by the classification of key ecological and hydrological features into seven landscape classes (Figure 12). Three landscape classes cover more than 80% of the region: floodplain and alluvium (Coongie Lakes (Figure 10) and Cullyamurra waterhole (Figure 13) are important features of this landscape class), inland dunefields (Figure 14), and undulating country on fine-grained sedimentary rocks. There are smaller areas of loamy and sandy plains, tablelands and duricrusts, clay plains, and springs (Section 4.3 in baseline synthesis and gap analysis (Holland et al., 2020); protected matters technical appendix (O'Grady et al., 2020)).

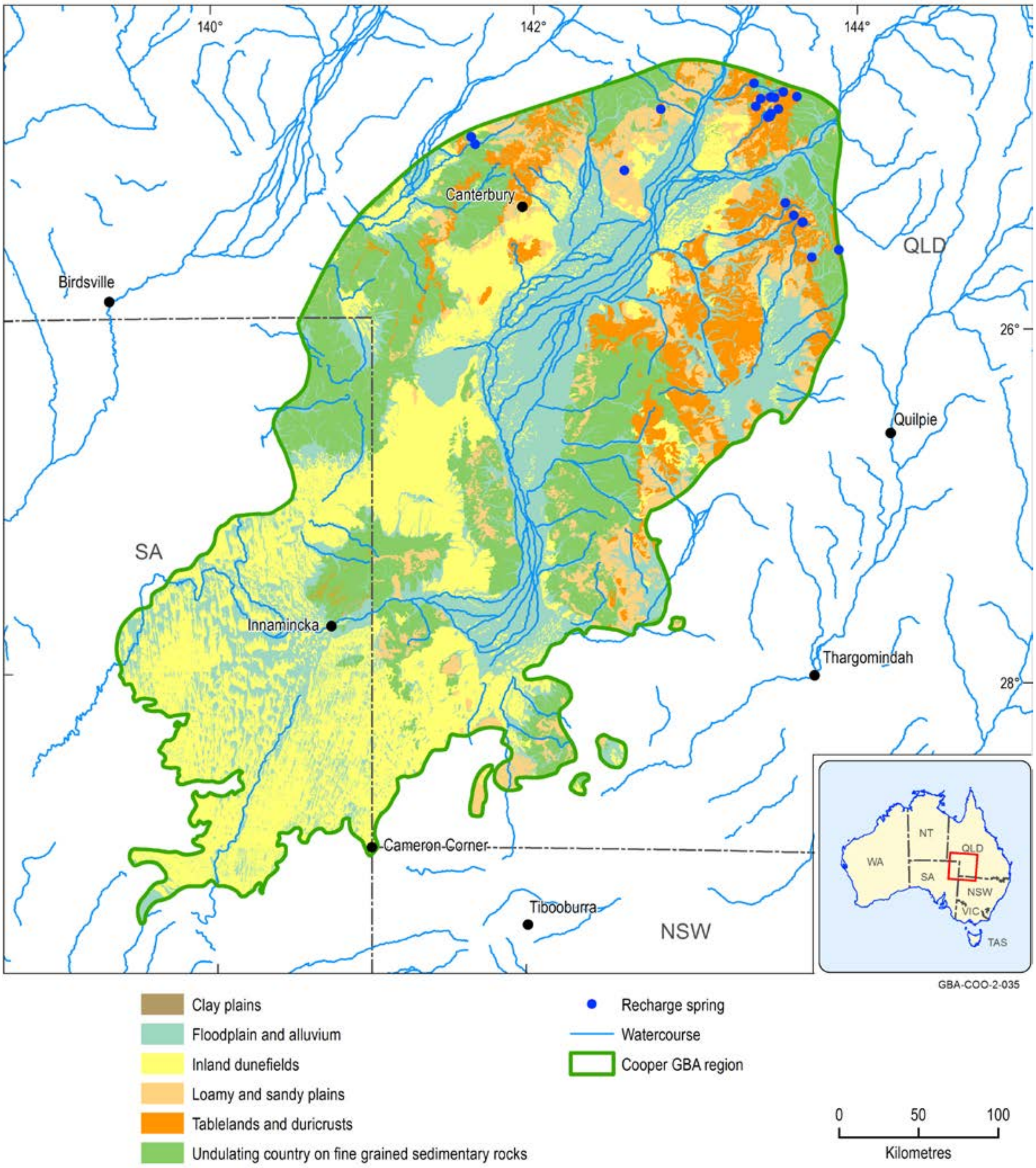

Figure 12 Landscape classes within the Cooper GBA region

Data: Geological and Bioregional Assessment Program (2018b)
Element: GBA-COO-2-035

Figure 13 Cullyamurra waterhole, looking north-west

Credit: Geological and Bioregional Assessment Program, Russell Crosbie (CSIRO), September, 2018
Element: GBA-COO-2-224

