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BIOREGIONAL ASSESSMENTS

CSIRO

Geological and environmental baseline assessment for the Isa 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 shale and tight gas projects on 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.

Cover photograph

The Burketown Bore, drilled in 1897 by the Queensland Government, is a naturally flowing bore that taps the artesian Gilbert River Formation aquifer at a depth of about 700 m below surface. Groundwater within this aquifer naturally contains a variety of dissolved chemical compounds that have deposited around the bore as the hot water (around 68 °C) has evaporated over the years, leading to the formation of a distinctive multi-coloured mound.

Credit: Steven Lewis, Geoscience Australia, July 2018 Element: GBA-ISA-2-264

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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 appropriate management approaches. The geological and environmental knowledge, data and tools produced by the Program will assist governments, industry, landowners and the community by informing decision making and enabling the coordinated management of potential impacts. Stage 2 baseline data, knowledge and conceptual models for the Isa GBA region (Figure 1) can be used to support impact assessments of future shale gas developments.

Geology and gas resources: Areas of higher prospectivity for the main shale gas plays include the River Supersequence over most of the Isa GBA region and the Lawn Supersequence over the central and western parts of the region (Figure 1).

Groundwater*:* There are two broad and potentially connected groundwater systems that occur at different depths. The deeper groundwater system contains the targets for shale gas extraction. The shallower system, including part of the Great Artesian Basin, hosts the region's most readily accessible groundwater resources. Groundwater-dependent ecosystems occur along many streams and on nearby floodplains, and also as environmentally and culturally important springs in the south-west of the region.

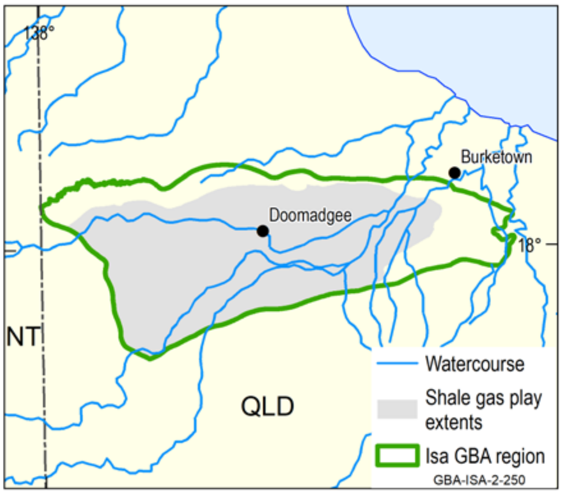

Figure 1 Isa GBA region
Element: GBA-ISA-2-250

Surface water: The Nicholson River, which rises to the west of the region in the NT and passes near the remote township of Doomadgee, is the major river of interest. Discharging into the Gulf of Carpentaria, it flows through the nationally listed wetlands of the Nicholson Delta and Southern Gulf aggregations.

Water availability: A future shale gas industry will need authorisation to take water from aquifers, watercourses or lakes through the relevant Queensland Government water plans. Produced water from shale gas reservoirs could possibly be used for drilling and hydraulic fracturing, although the volumes available and the economic viability are uncertain.

Potential hydrological connections: There is some evidence of potential existing connectivity between deep and shallow groundwater systems. Considerably more information is needed to understand these potential hydrological connections. Research questions have been devised to address the most important data and knowledge gaps.

Protected matters: Matters of national and state environmental significance include threatened species (plants, reptiles, birds and mammals) and ecological communities and wetlands. Two landscape classes dominate the region: 'floodplain and alluvium' (36% of the region) and 'loamy and sandy plains' (33%).

Eleven Matters of National Environmental Significance and two Matters of State Environmental Significance are recommended for further assessment because of their importance (priority 1). This includes five endangered species and eight vulnerable species, as well as an endangered regional ecosystem and four nationally important wetlands.

Potential impacts: Over 200 individual hazards were systematically identified by considering all the possible ways that activities associated with shale gas development may cause impacts. Hazards were grouped into 14 causal pathways, and then aggregated into three causal pathway groups. Causal pathways connect hazards associated with shale gas development with the values to be protected for each landscape class.

The three causal pathway groups are: (i) landscape management, (ii) subsurface flow paths and (iii) water and infrastructure management. A variety of potential effects were identified across these causal pathway groups, with the highest priority effects including habitat fragmentation and loss, cultural heritage damage or loss, introduction of invasive species, changed groundwater quality and changed surface water flows.

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 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 Isa GBA region includes people from local government, natural resource management bodies, Queensland state government, 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 gas resources, water resources, protected matters (environmental and cultural) and risks to water (quantity and quality) and the environment in the Isa GBA region. Each section is colour coded to correspond with Figure 2.

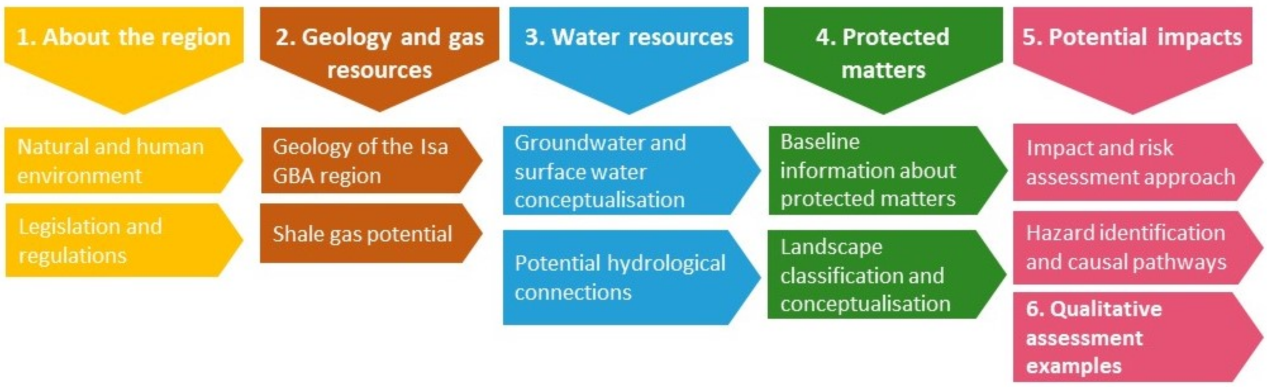

Figure 2 Geological and environmental baseline assessment report structure

Element: GBA-ISA-2-197

About the region

The Isa GBA region is in north-west Queensland and covers about 8223 km^2 (Figure 3). Defined specifically for GBA purposes, the region includes known shale gas systems of the geological Isa Superbasin. Centred on the area around the remote township of Doomadgee, the Isa GBA region contains the north-eastern part of the Isa Superbasin, which is mostly buried greater than 1 km below the surface beneath younger sedimentary basins, such as the Carpentaria Basin (part of the groundwater system known as the Great Artesian Basin (GAB)).

The Isa GBA region occurs mostly on relatively flat and low-lying savannah country south of the Gulf of Carpentaria, consisting of well-vegetated alluvial and near-coastal plains, with widespread native grasslands and areas of sparse to moderately dense native woodland. Along the far western margin of the Isa GBA region the landscape is more rocky and rugged, with isolated ridges and low undulating hills sweeping down towards the plains. At its north-eastern boundary near Burketown, the Isa GBA region is less than 50 km from the mangrove-fringed coastline of the Gulf of Carpentaria.

The human population is sparse, with fewer than 2000 people permanently residing within the region. Doomadgee is the main town in the Isa GBA region with an estimated population of about 1400 (90% of these people are of Indigenous heritage). Burketown sits just outside the region's north-east boundary. The multi-million-dollar beef cattle industry is the mainstay of the local economy and large pastoral holdings cover many thousands of square kilometres. Traditional homelands of the Gangalidda, Garawa and Waanyi peoples are in the Isa GBA region and native title rights have been determined for about 70% of the region (Figure 4).

Australia's emerging shale 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 and Queensland regulations that are relevant to the development of shale gas resources in the Isa GBA region are summarised in Section 1.6 of the baseline synthesis and gap analysis (Lewis et al., 2020).

