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

Assessing impacts of coal resource development on water resources in the Galilee subregion: key findings

Product 5: Outcome synthesis for the Galilee subregion from the Lake Eyre Basin Bioregional Assessment

2018

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

Galilee assessment at a glance

This bioregional assessment considered the potential cumulative impacts on water and water-dependent assets due to future coal resource development in the Galilee subregion of the Lake Eyre Basin bioregion in central Queensland (Figure 1). Seven of the 17 additional coal resource developments identified (Box 1) had sufficient available information to be modelled (Table 1). This assessment is a regional overview of potential impacts on, and risks to, water-dependent ecological, economic and sociocultural assets, identifying where potential changes in water resources and ecosystems may occur due to the seven modelled coal mines, and ruling out areas where impacts are *very unlikely* (less than 5% chance). Governments, industry and the community can then focus on the areas that are potentially impacted and apply local-scale data and modelling when making regulatory, water management and planning decisions.

HEADLINE FINDING

Cumulative hydrological changes in the Belyando river basin are* very likely *(greater than 95% chance), and extend farther than previously predicted from impact assessments of individual mines.

Groundwater: Drawdown in the near-surface aquifer due to modelled additional coal resource development occurs in two areas near clusters of coal mines in the east, with an area of 2820 km^2 *very likely* to experience greater than 0.2 m drawdown. Major aquifers of the geological Eromanga Basin (part of the Great Artesian Basin) are not expected to be impacted. *See page 12*

Surface water: Modelled additional coal resource development could impact 6285 km of streams (with at least a 5% chance). Of these, most are temporary streams. *See page 15*

Ecosystem impacts: In the zone of potential hydrological change (Figure 1), 8% of groundwater-dependent streams are at some level of risk of ecological and hydrological changes, and 188 springs have a source aquifer with at least a 5% chance of greater than 0.2 m drawdown due to modelled additional coal resource development. *See page 21*

Asset impacts: Of 241 potentially impacted ecological assets, 148 are relatively 'more at risk of hydrological changes'. In addition, one surface water right, five groundwater economic assets, and four heritage or Indigenous sites are potentially impacted. *See page 29*

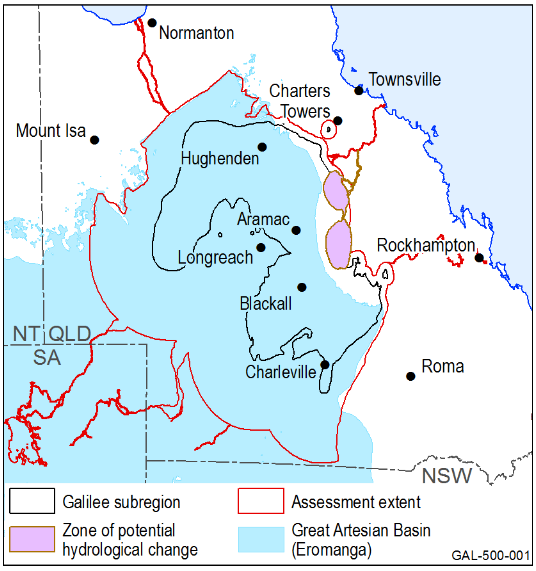

Figure 1 The zone of potential hydrological change

The zone defines the area in the Galilee subregion outside of which impacts are ruled out (see Box 5 for details). The assessment of potential impacts from seven modelled mines was therefore focused within this zone, which combines:

- the area with at least a 5% chance of exceeding 0.2 m drawdown in the near-surface aquifer due to additional coal resource development
- the area with at least a 5% chance of exceeding thresholds in specified surface water characteristics due to additional coal resource development.