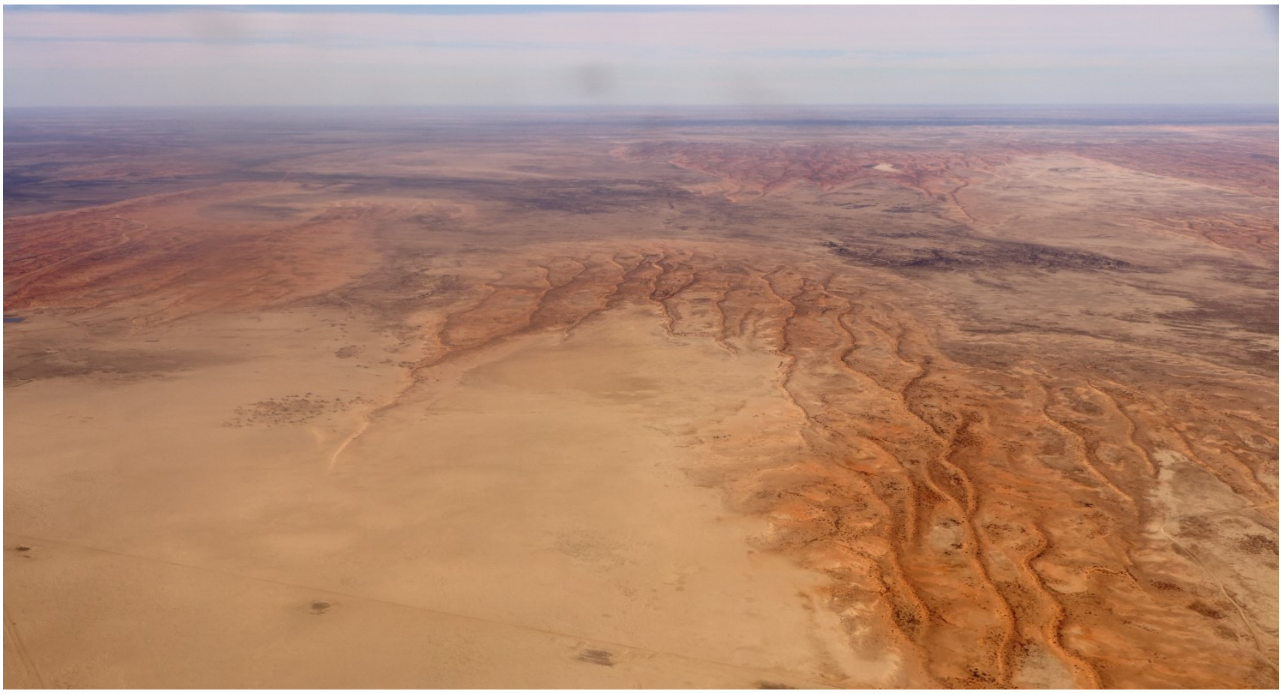

Figure 14 Examples of dunefields in the Cooper GBA region

Credit: Geological and Bioregional Assessment Program, Russell Crosbie (CSIRO), September, 2018
Element: GBA-COO-2-221

Potential impacts due to shale, tight and deep coal gas development

The risk assessment approach follows the principles for ecological risk assessment, with a view to meeting regulatory processes for the Cooper GBA region (Figure 15). Stage 2 establishes the context for the impact and risk assessment, including identifying hazards that are aggregated into a smaller set of causal pathways. Much of the impact and risk assessment will occur in Stage 3, when the causal pathways and endpoints identified in Stage 2 – the key building blocks for the impact and risk assessment – are finalised (Section 5.1 in baseline synthesis and gap analysis (Holland et al., 2020)).

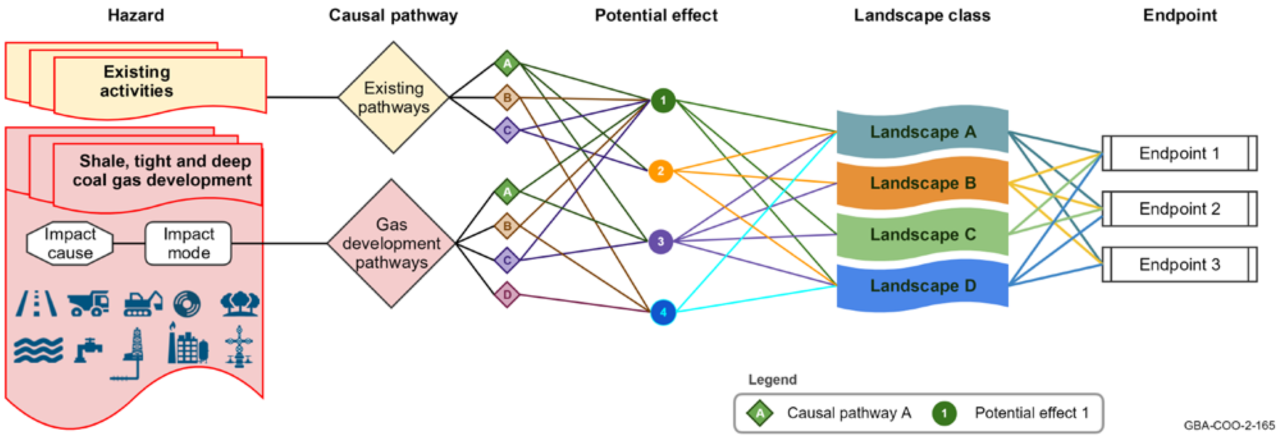

Figure 15 Overview of GBA impact and risk assessment approach, connecting hazards and potential effects from existing and future development through causal pathways to landscape classes and values assessed as endpoints

'Hazard' = an event, or chain of events, that might result in an effect; '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 or quantity of surface water or groundwater); 'causal pathway' = the logical chain of events, either planned or unplanned, that link unconventional gas resource development and potential impacts on water and the environment; 'potential effect' = specific types of impacts or changes to water or the environment, such as changes to the quantity and/or quality of surface water or groundwater or to the availability of suitable habitat; 'landscape class' = a collection of ecosystems with characteristics that are expected to respond similarly to changes in groundwater and/or surface water due to unconventional gas resource development; 'endpoint' = includes 'assessment endpoints' – an explicit expression of the ecological, economic and / or social values to be protected; and 'measurement endpoints' – measurable characteristics or indicators related to the assessment endpoint. Conceptual links are shown by coloured lines.
Element: GBA-COO-2-165

Hazards were systematically identified by considering all the possible ways an activity in the life cycle of shale, tight and deep coal gas development (Figure 16) may have an impact on ecological, economic and/or social values (Section 5.2 in baseline synthesis and gap analysis (Holland et al., 2020)).