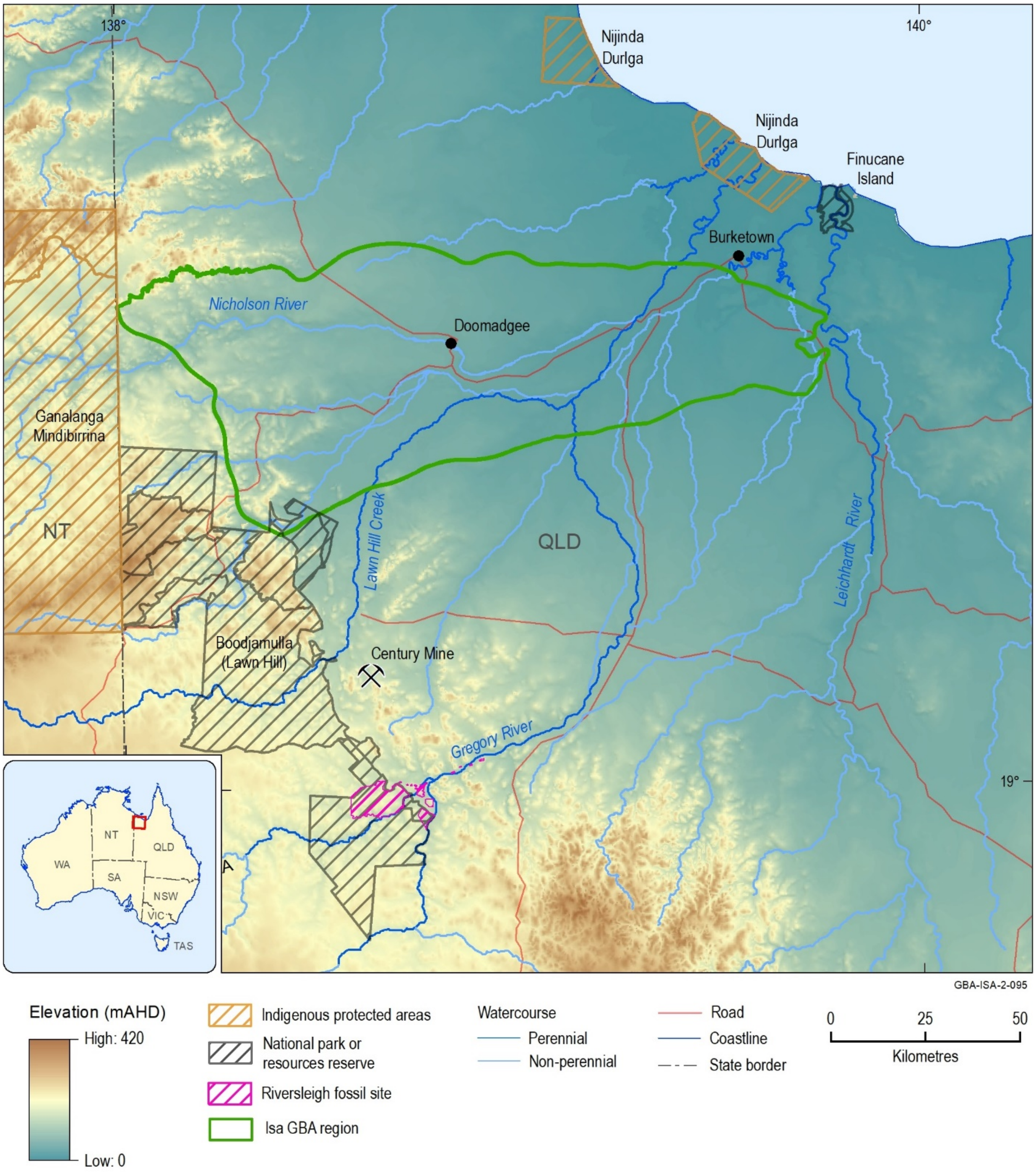

Figure 3 Land surface elevation and selected topographic features of the Isa GBA region

The two national parks labelled here are Boodjamulla (Lawn Hill) and Finucane Island. The Century Mine was one of the world's largest zinc mines during its 16-year operation from 1999 to 2015. New owners restarted operations at Century in 2018, with an initial focus on re-treating the previous mine tailings.
Data: Department of the Environment and Energy (2008); Geoscience Australia (2008)
Element: GBA-ISA-2-095

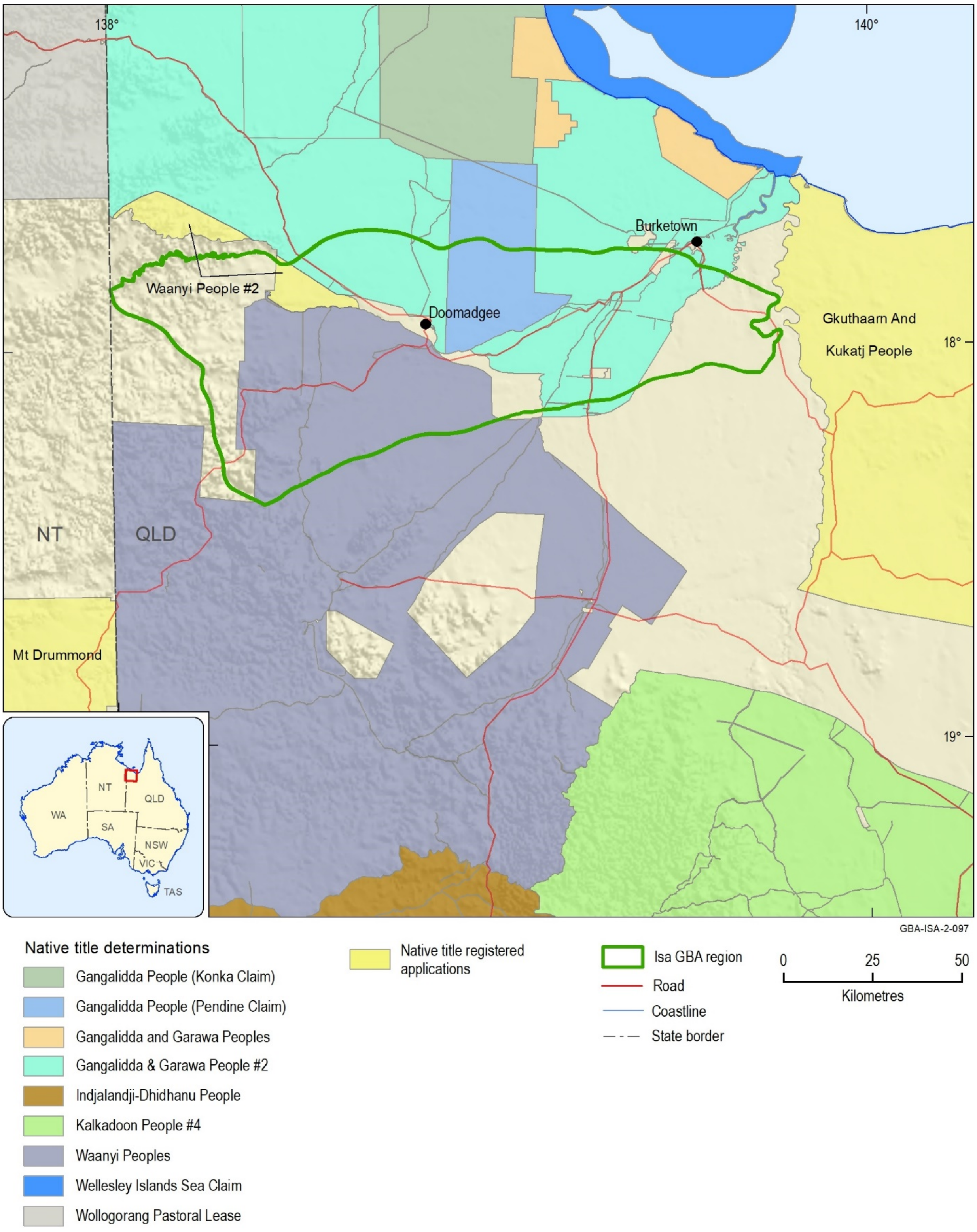

Figure 4 Areas of native title determinations and applications in north-western Queensland

Data: National Native Title Tribunal (2019)
Element: GBA-ISA-2-097

Geology and gas resources

The Paleoproterozoic to earliest Mesoproterozoic Isa Superbasin (formed approximately 1670 to 1575 million years before present) is a geological province in north-west Queensland. Although the complete extent of the superbasin is currently unknown, it is likely to extend under cover into the NT for several hundred kilometres. The Isa GBA region contains only that part of the Isa Superbasin in Queensland explored for shale gas resources (as of May 2020). Several geologically younger sedimentary basins overlie the Isa Superbasin and include the Mesoproterozoic South Nicholson Basin, the Mesozoic Carpentaria Basin and the Cenozoic Karumba Basin. Regional aquifers that supply groundwater for a variety of users occur within the Carpentaria Basin, including the artesian Gilbert River Formation (Section 2.1 in baseline synthesis and gap analysis (Lewis et al., 2020); geology technical appendix (Orr et al., 2020)).

The Isa Superbasin is an underexplored petroleum basin with limited hydrocarbon exploration and no hydrocarbon production to date (see Figure 5 for extent of seismic exploration and petroleum exploration wells). However, recent exploration indicates the potential for the Lawn and River supersequences of the Isa Superbasin to host volumetrically significant shale gas resources (Section 3.1 shale gas; prospectivity technical appendix (Bailey et al., 2020)).

Play fairway analysis undertaken by the GBA Program (Bailey et al., 2020) shows that the rocks of the River Supersequence are potentially prospective for shale gas over most of the Isa GBA region (Figure 6), whereas the Lawn Supersequence is most likely prospective over the central part of the region. The play fairway analysis provides the maximum possible area within which each play may occur based on regional geological criteria alone and does not capture any local-scale (<10 km) variations in geology or economic, political or social factors.