Data: Bioregional Assessment Programme (Dataset 1, Dataset 2)

BASELINE COAL RESOURCE DEVELOPMENTS (BOX 1)

0 x mines, 0 x CSG

ADDITIONAL COAL RESOURCE DEVELOPMENTS (BOX 1)

14 x mines   3 x CSG

Throughout this synthesis, the term '*very likely*' is used where modelling predicts a greater than 95% chance of something occurring, and '*very unlikely*' is used where modelling predicts a less than 5% chance (Box 5).

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CITATION

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COVER PHOTOGRAPH

Artesian Spring Wetland at Doongmabulla Nature Refuge, Queensland, 2013. Credit: Jeremy Drimer, University of Queensland

v20180613

Executive summary

About the subregion *see page 3*

This synthesis presents key findings from the bioregional assessment of the Galilee subregion (Figure 2), part of the Lake Eyre Basin bioregion. The subregion straddles the Great Dividing Range and extends west and north into the Lake Eyre surface water catchment and Flinders-Norman river basins. A diversity of ecological communities and species are adapted to the subregion's arid and semi-arid ecosystems.

The subregion covers about 248,000 km^2; however, the total area investigated for this assessment (the **assessment extent**) is about 612,000 km^2, as it includes groundwater and surface water systems that extend beyond the subregion boundary (Figure 1).

This assessment considered two futures: the **baseline**, which has no existing coal resource development, and the **coal resource development pathway** (Box 1), which includes 17 **additional coal resource developments**, of which seven had sufficient information to be modelled (Table 1). This assessment mainly focused on the potential cumulative impacts of these seven coal mines on water and water-dependent assets.

Potential hydrological changes *see page 12*

Regional-scale hydrological modelling identified potential changes in groundwater and streamflow due to seven modelled additional coal resource developments. A **zone of potential hydrological change** (Figure 1, Box 5) identified the area potentially impacted by these seven mines. The zone covers 14,030 km^2 and includes 6285 km of streams, most of which are temporary streams.

Potential impacts on ecosystems and assets *see page 21 and page 29*

Potential impacts to groundwater, surface water and water-dependent assets are mostly restricted to the Belyando and Suttor river basins, the location of the seven modelled coal mines (Figure 3). The largest groundwater drawdowns are in the coal-bearing layer, but very few assets source groundwater from this layer. Smaller drawdowns are expected in the Cenozoic alluvium (near-surface aquifer) and Clematis Group aquifers. The main Great Artesian Basin (GAB) aquifers of the Eromanga Basin are not predicted to be impacted.

Source aquifers for 188 of the 1559 springs in the assessment extent have at least a 5% chance of exceeding 0.2 m drawdown, including for 181 springs in the Doongmabulla Springs complex. In the zone, 8% of the 2801 km of groundwater-dependent streams show some level of risk of ecological and hydrological changes (Box 10), including parts of Native Companion, North and Sandy creeks, and the Belyando and Carmichael rivers. Some level of risk of ecological and hydrological changes was found for up to 3% of groundwater-dependent vegetation along floodplains associated with Alpha, North, Sandy and Tallarenha creeks, and the Belyando, Suttor and Carmichael rivers.

Of the 241 ecological assets potentially impacted due to modelled additional coal resource development, 148 are considered 'more at risk of hydrological changes' relative to other assets (Box 11). These include potential habitat of 12 threatened species and two threatened ecological communities listed under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

One surface water right, extracting from the Belyando River and a tributary of Native Companion Creek, and five groundwater economic assets are potentially impacted due to modelled additional coal resource development. Three of these groundwater assets are associated with the Clematis Group aquifer, including water access rights near the town of Jericho. However, it is *very unlikely* that any of the economic assets associated with the Clematis Group aquifer will experience more than 2 m of drawdown.

The greatest confidence in results is in those areas that are *very unlikely* to be impacted. Where potential impacts have been identified, further local-scale modelling may be required to determine the likelihood and magnitude of impacts.