The range of severity and likelihood scores for each hazard was agreed by experts from government and industry and members of the assessment team at five workshops for the Cooper GBA region between May and August 2018.

Stage 3 of the GBA Program will assess the likelihood and the consequences of the identified risks (risk analysis and risk evaluation phases).

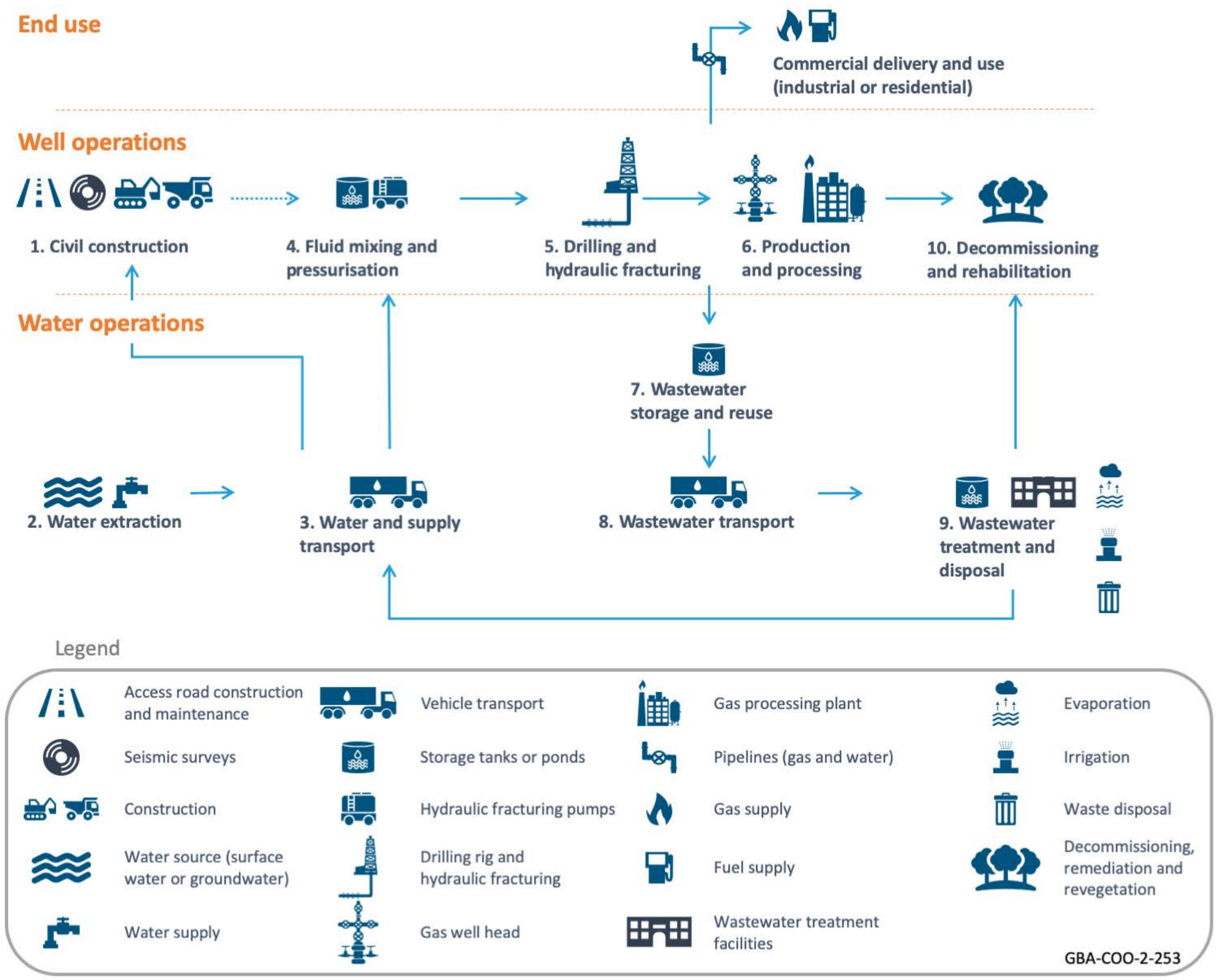

Figure 16 Ten major activities involved in typical shale, tight and deep coal gas resource development

Source: Adapted from Litovitz et al. (2013)
Element: GBA-COO-2-253

Each hazard was classified into one of 14 causal pathways – the logical chain of events that link unconventional gas resource development with potential impacts on water and the environment – aggregated (due to similar attributes) into three groups: 'landscape management', 'subsurface flow paths' and 'water and infrastructure management' (Section 5.3 in baseline synthesis and gap analysis (Holland et al., 2020)). Causal pathways play a central role in the assessment (Figure 15), connecting hazards arising from existing activities and unconventional gas resource development activities with the values to be protected for each landscape class.

Causal pathways were prioritised using the highest hazard score (severity + likelihood) (Table 3), which means that future analysis in Stage 3 can focus on higher priority risks (Section 5.3 in baseline synthesis and gap analysis (Holland et al., 2020)).

Seven causal pathways were prioritised for a detailed level of assessment in Stage 3 (priority 1). Remaining causal pathways were prioritised for assessment (priority 2). Important potential impacts to be assessed in Stage 3 are changes to groundwater quality; surface water flows; cultural heritage damage or loss; habitat fragmentation and loss; introduction of invasive species; and contamination of soil, groundwater and or surface water. Most of the priority hazards are in the landscape management (43 out of 94) and water and infrastructure management (41 of 90) causal pathway groups, with fewer (nine out of 22) in the subsurface flow paths causal pathway group.