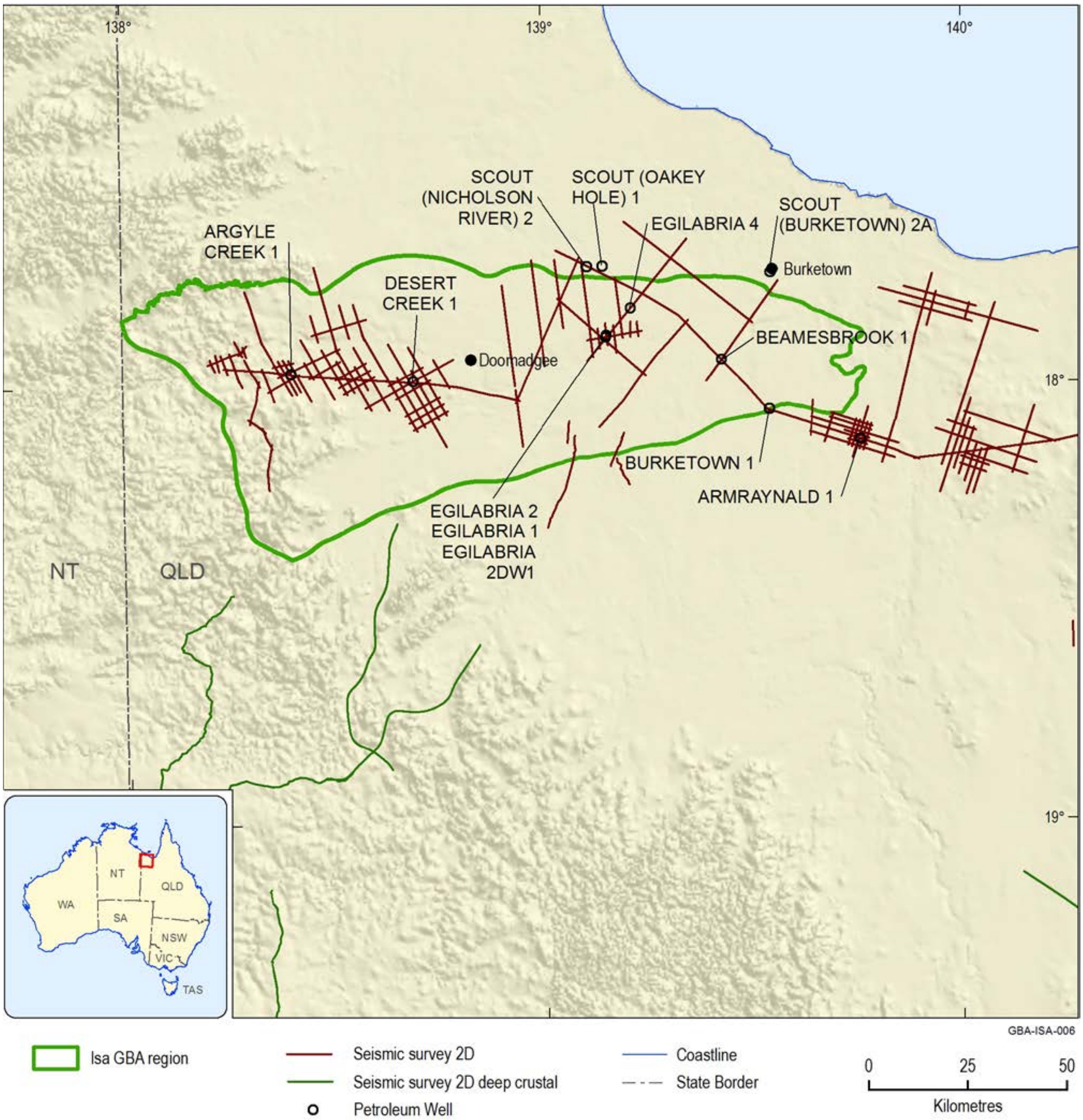

Figure 5 Two-dimensional seismic reflection data coverage across the Isa GBA region and surrounds

Data: Queensland two-dimensional seismic survey line locations from Department of Natural Resources, Mines and Energy (Qld) (2017), deep crustal seismic line locations from Department of Natural Resources, Mines and Energy (Qld) (2019), Queensland petroleum well locations from Department of Natural Resources, Mines and Energy (Qld) (2018). Background image is the GEODATA 9-second digital elevation model, version 3 (hillshade) (Hutchinson et al., 2008)
Element: GBA-ISA-2-006

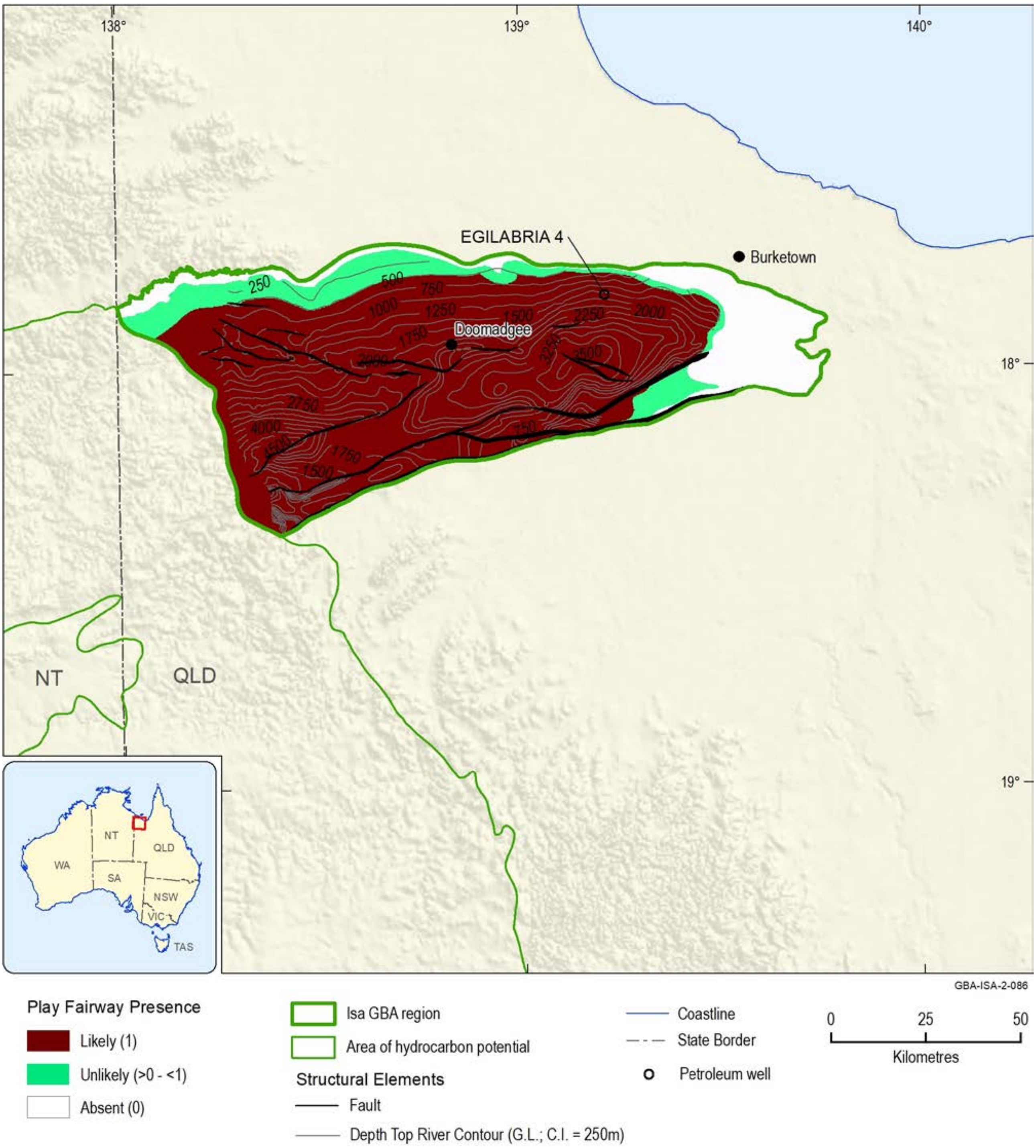

Figure 6 River Supersequence shale gas play fairway presence map

GL = relative to ground level; CI = contour interval
Source: petroleum prospectivity technical appendix (Bailey et al., 2020)
Data: Bradshaw et al. (2018)
Element: GBA-ISA-2-086

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 deeper source rocks into a trap containing porous and permeable reservoir rocks (Schmoker, 2002; Schmoker et al., 1995) (Figure 7).

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 7).

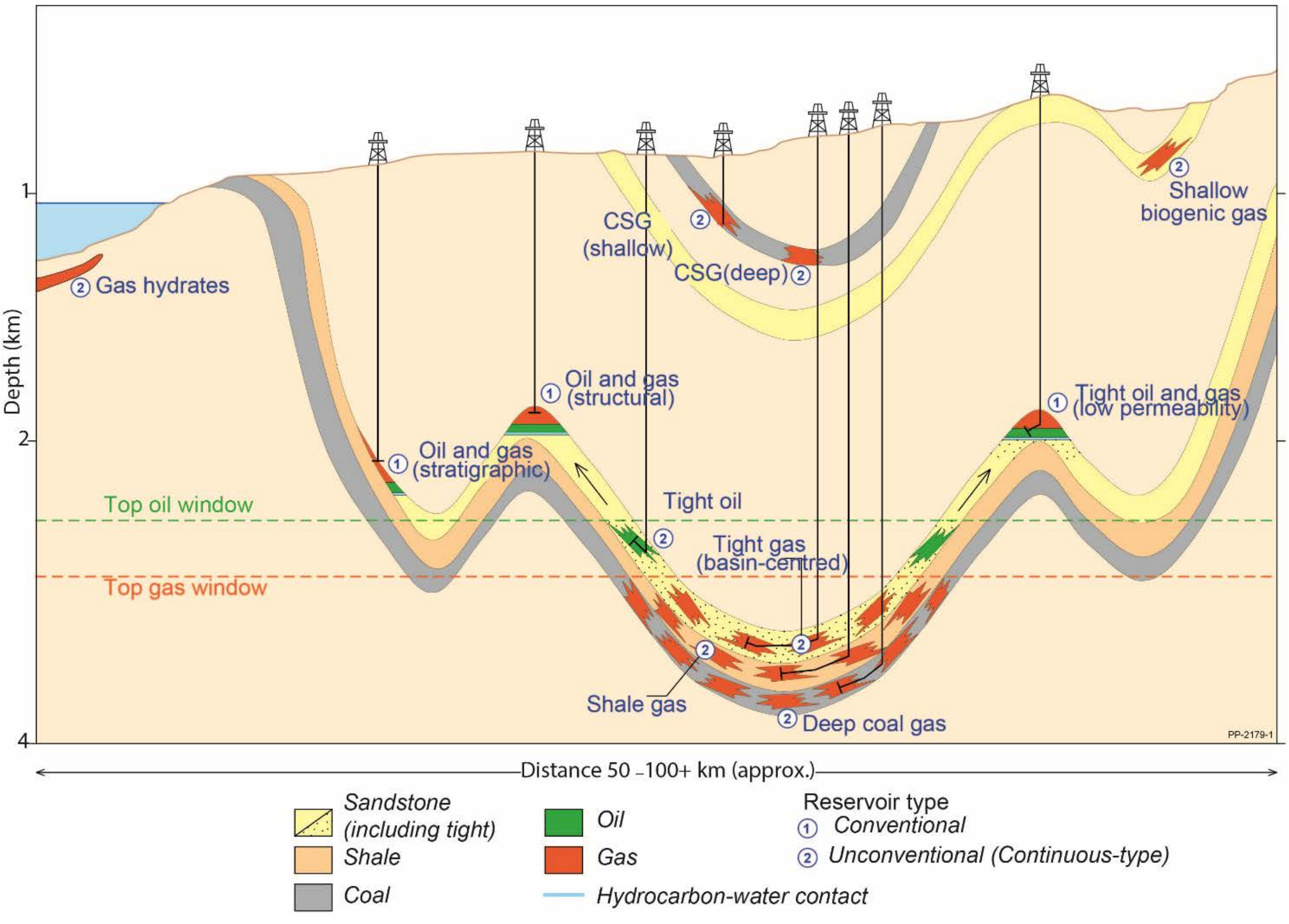

Figure 7 Generic illustration of some conventional and unconventional types of oil and gas accumulations

In the Isa GBA region, shale gas resources are thus far the only type of unconventional gas resource that has been discovered. 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.