Box 1 Investigating two potential futures

In bioregional assessments, results are reported for two potential futures:

- **baseline coal resource development (baseline):** a future that includes all coal mines and coal seam gas fields that were commercially producing as of December 2012. In the Galilee subregion the baseline is a 'no development' scenario as there was no coal resource production.
- **coal resource development pathway:** a future that includes a 'no-development' baseline as well as the **additional coal resource development**, which are those coal resource developments expected to begin commercial production after December 2012.

The difference in results between the coal resource development pathway and baseline is the change that is primarily reported in a bioregional assessment. This change is due to the **additional coal resource development**.

The coal resource development pathway for the Galilee subregion was based on information available as of December 2014. However, coal resource development proposals may change over time or be withdrawn, or timing of developments may change. Factors such as climate change or land use were held constant between the two futures. Although actual climate or land use may differ, the effect on results is expected to be minimal as the assessment focused on the difference in the results between the coal resource development pathway and baseline, minimising the impacts of changes that occur in both futures.

Explore this assessment

Bioregional assessments are independent scientific assessments of the potential cumulative impacts of coal seam gas (CSG) and coal mining developments on water resources and water-dependent assets such as rivers, wetlands and groundwater systems. These regional-scale assessments focus on 13 areas across Queensland, NSW, Victoria and SA where coal resource development is taking place, or could take place.

The assessments rule out areas where impacts on water resources and water-dependent assets are *very unlikely* (with a less than 5% chance). The zone of potential hydrological change (Box 5) identifies where potential impacts cannot be ruled out. Governments, industry and the community can then focus on areas that are potentially impacted and apply local-scale modelling when making regulatory, water management and planning decisions.

The assessment investigates:

- the characteristics of the subregion, including water resources, assets, and coal and CSG resources (Component 1)
- how future coal resource development could affect surface water and groundwater quantity (Component 2)
- how hydrological changes could impact on water-dependent ecosystems and assets (Component 3 and Component 4).

The assessments consider potential changes in water quantity and some impacts related to salinity but they do not assess a full suite of impacts on water quality.

The assessment of the **Galilee subregion**, part of the Lake Eyre Basin Bioregional Assessment, is reported in 12 technical products (Box 2), which are summarised in this synthesis.

Box 2 Technical products for the Galilee subregion

Component 1: Contextual information
1.1 Context statement
1.2 Coal and coal seam gas resource assessment
1.3 Description of the water-dependent asset register
1.5 Current water accounts and water quality
1.6 Data register

Component 2: Model-data analysis
2.1-2.2 Observations analysis, statistical analysis and interpolation
2.3 Conceptual modelling
2.5 Water balance assessment
2.6.1 Surface water numerical modelling
2.6.2 Groundwater numerical modelling
2.7 Receptor impact modelling

Component 3 and Component 4: Impact and risk analysis
3-4 Impact and risk analysis

The pages of this synthesis follow this colour guide when describing the assessment outputs. Product 1.4 (receptor register) and product 2.4 (two- and three-dimensional visualisations) were not produced for any bioregional assessment as evolution of the methods rendered them obsolete.

FIND MORE INFORMATION

www.bioregionalassessments.gov.au includes all technical products as well as information about all datasets used or created, most of which can be downloaded from data.gov.au. Additional resources are listed in this synthesis, and include methodologies, maps, models and lists of water-dependent assets, ecosystems and potential hazards. Users can visualise where potential impacts might occur using a map-based interface on the BA Explorer, available at www.bioregionalassessments.gov.au/explorer/GAL.

References, further reading and datasets are listed at the end of this synthesis.

CONTENTS OF THIS SYNTHESIS

About the subregion

The Galilee subregion in central Queensland, defined by the extent of the coal-bearing geological Galilee Basin, encompasses diverse natural environments from the Great Dividing Range through to vast expanses of semi-arid and arid inland Australia (Figure 2). The 248,000 km^2 subregion within the Lake Eyre Basin bioregion includes the headwaters of rivers that flow outwards into Lake Eyre, the Gulf of Carpentaria, the Pacific Ocean and the Murray–Darling Basin.