Table 3 Prioritisation of causal pathways for the Cooper GBA region

Causal pathway	Priority 1	Priority 2	Priority 3
'Landscape management' causal pathway group	**13**	**30**	**51**
Altering cultural heritage	2	3	2
Altering natural and agricultural productivity	0	4	16
Altering natural habitat and species distributions	4	17	22
Altering surface hydrology	3	5	4
Introduction of invasive species	4	1	7
'Subsurface flow paths' causal pathway group	**1**	**8**	**13**
Compromised well integrity	1	5	5
Gas extraction altering groundwaters	0	1	2
Hydraulic fracturing	0	2	6
'Water and infrastructure management' causal pathway group	**3**	**38**	**49**
Discharging into surface waters	0	8	2
Disposal and storage of site materials	1	7	11
Failure of surface infrastructure (ponds, tanks, pipelines, etc.)	2	13	15
Processing and using extracted water	0	7	1
Reinjecting water into aquifer	0	1	9
Sourcing water for site operations	0	2	11
Total	**17**	**76**	**113**

Source: Geological and Bioregional Assessment Program (2019c)

Potential impacts from drilling and hydraulic fracturing chemicals and two causal pathways – ‘hydraulic fracturing’ and ‘compromised well integrity’ – were assessed in greater detail because of concern from government, the community and industry.

Potential impacts – screening of drilling and hydraulic fracturing chemicals

The Tier 1 qualitative screening assessed 116 chemicals used between 2011 and 2016 for drilling and hydraulic fracturing at shale, tight and deep coal gas operations in GBA regions. About one-third (42 chemicals) were of ‘low concern’ and pose minimal risk to aquatic ecosystems. A further 33 chemicals were of ‘potentially high concern’ and 41 were of ‘potential concern’ (Figure 17). These chemicals would require site-specific quantitative chemical assessments to be undertaken to determine risks from specific operations to aquatic ecosystems (Section 6.1 in baseline synthesis and gap analysis (Holland et al., 2020); chemical screening technical appendix (Kirby et al., 2020)).

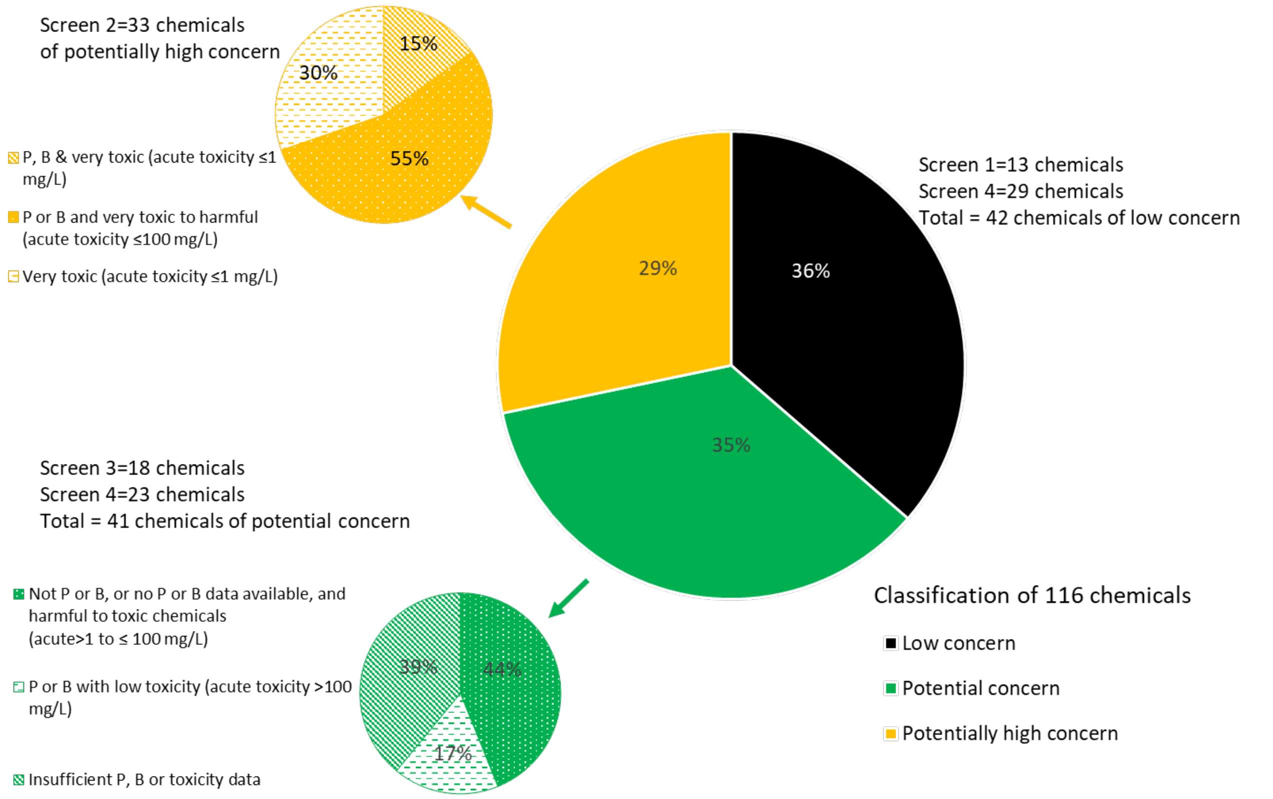

Figure 17 Tier 1 qualitative ERA of chemicals associated with shale, tight and deep coal gas operations in Australia