CSG = coal seam gas

Source: after Schenk and Pollastro (2002); Cook et al. (2013); Schmoker et al. (1995); Audibert (1976)

Element: GBA-ISA-2-205

Water resources – groundwater

The Isa GBA region is host to two broad and potentially interconnected groundwater systems. The first is a deeper groundwater system associated with the Proterozoic rocks of the Isa Superbasin and the South Nicholson Basin (Figure 8). The Proterozoic Isa Superbasin and South Nicholson Basin extend from surface (outcrop) in the west of the Isa GBA region dipping southwards to depths of over 9 km under a gradual thickening of the younger GAB. The Lady Loretta Formation (Loretta Supersequence) contains cavernous sections of carbonate-bearing rocks that make it the most productive Proterozoic aquifer. Most other Proterozoic rocks have hydraulic properties characteristic of partial aquitards or aquitards – where rocks typically have very low porosity and low hydraulic conductivity (Section 3.1 in baseline synthesis and gap analysis (Lewis et al., 2020); Section 4.1.1 hydrogeology technical appendix (Buchanan et al., 2020)). The salinity of groundwater in the Proterozoic units and the GAB is typically low to moderately saline, which makes it potentially useful for many purposes.

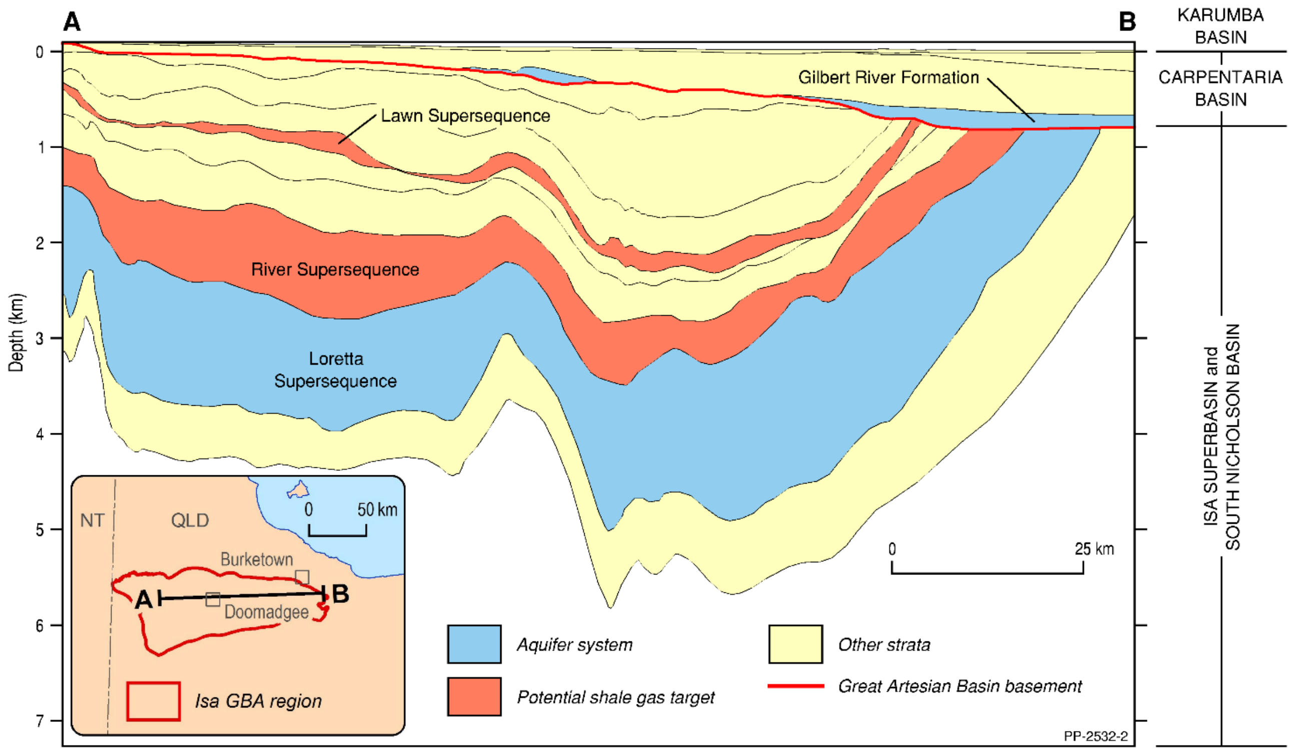

Figure 8 Cross-section through the Isa GBA region showing the relationship between the main aquifer systems and potential shale gas sequences

The insert shows the location of the cross-section. The Normanton Formation is shown by the thin wedge-shaped aquifer at the top of the Carpentaria Basin sequence, extending about 20 km westwards from the far eastern edge of the cross-section. The Carpentaria Basin is a part of the Great Artesian Basin (GAB) and is shown in more detail in Figure 9.
Source: Bradshaw et al. (2018)
Element: GBA-ISA-2-139

The second groundwater system occurs in the shallower Mesozoic Carpentaria Basin (part of the GAB) and Cenozoic Karumba Basin, where the major aquifers include the basal Gilbert River Formation, the Normanton Formation and the near-surface sediments of the Karumba Basin (Figure 9). These hydrostratigraphic units host the region's most readily accessible groundwater resources. Groundwater salinity in the Gilbert River Formation is typically low to moderate (Section 3.1.2 in baseline synthesis and gap analysis (Lewis et al., 2020)). The well-known Burketown Bore (see cover photo) accesses artesian groundwater from the Gilbert River Formation.

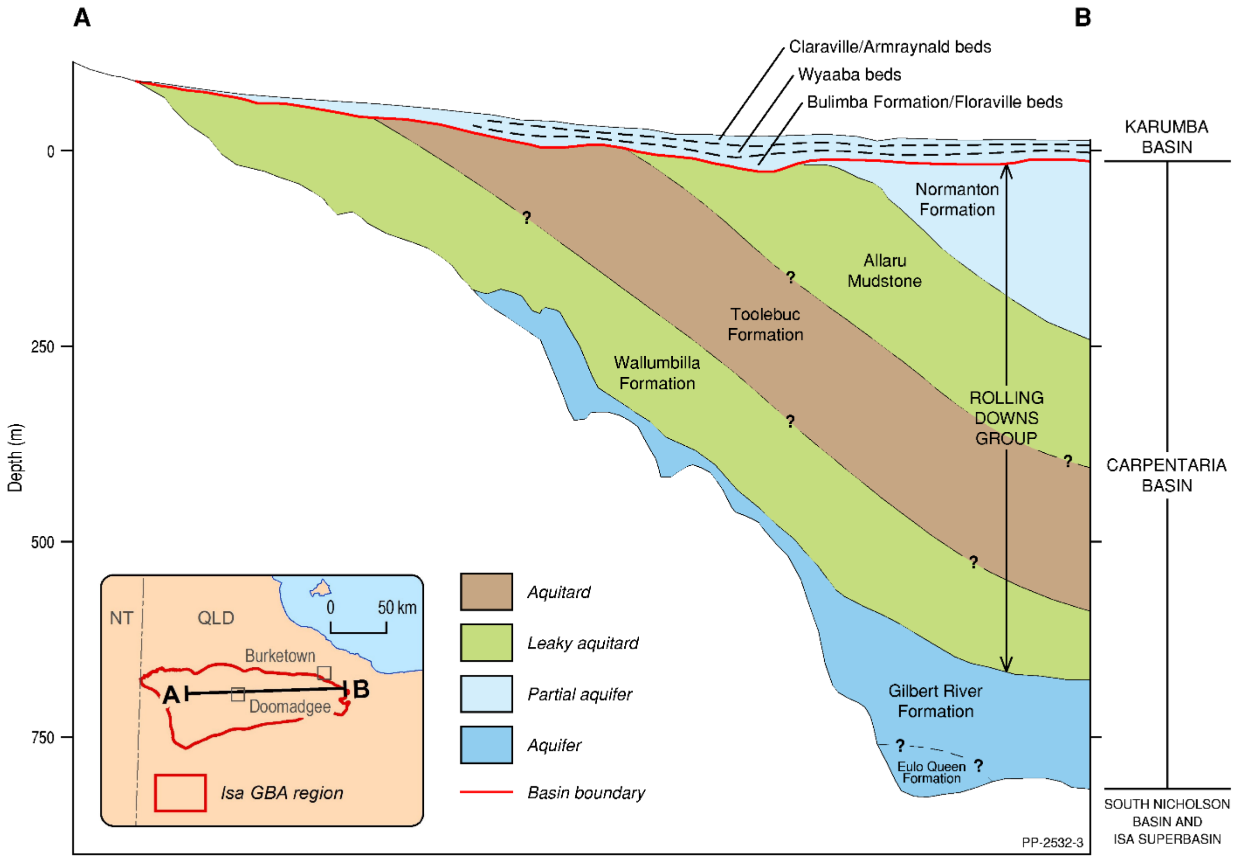

Figure 9 Conceptual hydrogeology of the Carpentaria and Karumba basins in the Isa GBA region

The thickness of the Toolebuc unit is indicative only and shown to illustrate hydrostratigraphic relationships.
Data: Geoscience Australia (2018c)
Element: GBA-ISA-2-140

There are no existing water licences or allocations for the petroleum and gas industry in the Isa GBA region. Several groundwater and surface water sources are potentially available to supply water requirements for any potential future shale gas development. These include accessing some of the available water reserves from the GAB, as well as surface water or groundwater resources from the Nicholson River catchment. Recycling or reusing flowback or produced water that may be associated with gas production may also be an option, although there is considerable uncertainty about the volumes of produced water likely to be recovered from shale gas wells in the Isa GBA region and the economic feasibility of its reuse (Section 3.5 in baseline synthesis and gap analysis (Lewis et al., 2020)).

Water resources – potential hydrological connections

Conceptual hydrogeological models developed (e.g. Figure 10) to assess potential hydrological connections in the Isa GBA region indicate that there may be five main connectivity pathways (Table 1; Section 3.4 in baseline synthesis and gap analysis (Lewis et al., 2020); Section 5 hydrogeology technical appendix (Buchanan et al., 2020)). Dissolved gas concentrations within the Gilbert River Formation aquifer and Normanton Formation partial aquifer provide some evidence of potential connectivity between the deep and shallow hydrogeological systems.