The Galilee assessment extent of about 612,000 km^2 is much larger than the subregion boundary because at the start of the assessment a precautionary approach was adopted to define the area potentially impacted by hydrological changes due to future coal resource development. The main area of interest was further refined and reduced in size during the course of the assessment as more information about the area of potential impact was developed. This process led to the development of the **zone of potential hydrological change** for the Galilee subregion (Figure 1 and Box 5).

The assessment extent includes the Great Dividing Range and extends further west and north, well into the Lake Eyre surface water catchment and the Flinders–Norman river basin. To the east, outflow from the subregion occurs mainly along the Burdekin River, discharging to the Pacific Ocean near the Great Barrier Reef. Surface water flow is strongly seasonal and can vary greatly from year to year, from almost no flow to major floods. Most rivers and streams are intermittent.

The subregion has several large regional groundwater systems, with the main ones hosted in aquifers of the geological Eromanga and Galilee basins. Due to variability of reliable surface water resources in the subregion, there is a strong dependence on groundwater supplies. Groundwater is used mainly for agricultural purposes, including thousands of stock and domestic bores, as well as town water supplies.

The Galilee subregion is predominantly used for livestock grazing on native pastures and is only sparsely populated with around 20,000 people. The main towns are Blackall, Barcaldine, Hughenden and Charleville. Other than relatively small areas of plantation forestry and minor clearing for pasture improvement, there is very little modification of the natural land cover. This large area has diverse ecological communities and species, as well as biologically significant climate gradients.

The main natural and human-modified ecosystems in the assessment extent were categorised for this assessment through a landscape classification (Box 8), based on the subregion's geology, geomorphology (physical features), hydrogeology (the way water moves through porous rocks), land use and ecology. See 'What are the potential impacts of additional coal resource development on ecosystems?' (page 21) for more information.

The regional community nominated assets that they consider important due to their ecological, economic or sociocultural values (Sparrow et al., 2015; Bioregional Assessment Programme, 2017; Dataset 3). These include ecosystems such as springs that provide habitat for a variety of plants and animals, groundwater used for agricultural purposes, and sites of heritage or cultural significance. See 'What are the potential impacts of additional coal resource development on water-dependent assets?' (page 29) for more information.

Coal resource development

Key finding 1: For the Galilee subregion, 14 new coal mines and three coal seam gas projects were deemed the most likely future coal resource development as at December 2014. Sufficient information was available to model seven of these coal mines. There are no existing (baseline) coal resource developments in the subregion.

The coal resource development pathway (CRDP, Box 1) defines the most likely future for the subregion. In the absence of commercially producing coal mines or CSG fields in the subregion, the focus of this bioregional assessment is on understanding the potential for cumulative hydrological impacts due to the seven large coal mines initially planned for future development in an area that stretches for about 250 km near the eastern margin of the central Galilee subregion (Figure 2).

Almost all of the proposed coal mine developments are in the headwaters of the Burdekin river basin – in particular, the western flank of the Belyando river basin (Figure 3). The seven developments included in the numerical surface water and groundwater models (Table 1) include the proposed open-cut coal mines Alpha and Hyde Park, and the combined open-cut and underground coal mines Carmichael, China First, China Stone, Kevin's Corner and South Galilee. Mining operations were modelled based on estimated scheduling as of December 2014 (Figure 4).