Refer to Figure 87 in baseline synthesis and gap analysis (Holland et al., 2020) for Screen 1 to 4 details; percentage of chemicals in each category are shown in each segment; further breakdown of chemicals of ‘potential concern’ and ‘potentially high concern’ are shown in the smaller coloured circles; P = persistent; B = bioaccumulative; T = toxic
Source: Geological and Bioregional Assessment Program (2018c)
Element: GBA-COO-2-117

Natural rock formations contain elements and compounds (geogenic chemicals) that could be mobilised into flowback and produced waters during hydraulic fracturing. Laboratory-based leachate tests were designed to provide an upper-bound estimate of geogenic chemical mobilisation from target formations in the Cooper GBA region and are intended to guide future field-based monitoring, management and treatment options. Laboratory-based leachate tests on powdered rock samples identified several elements and priority organic chemicals that could be mobilised into solutions by hydraulic fracturing fluids (Section 6.1 in baseline synthesis and gap analysis (Holland et al., 2020)). The independent collection, as well as open and transparent reporting of water quality data at future gas operations before, during and after hydraulic fracturing would improve knowledge of the process and outputs, and inform wastewater management and treatment.

Potential impacts – hydraulic fracturing and compromised well integrity

Hydraulic fracturing has been used to stimulate conventional oil and gas and unconventional gas reservoirs in the Cooper Basin for over 50 years (Figure 18). Risks from hydraulic fracturing have been the focus for industry, government and academia for more than a decade. A qualitative review of nine domestic and international inquiries into onshore gas industry operations, historical Cooper Basin data and the hazard scoring for the Cooper GBA region indicated that the likelihood of occurrence of the three impact modes associated with hydraulic fracturing (hydraulic fracture growth into an aquifer, a well or a fault) is low. While the three hydraulic fracturing impact modes were not ranked highly in the hazard assessment process, heightened community concern and relative proximity of important aquifers to prospective gas plays (300 to 2,000 m vertical separation) mean that further assessment of the 'hydraulic fracture growth into aquifer' impact mode will be investigated in Stage 3.

Regulated construction of wells for shale, tight and deep coal gas development activities aims to ensure that fluid and gas are prevented from flowing unintentionally from the reservoir into another geological layer or to the surface. A qualitative review of risks from compromised well integrity based on Cooper GBA region historical data, findings from international and domestic inquiries and hazard scoring for the Cooper GBA region (Section 5.2 in baseline synthesis and gap analysis (Holland et al., 2020) are broadly consistent. Two impact modes – 'migration of fluids along casing between geological layers' and 'migration of fluids along decommissioned or abandoned wells' – have been prioritised for inclusion in Stage 3 analysis (Section 6.2.2 in baseline synthesis and gap analysis (Holland et al., 2020); hydraulic fracturing technical appendix (Kear and Kasperczyk, 2020)).