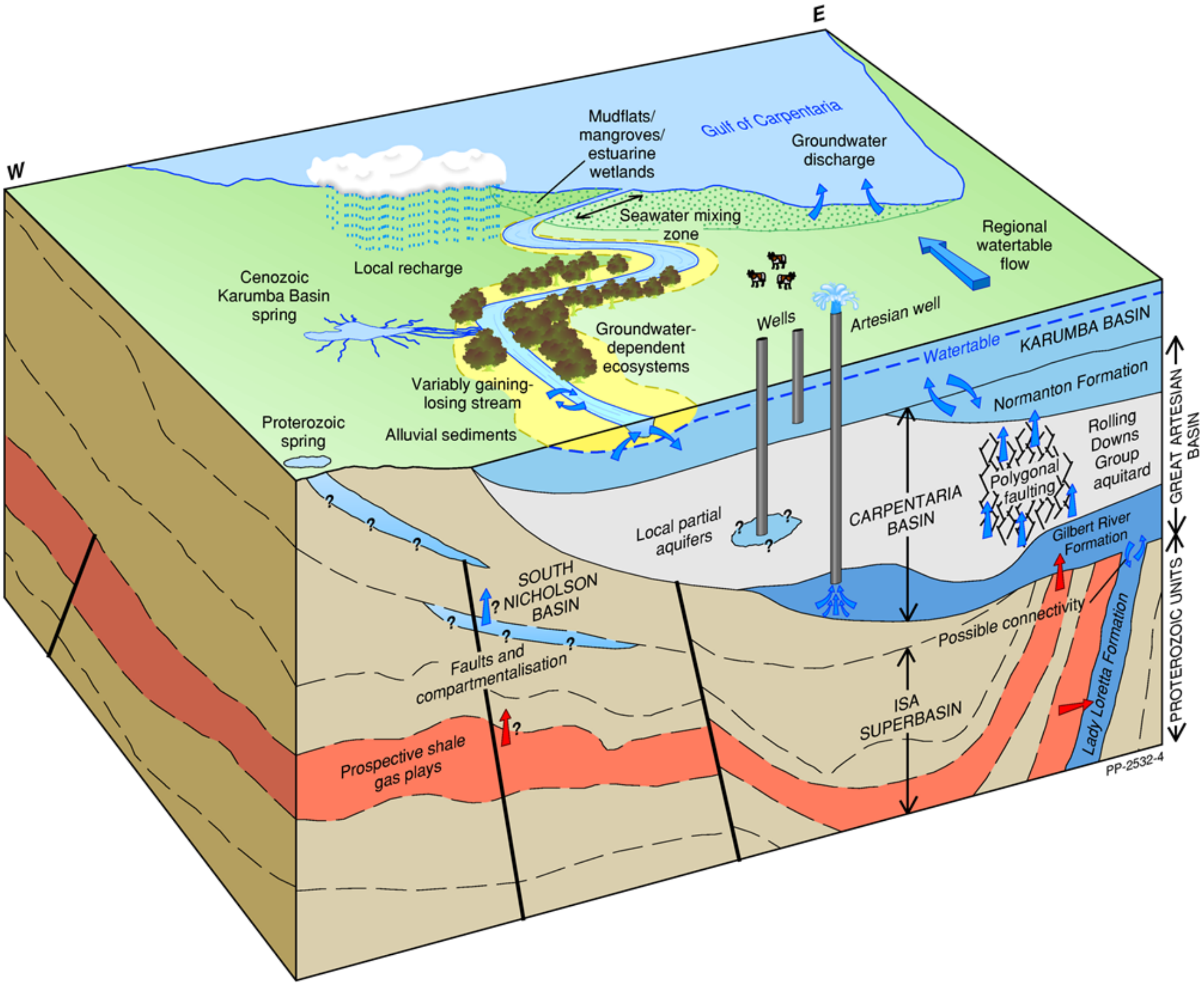

Figure 10 Key components of the groundwater systems of the Isa GBA region and potential connectivity pathways between aquifers and surface waters

The groundwater system includes the deeper Proterozoic units of the Isa Superbasin and South Nicholson Basin and the overlying Carpentaria Basin (part of the Great Artesian Basin) and Karumba Basin. The Isa Superbasin is host to the prospective shale gas plays and the Loretta Supersequence (Lady Loretta Formation) aquifer. Red arrows depict potential pathways for gas migration; blue arrows represent potential pathways for the movement of water.
This diagram is a schematic representation and is not drawn to scale. The diagram has been vertically exaggerated to emphasise key features and processes in the region.
Element: GBA-ISA-2-141

The assessment highlights that there are considerable gaps in our understanding of potential hydrological pathways in the subsurface, and it describes conceptual models that can be tested in the future to improve knowledge of their extent and influence (Section 5.7 of hydrogeology technical appendix (Buchanan et al., 2020)). Further investigations to assess the likelihood of these potential hydrological pathways are recommended prior to any shale gas production from the Isa GBA region.

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

Potential hydrological connections	Potential impacts on water and the environment
① Potential connection via direct stratigraphic contact between shale gas plays of the Paleoproterozoic River and Lawn supersequences and underlying or overlying aquifers.	Water bores that access the GAB and shallower aquifers, and surface water bodies and GDEs.
② Potential connection through deep-seated faults potentially intersecting shale gas reservoirs in the River Supersequence and overlying partial aquifers of the Lawn Hill Formation and some GAB aquifers.	Water bores that access aquifers or partial aquifers and spring complexes in the south-west of the region.
③ Potential connection through porous aquifers, such as those within the GAB and karstic Proterozoic aquifers.	Water bores that access these aquifers, partial aquifers and overlying potential receptors. There may also be an intermediate conduit through other pathways (e.g. pathway 2).
④ Potential connection through partial aquifers/aquitards.	Bores that access the overlying Normanton Formation partial aquifer.
⑤ Potential connection at catchment constrictions and river diversions (likely controlled by geological structures).	Water bores, springs, GDEs and perched watertables associated with the alluvial aquifer.

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

Water resources – surface water – groundwater conceptualisation

Most of the Isa GBA region is in the Nicholson River catchment (8020 km^2), with smaller areas in the adjacent Settlement Creek (190 km^2) and Leichhardt River (8 km^2) catchments. There is a strong rainfall runoff gradient from south to north with the highest runoff generated near the coast. The Nicholson River discharges into the Gulf of Carpentaria after flowing through the extensive wetlands of the Nicholson Delta Aggregation, which is listed as a nationally important wetland (Environment Australia, 2001). The Nicholson River becomes perennial downstream of the confluence of Gregory River, with dry-season flows decreasing toward the coast due to riparian zone evapotranspiration (CSIRO, 2009).

Gregory River and Lawn Hill Creek are perennial tributaries of Nicholson River fed by groundwater from limestone aquifers of the geological Georgina Basin upstream of the Isa GBA region (Figure 16).

Surface water quality in the Isa GBA region is variable in space and time. Median recorded total dissolved solids (TDS) at three stream gauges on the Nicholson River, Gregory River and Leichardt River were 36 mg/L, 281 mg/L and 105 mg/L respectively which is considered good quality for drinking water (NHMRC/ARMCANZ, 1996) and suitable for stock watering (ANZECC/ARMCANZ, 2000).

The alluvial floodplains of the Isa GBA region have the greatest potential for surface water – groundwater interactions, arising from connectivity between shallow groundwater hosted in the Karumba Basin sediments and surface waters. Spring ecosystems in the south-west of the region are also supported by groundwater, potentially sourced from Proterozoic sandstone aquifers. The mechanisms of surface water – groundwater interactions vary spatially and are dynamically linked to seasonal rainfall patterns. Groundwater provides baseflow to streams that intersect aquifers, emerges at spring vents and discharges offshore. Surface waters also recharge the groundwater system at certain times of the year – for example, during large floods.

Groundwater supports many aquatic and terrestrial groundwater-dependent ecosystems in the region, including the springs in the south-west (Figure 11; Section 3.3 in baseline synthesis and gap analysis (Lewis et al., 2020)), the Nicholson Delta Aggregation nationally important wetland and the Gulf Rivers strategic environmental area.