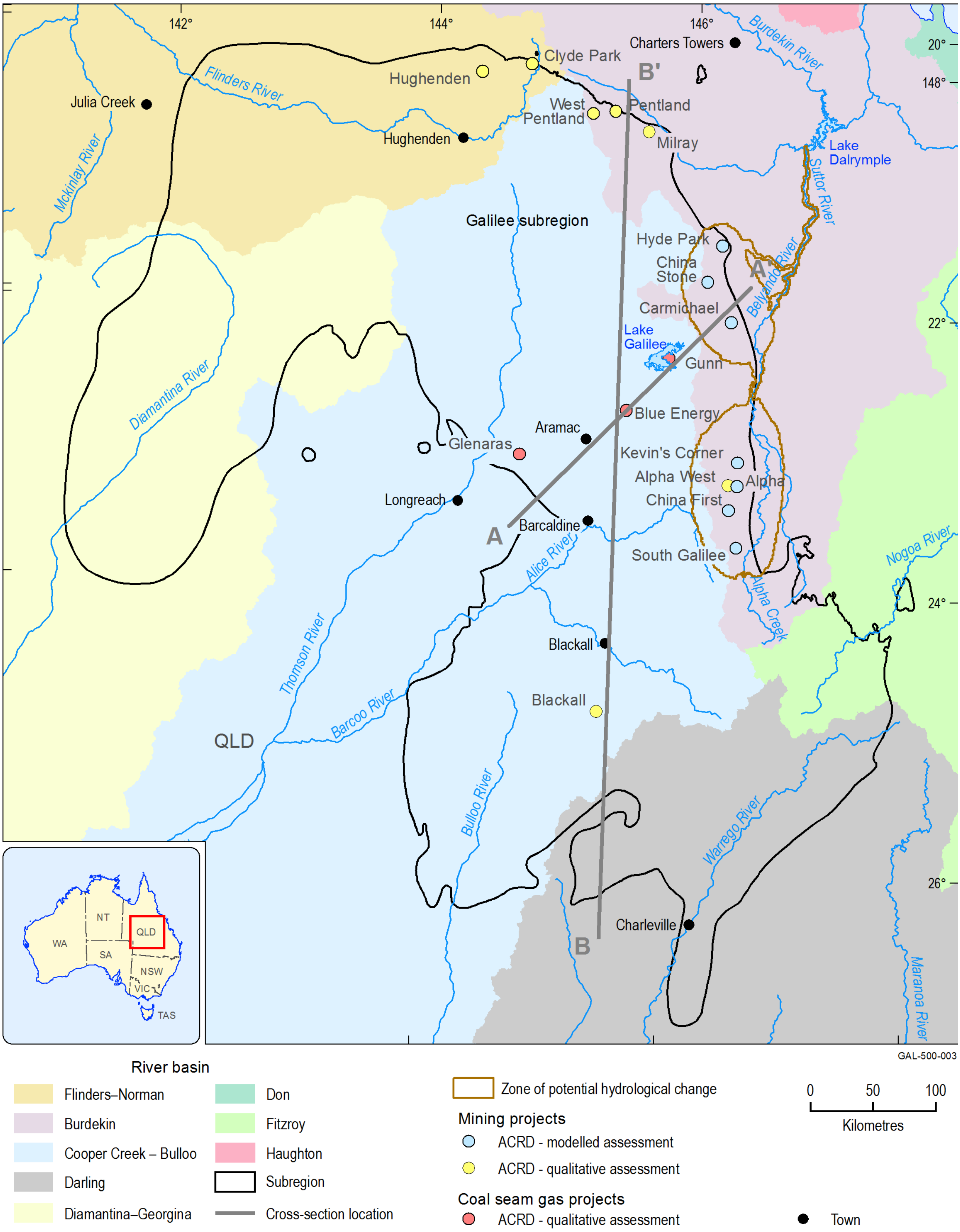

Figure 2 Proposed coal mines and coal seam gas operations in the Galilee subregion

The coal resource development pathway (CRDP) includes baseline and additional coal resource developments (ACRD). Because there are no coal resource developments in the baseline for the Galilee subregion, the CRDP includes only the ACRD. See Figure 5 for cross-section of line A–A', and Figure 6 for cross-section of line B–B'

Data: Bureau of Meteorology (Dataset 4, Dataset 5); Geoscience Australia (Dataset 6); Geological Survey of Queensland (Dataset 7)