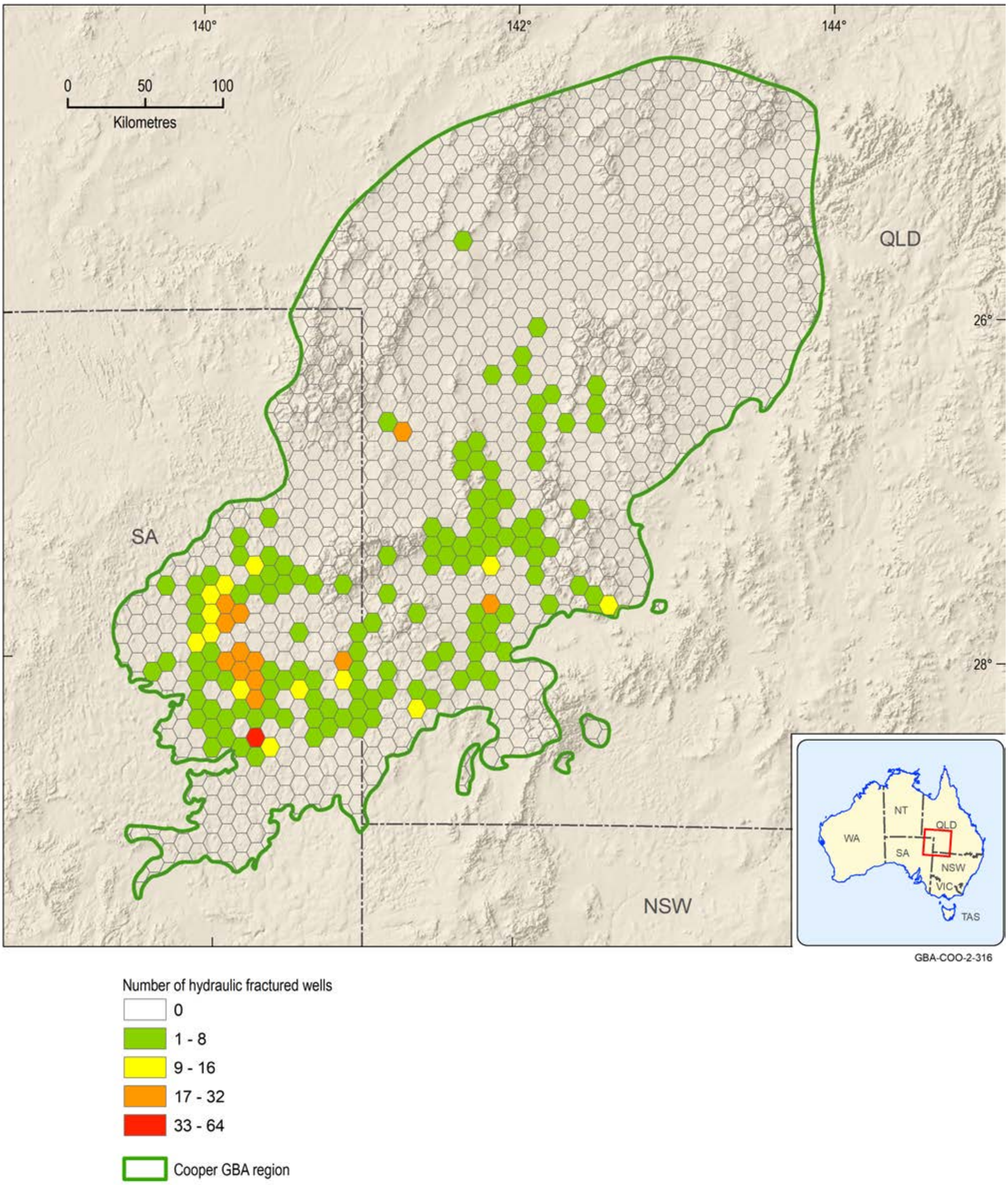

Figure 18 Location of 817 hydraulically fractured petroleum wells in the Cooper GBA region

Data: Department for Energy and Mining (SA) (2018) and State of Queensland (2018)
Element: GBA-COO-2-316

Conclusion

The baseline data, knowledge and conceptual models presented in Stage 2 (Section 7.1 in baseline synthesis and gap analysis (Holland et al., 2020)) are the building blocks for the Stage 3 impact analysis and management for the Cooper GBA region. Plausible development scenarios to test the range of potential impacts will be developed in Stage 3 in consultation with industry, state governments and Commonwealth agencies. Field and modelling investigations in Stage 3 will test key questions related to management, mitigation and monitoring of potential impacts, including:

- **How does water move between floodplains, wetlands and waterholes along Cooper Creek?**

Cooper Creek supports highly valued waterholes, wetlands and terminal lakes (Figure 19), including the Ramsar-listed Coongie Lakes. Remotely sensed ecohydrological information, a high-resolution flood inundation model and field measurements in Stage 3 will improve understanding of potential impacts from changes to the water regimes that support aquatic flora and fauna.

- **How well connected is groundwater in the Cooper, Eromanga and Lake Eyre basins?**

Stage 3 will test hypotheses related to the nature of the hydrological connection (if any) between deeper groundwaters and surface waters, including how water moves via structural features such as faults; aquitards and areas of geological contact. In addition, to address the gap between engineering-based risk assessments and heightened community concerns, Stage 3 will assess potential impacts from hydraulic fracturing and compromised well integrity.

- **Can the shallow Lake Eyre Basin aquifers supply enough water for future development?**

Stage 3 will refine the geological architecture of the Cenozoic and Winton-Mackunda partial aquifers using existing petroleum well data, complemented by baseline groundwater level and hydrochemistry sampling (including environmental tracers) to improve understanding of important processes such as recharge, aquifer compartmentalisation and connectivity.

Figure 19 Cooper floodplain, just south of Windorah

Credit: Geological and Bioregional Assessment Program, Russell Crosbie (CSIRO), March, 2018
Element: GBA-COO-2-222

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Glossary

The register of terms and definitions used in the Geological and Bioregional Assessment Program is available online at https://w3id.org/gba/glossary.

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 bores and springs

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

asset: an entity that has value to the community and, for the purposes of geological and bioregional assessments, is associated with a GBA region. An asset is a store of value and may be managed and/or used to maintain and/or produce further value. An asset may have many values associated with it that can be measured from a range of perspectives; for example, the values of a wetland can be measured from ecological, sociocultural and economic perspectives.

basement: the oldest rocks in an area; commonly igneous or metamorphic rocks of Precambrian or Paleozoic age that underlie other sedimentary formations. Basement generally does not contain significant oil or gas, unless it is fractured and in a position to receive these materials from sedimentary strata.

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.

casing: a pipe placed in a well to prevent the wall of the hole from caving in and to prevent movement of fluids from one formation to another

causal pathway group: causal pathways with similar attributes (e.g. landscape management) that are grouped for further analysis

coal seam gas: coal seam gas (CSG) is a form of natural gas (generally 95% to 97% pure methane, CH_4) extracted from coal seams, typically at depths of 300 to 1000 m. Also called coal seam methane (CSM) or coalbed methane (CBM).

conceptual model: an abstraction or simplification of reality that describes the most important components and processes of natural and/or anthropogenic systems, and their response to interactions with extrinsic activities or stressors. They provide a transparent and general representation of how complex systems work, and identify gaps or differences in understanding. They are often used as the basis for further modelling, form an important backdrop for assessment and evaluation, and typically have a key role in communication. Conceptual models may take many forms, including descriptive, influence diagrams and pictorial representations.

confined aquifer: an aquifer saturated with confining layers of low-permeability rock or sediment both above and below it. It is under pressure so that when the aquifer is penetrated by a bore, the water will rise above the top of the aquifer.

conventional gas: conventional gas is obtained from reservoirs that largely consist of porous sandstone formations capped by impermeable rock, with the gas trapped by buoyancy. The gas can often move to the surface through the gas wells without the need to pump.

Cooper Basin: the Cooper Basin geological province is an Upper Carboniferous – Middle Triassic geological sedimentary basin that is up to 2500 m thick and occurs at depths between 1000 and 4400 m. It is overlain completely by the Eromanga and Lake Eyre basins. Most of the Cooper Basin is in south-west Queensland and north-east SA, and includes a small area of NSW at Cameron Corner. It occupies a total area of approximately 130,000 km^2, including 95,740 km^2 in Queensland, 34,310 km^2 in SA and 8 km^2 in NSW.

cumulative impact: for the purposes of geological and bioregional assessments, the total environmental change resulting from the development of selected unconventional hydrocarbon resources when all past, present and reasonably foreseeable actions are considered

deep coal gas: gas in coal beds at depths usually below 2000 m are often described as 'deep coal gas'. Due to the loss of cleat connectivity and fracture permeability with depth, hydraulic fracturing is used to release the free gas held within the organic porosity and fracture system of the coal seam. As dewatering is not needed, this makes deep coal gas exploration and development similar to shale gas reservoirs.