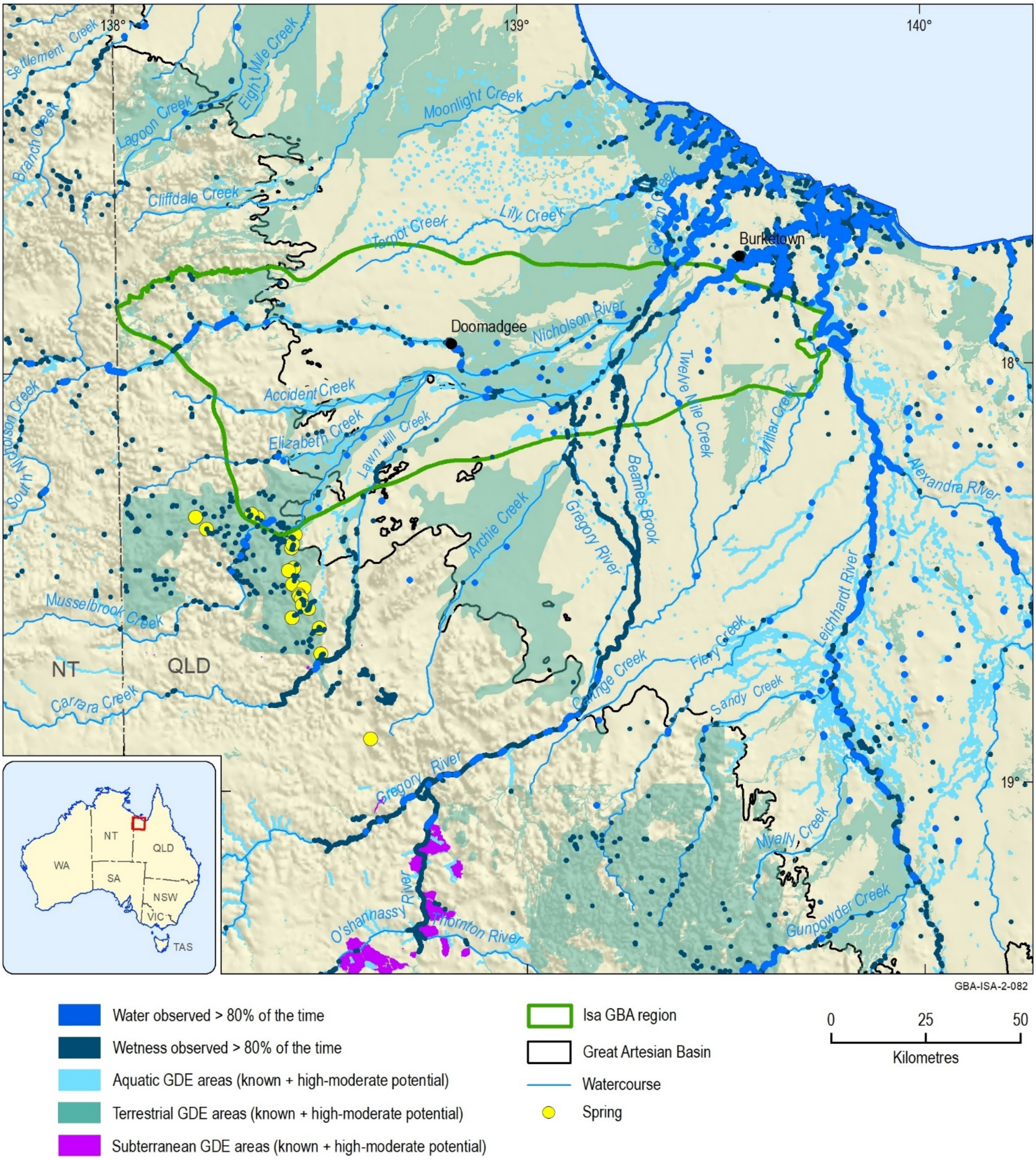

Figure 11 Composite of remote sensing analyses and mapped groundwater-dependent ecosystems (GDEs)

Remote sensing products include Water Observations from Space (WOfS) summary statistic (medium blue) (1987–2018) and Tasselled Cap Wetness (TCW) exceedance composite (dark blue) (May–October 2015). Pixels have been polygonised and classified to visually enhance key data in the remote sensing products. Groundwater-dependent ecosystems (GDEs) include aquatic, terrestrial and subterranean types.
Data: WOfS classified (Geoscience Australia, 2018b); TCW classified (Geoscience Australia, 2018a); *National atlas of groundwater dependent ecosystems* (Bureau of Meteorology, 2017); springs (Department of Environment and Science (Qld), 2018a)
Element: GBA-ISA-2-082

Protected matters – environmental and cultural assets

Matters of National Environmental Significance (MNES) are Australia's national environmental assets as defined in the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). MNES, other protected matters and Matters of State Environmental Significance (MSES) that occur or potentially occur in the Isa GBA region may potentially be impacted by shale gas development.

The MNES that occur or potentially occur within the Isa GBA region include two subspecies of bar-tailed godwit and 24 other vertebrate species listed nationally as threatened (critically endangered, endangered or vulnerable) (Table 2). There are also 32 species that are listed as migratory and 11 species that are both threatened and migratory. No places were identified within the Isa GBA region from the Queensland Heritage Register.

Other protected matters in the Isa GBA region include seven listed marine species (six birds and one reptile) that are not listed as threatened and/or migratory. Matters of State Environmental Significance (MSES) include four nationally important wetlands, three state and territory reserves, the Gulf Rivers strategic environmental area and three state-listed threatened species (Figure 12; Section 4.1 in baseline synthesis and gap analysis (Lewis et al., 2020); protected matters technical appendix (MacFarlane et al., 2020)).

Table 2 Species protected under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* or Queensland's *Nature Conservation Act 1992* that occur, or potentially occur, in the Isa GBA region

Conservation status	Taxon	Occur or potentially occur
Critically endangered	Birds	3
	Sharks	1
Endangered	Birds	3
	Mammals	1
	Reptiles	4
Vulnerable	Birds	6
	Mammals	3
	Reptiles	4
	Sharks	3
Special least concern[a]	Plants	1
Migratory[b]	Birds	15
	Cetaceans	2
	Rays	2
	Sharks	1
	Reptiles	1

[a]category of conservation status under the *Queensland Nature Conservation Act 1992*
[b]a further 11 species are listed as both threatened and migratory and are counted in the list of threatened species
Data: assets Geological and Bioregional Assessment Program (2019a), Department of Environment and Science (Qld) (2018b)

To help focus any future impact and risk assessment in the region, protected matters were prioritised based on how important the Isa GBA region is to each matter. This prioritisation process identified 11 MNES, which are recommended for more detailed assessment as part of any future impact and risk analysis undertaken prior to shale gas development. These species include:

- the endangered species
  - *Amytornis dorotheae* (Carpentaria grasswren)
  - *Erythrura gouldiae* (Gouldian finch)
  - *Rostratula australis* (Australian painted-snipe)
  - *Dasyurus hallucatus* (northern quoll)
  - *Elseya lavarackorum* (gulf snapping turtle)
- the vulnerable species
  - *Erythrotriorchis radiatus* (red goshawk)
  - *Tyto novaehollandiae kimberli* (masked owl (northern))
  - *Macroderma gigas* (ghost bat)
  - *Saccolaimus saccolaimus nudicluniatus* (bare-rumped sheath-tailed bat)
  - *Acanthophis hawkei* (plains death adder)
  - *Pristis pristis* (freshwater sawfish, also known as the largetooth sawfish, river sawfish, Leichhardt's sawfish or northern sawfish).

In addition, two species identified as MSES, the purple-crowned fairy wren (*Malurus coronatus*) and the plant *Solanum carduiforme,* would also benefit from further assessment. Both species are listed as vulnerable under state legislation (Section 4.4 in baseline synthesis and gap analysis (Lewis et al., 2020)).

The entire Isa GBA region has supported Indigenous cultures for many thousands of years. Cultural assets were identified by searching the Commonwealth EPBC Act protected matters database and the Queensland Heritage Register (Section 2 in protected matters technical appendix (MacFarlane et al., 2020)). Indigenous people continue to maintain a strong and ongoing connection to the region and cultural assets and practices are likely to occur that are not listed under Queensland or Commonwealth legislation.

Protected matters – landscape classes

Key ecological and hydrological features of the Isa GBA region are categorised into ten landscape classes, based mainly on Queensland Land Zones (Figure 13). The Isa GBA region is dominated by the landscape classes ‘floodplain and alluvium’ (36% of the region) and ‘loamy and sandy plains’ (33%). It also contains substantial areas of ‘clay plains’ (15%) and of ‘tablelands and duricrusts’ (12%). There are small areas of ‘undulating country on fine-grained sedimentary rocks’, ‘hills and lowlands on metamorphic rocks’ and ‘sandstone ranges’, as well as two springs (Figure 13; Section 4.3 in baseline synthesis and gap analysis (Lewis et al., 2020); protected matters technical appendix (MacFarlane et al., 2020)).

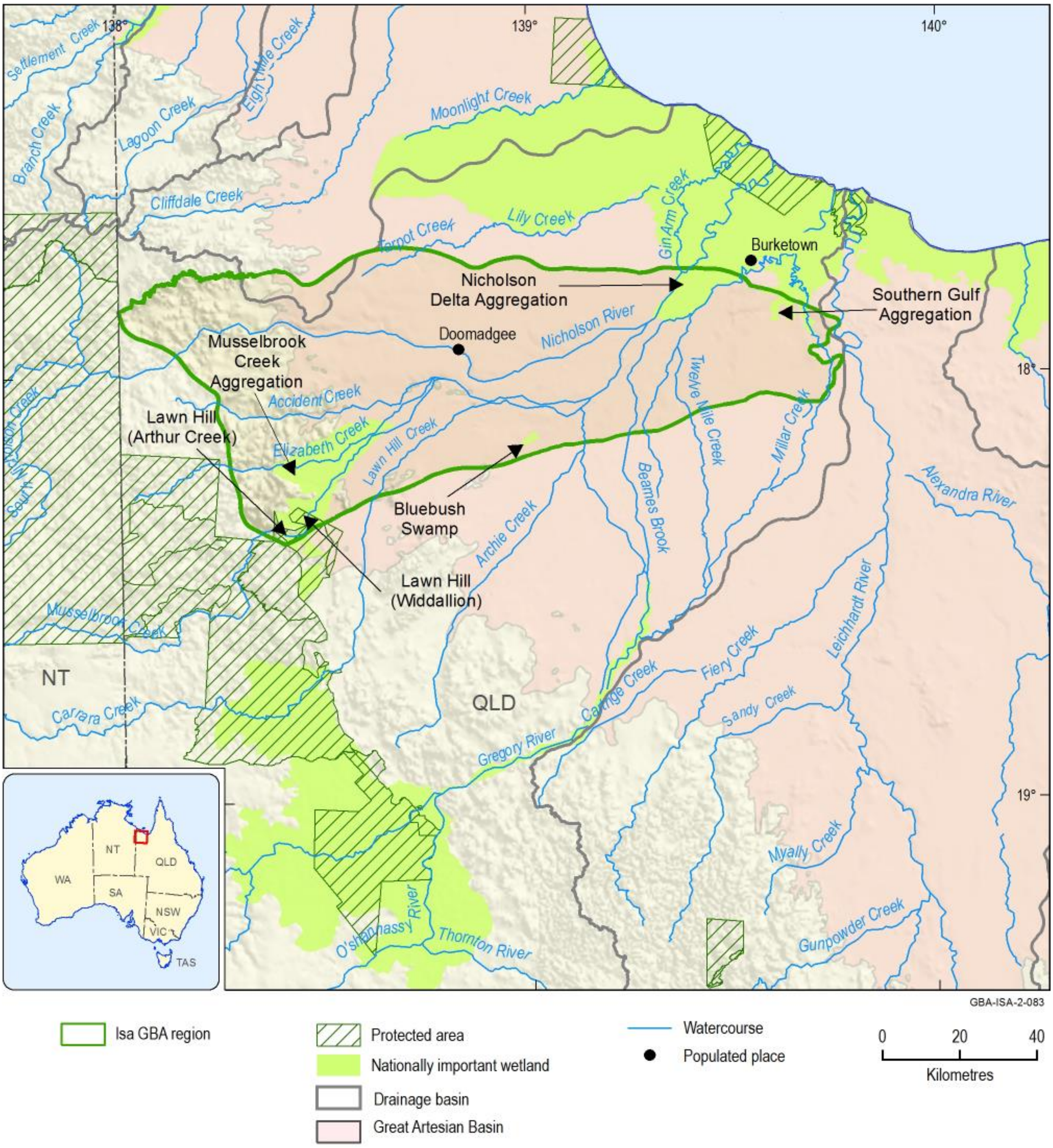

Figure 12 Nationally important wetlands and protected areas in the Isa GBA region