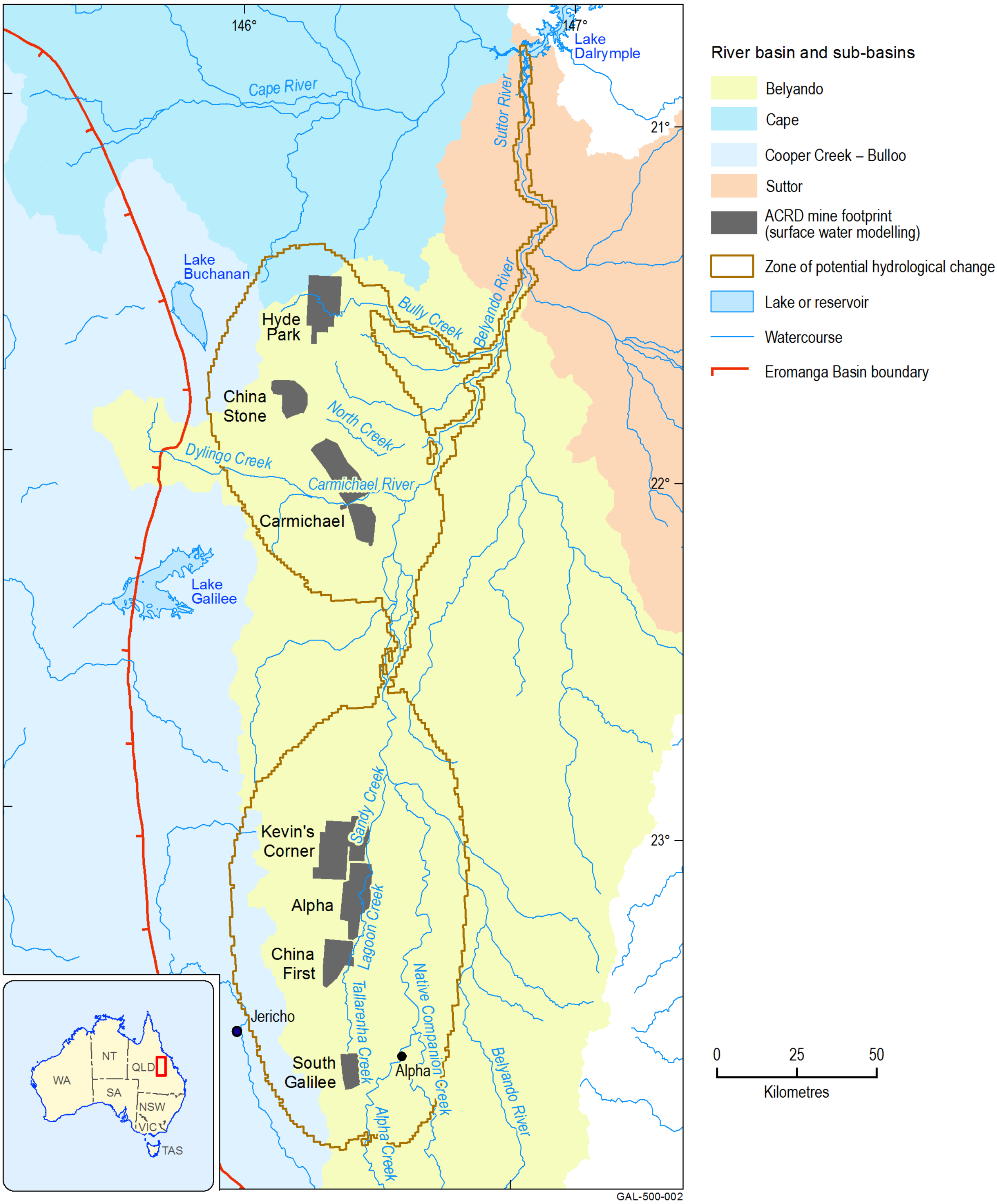

Figure 3 Proposed coal mine extents in the central-eastern Galilee Basin, showing relationship to the zone of potential hydrological change and the main rivers, creeks and surface water catchments