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), a change to water or the environment, such as changes to the quantity and/or quality of surface water or groundwater, or to the availability of suitable habitat. An effect is a specific type of an impact (any change resulting from prior events).

Eromanga Basin: an extensive geologic sedimentary basin formed from the Early Jurassic to the Late Cretaceous that can be over 2500 m thick. It overlies several older geological provinces including the Cooper Basin, and is in part overlain by the younger Cenozoic province, the Lake Eyre Basin. The Eromanga Basin is found across much of Queensland, northern SA, southern NT, as well as north-western NSW. The Eromanga Basin encompasses a significant portion of the Great Artesian Basin.

fault: a fracture or zone of fractures in the Earth's crust along which rocks on one side were displaced relative to those on the other side

floodplain: a flat area of unconsolidated sediment near a stream channel that is submerged during or after high flows

flowback: the process of allowing fluids and entrained solids to flow from a well following a treatment, either in preparation for a subsequent phase of treatment or in preparation for cleanup and returning the well to production. The flowback period begins when material introduced into the well during the treatment returns to the surface following hydraulic fracturing or refracturing. The flowback period ends when either the well is shut in and permanently disconnected from the flowback equipment or at the startup of production.

fracking: see hydraulic fracturing

fracture: a crack or surface of breakage within rock not related to foliation or cleavage in metamorphic rock along which there has been no movement. A fracture along which there has been displacement is a fault. When walls of a fracture have moved only normal to each other, the fracture is called a joint. Fractures can enhance permeability of rocks greatly by connecting pores together, and for that reason, fractures are induced mechanically in some reservoirs in order to boost hydrocarbon flow. Fractures may also be referred to as natural fractures to distinguish them from fractures induced as part of a reservoir stimulation or drilling operation. In some shale reservoirs, natural fractures improve production by enhancing effective permeability. In other cases, natural fractures can complicate reservoir stimulation.

geogenic chemical: a naturally occurring chemical originating from the earth – for example, from geological formations

geological architecture: the structural style and features of a geological province, like a sedimentary basin

geological formation: stratigraphic unit with distinct rock types, which is able to mapped at surface or in the subsurface, and which formed at a specific period of geological time

groundwater: water occurring naturally below ground level (whether stored in or flowing through aquifers or within low-permeability aquitards), 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 require access to groundwater on a permanent or intermittent basis to meet all or some of their water requirements

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

groundwater recharge: replenishment of groundwater by natural infiltration of surface water (precipitation, runoff), or artificially via infiltration lakes or injection

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.

hydraulic fracturing: also known as ‘fracking’, ‘fraccing’ or ‘fracture simulation’. This is a process by which geological formations bearing hydrocarbons (oil and gas) are ‘stimulated’ to increase the flow of hydrocarbons and other fluids towards the well. In most cases, hydraulic fracturing is undertaken where the permeability of the formation is initially insufficient to support sustained flow of gas. The process involves the injection of fluids, proppant and additives under high pressure into a geological formation to create a conductive fracture. The fracture extends from the well into the production interval, creating a pathway through which oil or gas is transported to the well.

hydraulic fracturing fluid: the fluid injected into a well for hydraulic fracturing. Consists of a primary carrier fluid (usually water or a gel), a proppant such as sand and chemicals to modify the fluid properties.

hydrocarbons: various organic compounds composed of hydrogen and carbon atoms that can exist as solids, liquids or gases. Sometimes this term is used loosely to refer to petroleum.

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

impact: the difference between what could happen as a result of activities and processes associated with extractive industries, such as shale, tight and deep coal gas development, and what would happen without them. Impacts may be changes that occur to the natural environment, community or economy. Impacts can be a direct or indirect result of activities, or a cumulative result of multiple activities or processes.

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

Lake Eyre Basin: a geologic province containing Cenozoic terrestrial sedimentary rocks within the Lake Eyre surface water catchment. It covers parts of northern and eastern SA, south-eastern NT, western Queensland and north-western NSW. In the Cooper GBA region, the basin sedimentary package is less than 300 m thick.

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

major activity: for the purposes of Impact Modes and Effects Analysis (IMEA), a group of activities associated with a common part of the shale, tight or deep coal gas resource development process. There are ten major activities used in geological and bioregional assessments ranging from ‘construction’ through to ‘well abandonment and rehabilitation’. Major activities may occur across different life cycles, though often with differing levels of intensity; for example, drilling may occur in the exploration, appraisal, development and production life cycles but is at its peak during development.

migration: the process whereby fluids and gases move through rocks. In petroleum geoscience, 'migration' refers to when petroleum moves from source rocks toward reservoirs or seep sites. Primary migration consists of movement of petroleum to exit the source rock. Secondary migration occurs when oil and gas move along a carrier bed from the source to the reservoir or seep. Tertiary migration is where oil and gas move from one trap to another or to a seep.

natural gas: the portion of petroleum that exists either in the gaseous phase or is in solution in crude oil in natural underground reservoirs, and which is gaseous at atmospheric conditions of pressure and temperature. Natural gas may include amounts of non-hydrocarbons.

oil: a mixture of liquid hydrocarbons and other compounds of different molecular weights. Gas is often found in association with oil. Also see petroleum.