Data: Department of the Environment and Energy (2010, 2016)
Element: GBA-ISA-2-083

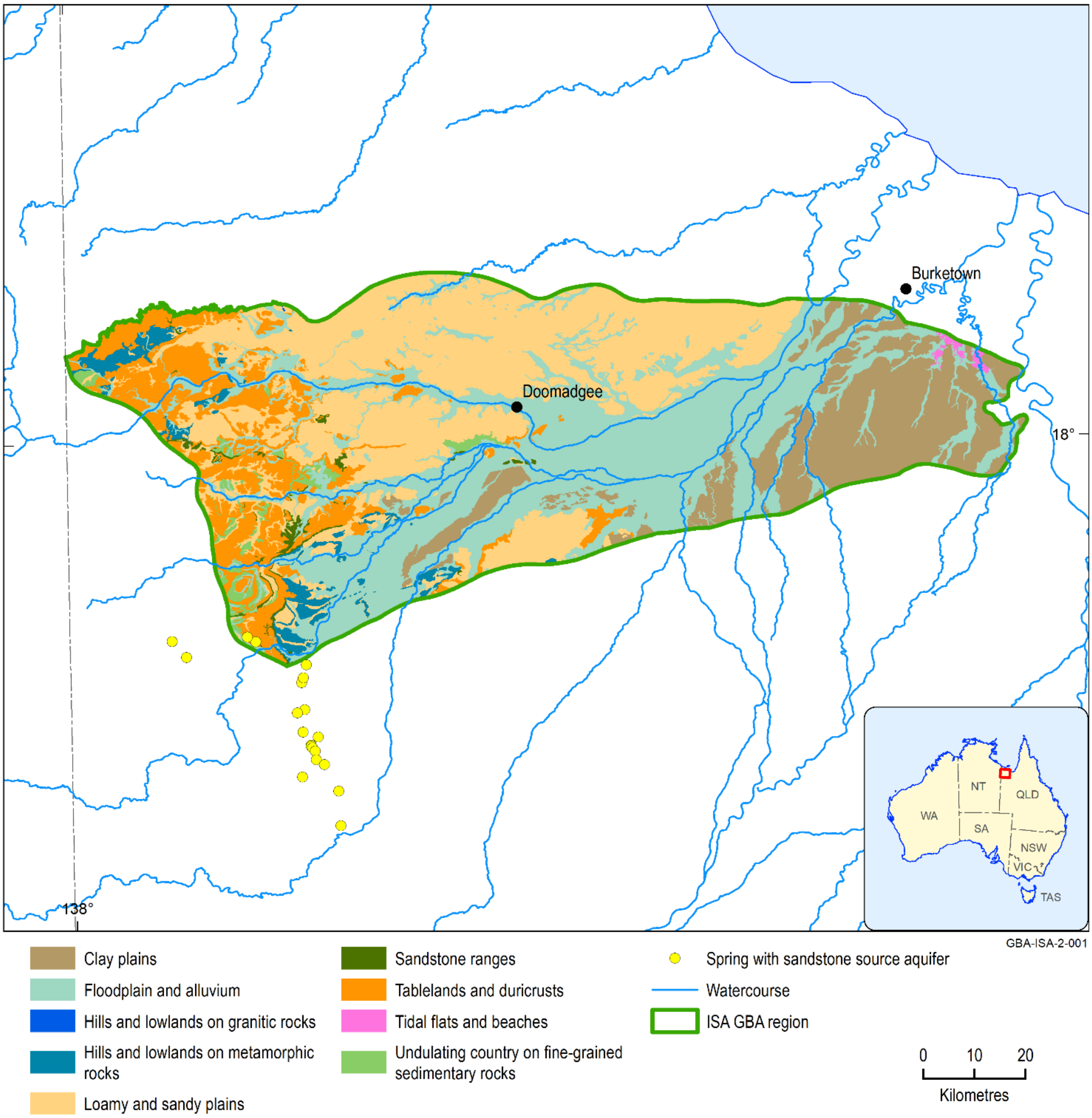

Figure 13 Landscape classes within the Isa GBA region

The 'springs' landscape class is identified as point locations for the purposes of this assessment.
Source: Geological and Bioregional Assessment Program (2018)
Element: GBA-ISA-2-001

Potential impacts due to shale gas development

The risk assessment approach follows the principles for ecological risk assessment, with a view to meeting regulatory processes for the Isa GBA region (Figure 14). Stage 2 establishes the context for the impact and risk assessment, including identifying hazards that are aggregated into a smaller set of causal pathways. The causal pathways and endpoints identified in Stage 2 are key building blocks for any future impact and risk assessment in the Isa GBA region (Section 5.1 in baseline synthesis and gap analysis (Lewis et al., 2020)).

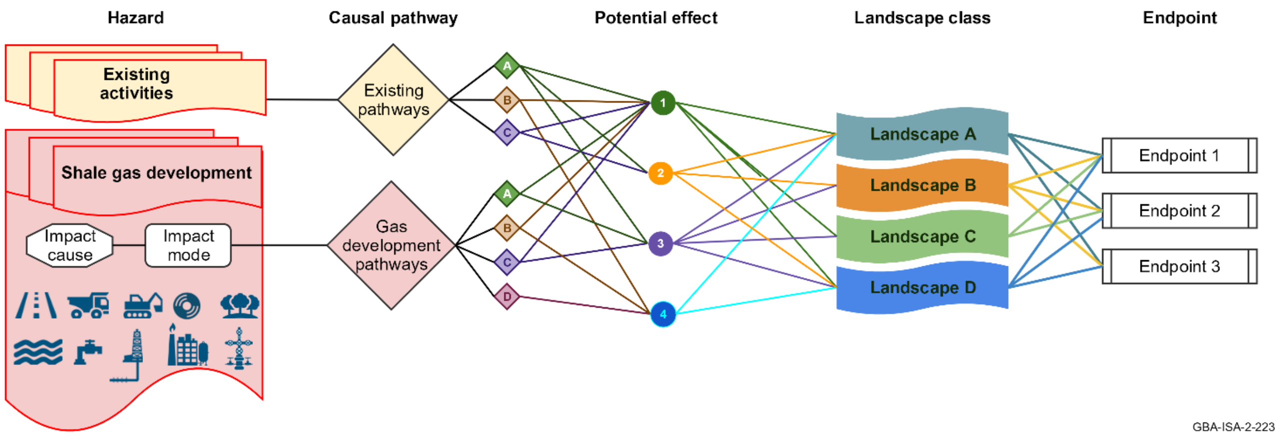

Figure 14 Overview of GBA impact and risk assessment approach, connecting hazards and potential effects from existing and future development through causal pathways to landscape classes and values assessed as endpoints

See Table 3 for explanation of terms used in this diagram.
Element: GBA-ISA-2-223

Table 3 Definition of terms used in GBA impact and risk assessment approach

Impact Modes and Effects Analysis term	Definition
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 (e.g. a 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’, which are an explicit expression of the ecological, economic and/or social values to be protected; and ‘measurement endpoints’, which are measurable characteristics related to the assessment endpoint

Hazards were systematically identified by considering all possible ways an activity in the life cycle of shale gas development (Figure 15) may impact on ecological, economic and/or social values (Section 5.2 in baseline synthesis and gap analysis (Lewis 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 several workshops for the Isa GBA region between May and August 2018.

Importantly, the frontier status of the Isa GBA region and the low level of previous exploration work undertaken for shale gas resources mean that many of the development activities outlined in Stage 2 have not yet actually occurred in the region. This may mean that some of the specific hazards that have been identified through Stage 2 may not eventuate in future, depending upon specific design and development approaches used by a potential future shale gas industry.