The coal resource development pathway (CRDP) includes baseline and additional coal resource developments (ACRD). Because there are no coal resource developments in the baseline for the Galilee subregion, the CRDP includes only the ACRD. The impact and risk analysis focused on this smaller area where the seven most advanced mining projects occur with sufficient information to include in the hydrological modellings. A qualitative assessment of the potential impacts of the other ACRDs (seven coal mines and three coal seam gas projects) is presented in Section 3.6 of the impact and risk analysis (Lewis et al., 2018). The Belyando, Cape and Suttor river basins are subdivisions of the larger Burdekin river basin (shown in Figure 2).
Data: Bioregional Assessment Programme (Dataset 1, Dataset 8, Dataset 9); Geoscience Australia (Dataset 2); Bureau of Meteorology (Dataset 4, Dataset 5)

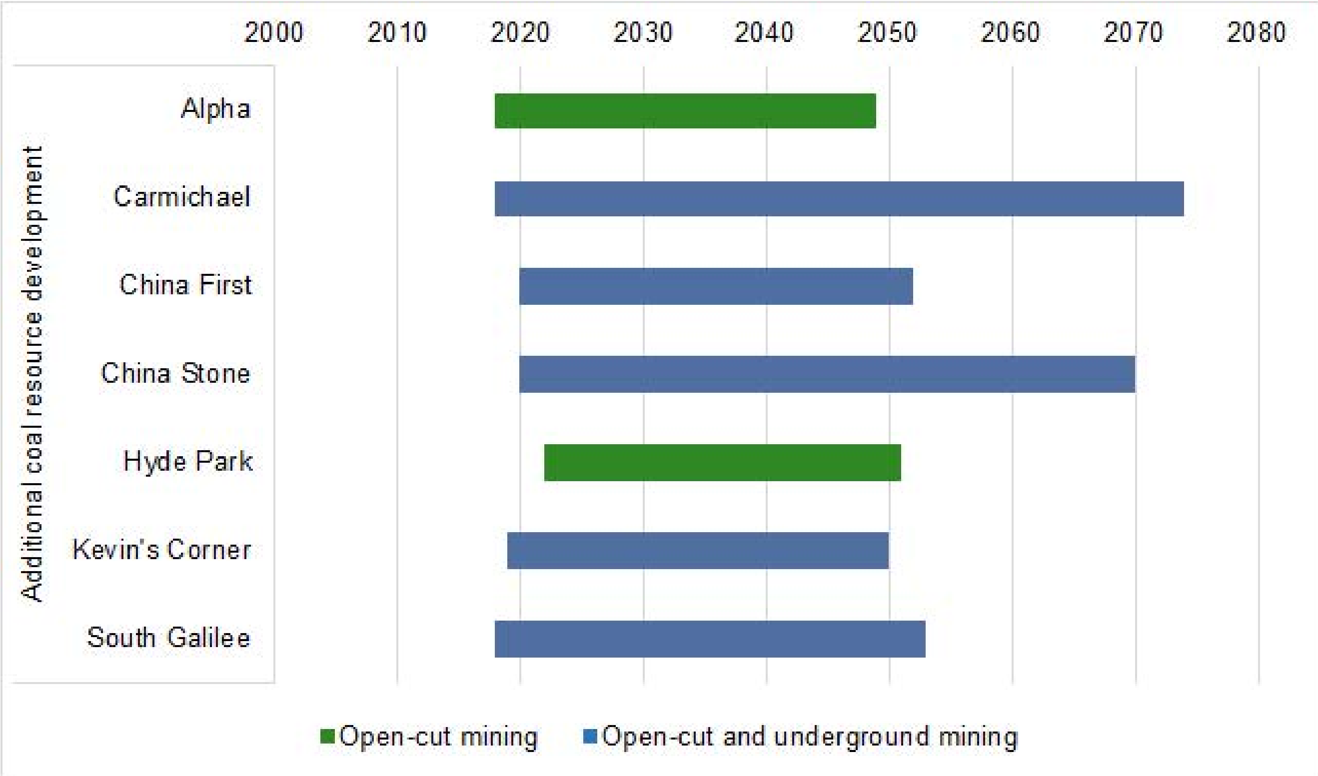

Figure 4 Estimated scheduling of additional coal resource developments modelled in the bioregional assessment for the Galilee subregion

The coal resource development pathway (CRDP) includes baseline and additional coal resource developments (ACRD). Because there are no coal resource developments in the baseline for the Galilee subregion, the CRDP includes only the ACRD. Dates are best available estimates as of December 2014 when the CRDP for the Galilee subregion was developed. Actual operational start and end dates and production time frames may change. Further information is outlined in Section 2.3.4 of Evans et al. (2018b).

The remaining proposed coal mines in the CRDP are the open-cut Blackall, underground Alpha West and Hughenden, and the likely combined open-cut and underground operations at Clyde Park, Milray, Pentland and West Pentland (Table 1 and Figure 2). Plans for these mines were not sufficiently advanced for quantitative hydrological modelling or impact and risk analysis to be undertaken in this assessment. Qualitative analysis of potential impacts on water resources and water-dependent assets due to the seven non-modelled coal mines is reported in the impact and risk analysis (Section 3.6 in Lewis et al. (2018)). It is important to note that the zone of potential hydrological change and the impact and risk analysis reported in this synthesis are based only on the seven modelled coal mines.