oil field: an area with an underlying oil reservoir. Typically, industry professionals use the term with an implied assumption of economic size

organic matter: biogenic, carbonaceous materials. Organic matter preserved in rocks includes kerogen, bitumen, oil and gas. Different types of organic matter can have different oil-generative potential.

partial aquifer: a permeable geological material with variable groundwater yields that are lower than in an aquifer and range from fair to very low yielding locally

permeability: the measure of the ability of a rock, soil or sediment to yield or transmit a fluid. The magnitude of permeability depends largely on the porosity and the interconnectivity of pores and spaces in the ground.

petroleum: a naturally occurring mixture consisting predominantly of hydrocarbons in the gaseous, liquid or solid phase

petroleum system: the genetic relationship between a pod of source rock that is actively producing hydrocarbon, and the resulting oil and gas accumulations. It includes all the essential elements and processes needed for oil and gas accumulations to exist. These include the source, reservoir, seal, and overburden rocks, the trap formation, and the hydrocarbon generation, migration and accumulation processes. All essential elements and processes must occur in the appropriate time and space in order for petroleum to accumulate.

play: a conceptual model for a style of hydrocarbon accumulation used during exploration to develop prospects in a basin, region or trend and used by development personnel to continue exploiting a given trend. A play (or group of interrelated plays) generally occurs in a single petroleum system.

porosity: the proportion of the volume of rock consisting of pores, usually expressed as a percentage of the total rock or soil mass

produced water: a term used in the oil industry to describe water that is produced as a by-product along with the oil and gas. Oil and gas reservoirs often have water as well as hydrocarbons, sometimes in a zone that lies under the hydrocarbons, and sometimes in the same zone with the oil and gas. The terms 'co-produced water' and 'produced water' are sometimes used interchangeably by government and industry. However, in the geological and bioregional assessments, 'produced water' is used to describe water produced as a by-product of shale and tight gas resource development, whereas 'co-produced water' refers to the large amounts of water produced as a by-product of coal seam gas development.

production: in petroleum resource assessments, 'production' refers to the cumulative quantity of oil and natural gas that has been recovered already (by a specified date). This is primarily output from operations that has already been produced.

prospectivity assessment: the assessment of an area to determine the likelihood of discovering a given resource (e.g. oil, gas, groundwater) by analysing the spatial patterns of foundation datasets. The key objective is to identify areas of increased likelihood of discovering previously unrecognised potential. Sometimes referred to as ‘chance of success’ or ‘common risk segment’ analysis.

reservoir: a subsurface body of rock having sufficient porosity and permeability to store and transmit fluids and gases. Sedimentary rocks are the most common reservoir rocks because they have more porosity than most igneous and metamorphic rocks and form under temperature conditions at which hydrocarbons can be preserved. A reservoir is a critical component of a complete petroleum system.

risk: the effect of uncertainty on objectives (ASNZ ISO 3100). This involves assessing the potential consequences and likelihood of impacts to environmental and human values that may stem from an action, under the uncertainty caused by variability and incomplete knowledge of the system of interest.

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

sandstone: a sedimentary rock composed of sand-sized particles (measuring 0.05–2.0 mm in diameter), typically quartz

seal: a relatively impermeable rock, commonly shale, anhydrite or salt, that forms a barrier or cap above and around reservoir rock such that fluids cannot migrate beyond the reservoir. A seal is a critical component of a complete petroleum system.

sedimentary rock: a rock formed by lithification of sediment transported or precipitated at the Earth’s surface and accumulated in layers. These rocks can contain fragments of older rock transported and deposited by water, air or ice, chemical rocks formed by precipitation from solution, and remains of plants and animals.

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

shale gas: generally extracted from a clay-rich sedimentary rock, which has naturally low permeability. The gas it contains is either adsorbed or in a free state in the pores of the rock.

source rock: a rock rich in organic matter which, if heated sufficiently, will generate oil or gas. Typical source rocks, usually shales or limestones, contain about 1% organic matter and at least 0.5% total organic carbon (TOC), although a rich source rock might have as much as 10% organic matter. Rocks of marine origin tend to be oil-prone, whereas terrestrial source rocks (such as coal) tend to be gas-prone. Preservation of organic matter without degradation is critical to creating a good source rock, and necessary for a complete petroleum system. Under the right conditions, source rocks may also be reservoir rocks, as in the case of shale gas reservoirs.

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: the study of the history, composition, relative ages and distribution of stratified rock strata, and its interpretation to reveal Earth's history. However, it has gained broader usage to refer to the sequential order and description of rocks in a region.

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

structure: a geological feature produced by deformation of the Earth's crust, such as a fold or a fault; a feature within a rock, such as a fracture or bedding surface; or, more generally, the spatial arrangement of rocks

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

tight gas: tight gas is trapped in reservoirs characterised by very low porosity and permeability. The rock pores that contain the gas are minuscule, and the interconnections between them are so limited that the gas can only migrate through it with great difficulty.

trap: a geologic feature that permits an accumulation of liquid or gas (e.g. natural gas, water, oil, injected CO_2) and prevents its escape. Traps may be structural (e.g. domes, anticlines), stratigraphic (pinchouts, permeability changes) or combinations of both.

unconventional gas: unconventional gas is generally produced from complex geological systems that prevent or significantly limit the migration of gas and require innovative technological solutions for extraction. There are numerous types of unconventional gas such as coal seam gas, deep coal gas, shale gas and tight gas.

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, injecting or recovering various natural resources, such as hydrocarbons (oil and gas), water or carbon dioxide. Wells are sometimes known as a 'wellbore'.

well integrity: maintaining full control of fluids (or gases) within a well at all times by employing and maintaining one or more well barriers to prevent unintended fluid (gas or liquid) movement between formations with different pressure regimes, or loss of containment to the environment.

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