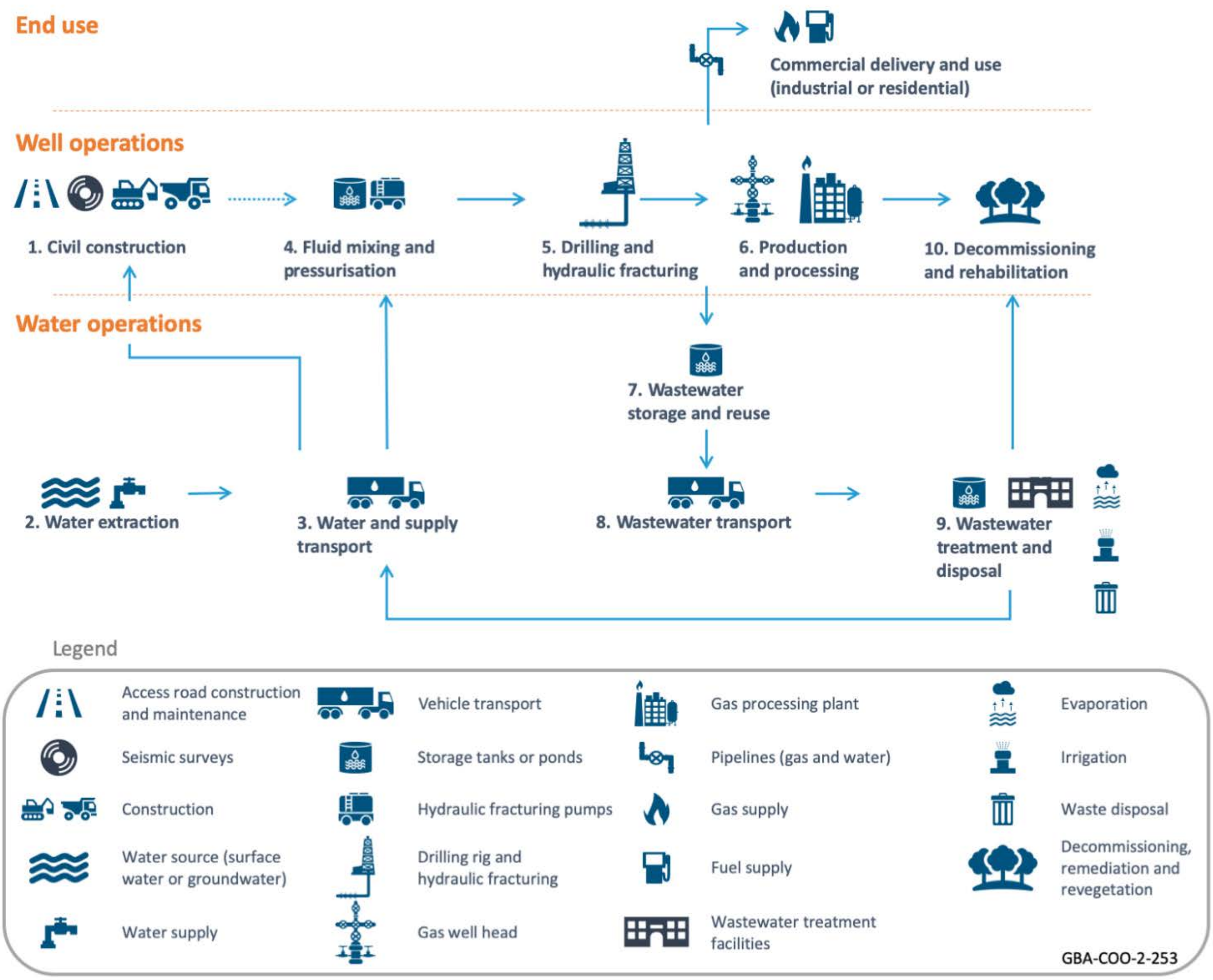

Figure 15 Ten major activities involved in typical shale gas resource development

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 (Lewis et al., 2020)). Causal pathways play a central role in the assessment, connecting hazards arising from existing activities and unconventional gas resource development activities with the values to be protected for each landscape class. Stage 2 provides a preliminary conceptual model for each pathway and illustrates the current knowledge base, showing how potential impacts may link to landscape classes and assessment endpoints. These conceptualisations provide a framework for subsequent and more detailed assessments that may occur in the future.

Causal pathways were prioritised (Table 4) using the highest hazard score (severity + likelihood) to identify the key pathways that could cause impacts which would need to be assessed by a potential future gas industry in the Isa GBA region.

Twelve of the 14 causal pathways in the Isa GBA region were prioritised as needing a higher level of assessment (priority 1) through future impact and risk assessments of potential shale gas developments. Important potential impacts that would need to be further assessed are changed surface water flows; cultural heritage damage or loss; habitat fragmentation or loss; introduction of invasive species leading to increased competition and predation and change in habitat structure; increased mortality of native species; increased soil erosion; changes to groundwater levels, pressures or quality and contamination of soil, groundwater and/or surface water. Most of the priority hazards are in the landscape management (38 out of 108) and water and infrastructure management (28 of 92) causal pathway groups, with fewer (two out of 22) in the subsurface flow paths causal pathway group.

Table 4 Prioritisation of causal pathways for the Isa GBA region

Causal pathway	Priority 1	Priority 2	Priority 3
'Landscape management' causal pathway group	**38**	**54**	**16**
Altering cultural heritage	5	2	0
Altering natural and agricultural productivity	1	14	5
Altering natural habitat and species distributions	22	27	8
Altering surface hydrology	5	4	3
Introduction of invasive species	5	7	0
'Subsurface flow paths' causal pathway group	**2**	**8**	**12**
Compromised well integrity	2	4	5
Gas extraction altering groundwaters	0	1	2
Hydraulic fracturing	0	3	5
'Water and infrastructure management' causal pathway group	**28**	**31**	**33**
Discharging into surface waters	7	2	1
Disposal and storage of site materials	2	10	9
Failure of surface infrastructure (ponds, tanks, pipelines, etc.)	13	7	10
Processing and using extracted water	1	7	0
Reinjecting water into aquifer	1	3	6
Sourcing water for site operations	4	2	7
Total	**68**	**93**	**61**

Source: hazard identification dataset Geological and Bioregional Assessment Program (2019b)

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 heightened concerns from government, the community and industry.

Potential impacts – hydraulic fracturing and compromised well integrity

Hydraulic fracture stimulation is used to create hydraulic fractures in the target petroleum reservoir to maximise the flow of gas to the well. Over the past 50 years, hydraulic fracturing has been used to stimulate conventional oil and gas and unconventional gas reservoirs in Australia. Due to the low level of shale gas exploration in the Isa GBA region, only a single petroleum exploration well (Egilabria 2DW1) has previously been hydraulically fractured.

Risks from hydraulic fracturing have been the focus for industry, government and academia for more than a decade. A qualitative review of nine previous domestic and international inquiries into onshore gas industry operations, coupled with historical Isa GBA region data and the hazard scoring for the 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 this initial assessment did not highlight any of the three hydraulic fracturing impact modes as a high priority, there is one impact mode, 'hydraulic fracture growth into aquifer', that is recommended for further analysis based on heightened community concern around hydraulic fracturing and the geological characteristics of the Isa GBA region.

Regulated construction of wells for shale 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 Isa GBA region historical data, findings from international and domestic inquiries and hazard scoring for the region (Section 5.2 in baseline synthesis and gap analysis (Lewis et al., 2020)) are broadly consistent. Two priority impact modes are recommended for further investigation as part of any future impact and risk analysis: 'migration of fluids between different geological layers along a failure of the well casing' and 'failure of well integrity after well decommissioning/abandonment' (Section 6.4 in baseline synthesis and gap analysis (Lewis et al., 2020); hydraulic fracturing technical appendix (Kear and Kasperczyk, 2020)).

Potential impacts – screening of drilling and hydraulic fracturing chemicals

Petroleum industry activity in the Isa GBA region has been minimal, with only one shale gas exploration well hydraulically fractured (after drilling) in 2013. Given the limited exploration in the region to date, the review of drilling and hydraulic fracturing chemicals focused on all hydraulic fracturing operations that have occurred in each of the three GBA regions between 2011 and 2016 to provide more data for analysis. 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 the three 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'. These chemicals would require site-specific quantitative chemical assessments to be undertaken to determine risks to aquatic ecosystems (Section 6.3 in baseline synthesis and gap analysis (Lewis et al., 2020); chemical screening technical appendix (Kirby et al., 2020)).

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 shale gas target formations in the Isa GBA region. The results of these tests will help 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 solution by hydraulic fracturing fluids (Section 6.3 in baseline synthesis and gap analysis (Lewis 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 better inform wastewater management and treatment.

Conclusion

Stage 2 of the geological and bioregional assessment of the Isa GBA region is a geological and environmental baseline analysis in the context of possible future shale gas development. In particular, the potential hazards and associated causal pathways that this industry may pose to the quality, quantity and availability of water resources (both surface water and groundwater) and the environment have been identified and prioritised for further investigation.

The compilation of baseline data and information for the Isa GBA region, combined with recognition of high-priority hazards and the development of preliminary conceptual models, are key building blocks for any future assessment of the potential impacts of shale gas development. The data and information compiled for Stage 2 (and explained in greater detail in the synthesis report and technical appendices) provides a solid foundation to support and inform any future shale gas impact assessments in the region. The outputs from this Stage 2 work can be used by industry and government regulators alike as a common starting point for further assessment and should help to focus any new investigations on the key uncertainties identified through this baseline analysis. Such investigations may include:

- gas fairway mapping that reflects economic considerations such as estimates of total and recoverable gas-in-place for priority plays and analyses to understand which plays are economic to commercialise, based on current and expected future market conditions
- improving knowledge of the region's groundwater systems, the degree of hydrological connectivity within and between the two main groundwater systems (i.e. Proterozoic-hosted groundwater and the shallower GAB), as well as improving knowledge of surface water – groundwater interactions and developing baseline water quality for key regional aquifers
- gathering accurate records of the distribution and biology of MNES and MSES, particularly for the 11 high priority threatened species, including information about preferred habitat, food sources and their trophic interactions.

Figure 16 The Gregory River downstream of its crossing on the Doomadgee – Burketown Road

Source: Geological and Bioregional Assessment Program, Steven Lewis (Geoscience Australia), July 2018
Element: GBA-ISA-2-210

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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.

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: for the purposes of geological and bioregional assessments, the logical chain of events – either planned or unplanned – that link unconventional gas resource development and potential impacts on water and the environment

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.

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).

fairway: a term used in geology to describe a regional trend along which a particular geological feature is likely to occur, such as a hydrocarbon fairway. Understanding and predicting fairways can help geologists explore for various types of resources, such as minerals, oil and gas.

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

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

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

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.

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

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 injection: the forcing or pumping of substances into a porous and permeable subsurface rock formation. Examples of injected substances can include either gases or liquids.

landscape class: for the purposes of geological and bioregional assessments (GBA), 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. 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 GBA region and their spatial coverage is exhaustive and non-overlapping. Conceptually, landscape classes can be considered as types of ecosystem assets.

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.

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.

play fairway analysis: sometimes referred to as play fairway mapping, play fairway analysis is used to identify areas where a specific play is likely to be successful, and where additional work on a finer scale is warranted in order to further develop an understanding of a prospect. The phrasing 'fairway' is used as prospective areas on the map are often visually similar to fairways on a golf course. Play fairway maps are created at a regional scale, often tens to hundreds of kilometres in scale, from multiple input sources that vary based on what information is available and relevant based on the requirements of the creator.

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

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

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: magnitude of an 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.

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.

unconfined aquifer: an aquifer whose upper water surface (watertable) is at atmospheric pressure and does not have a confining layer of low-permeability rock or sediment above it

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.

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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