The Galilee Basin also has potential for future development of CSG resources. To date, greenfield CSG exploration programs have been undertaken in parts of the central Galilee Basin (Figure 2), with a pilot wellfield established in the Aramac Trough (Figure 5). The three early-stage CSG projects in the CRDP are the Glenaras Gas Project, Gunn Project and Blue Energy’s exploration tenement 813, focused in the central Galilee Basin. At the time of this assessment there was insufficient information about the likely commercial timing and extent of these CSG developments, and they were not evaluated by hydrological modelling. However, similar to the non-modelled coal mines, a qualitative analysis of the potential impacts on, and risks to, ecosystems and water-dependent assets is discussed in the impact and risk analysis (Lewis et al., 2018). Three-dimensional geological cross-sections show the variable depth and extent of the coal-bearing layers in the Galilee Basin, and their relationship with the overlying formations of the Eromanga Basin (Figure 5 and Figure 6).

The regional hydrogeological conceptualisation developed for this assessment is a first for the Galilee Basin and demonstrates many important features, including how groundwater flow systems may interact with aquifers in the overlying Eromanga Basin. Further information about the regional groundwater systems in the Galilee and Eromanga basins is outlined in Evans et al. (2018a and 2018b).

Table 1 Proposed coal mines and coal seam gas operations (as of December 2014) included in the coal resource development pathway for the Galilee subregion

Coal mine – modelled	Coal mine – not modelled	Coal seam gas project – not modelled
Alpha	Alpha West	Glenaras Gas Project
Carmichael	Blackall	Gunn Project
China First	Clyde Park	Blue Energy's EPP 813
China Stone	Hughenden	
Hyde Park	Milray	
Kevin's Corner	Pentland	
South Galilee	West Pentland	

EPP = exploration permit for petroleum

FIND MORE INFORMATION

Context statement, product 1.1 (Evans et al., 2014a)

Coal and coal seam gas resource assessment, product 1.2 (Lewis et al., 2014)

Description of the water-dependent asset register, product 1.3 (Sparrow et al., 2015)

Current water accounts and water quality, product 1.5 (Evans et al., 2015)

Observations analysis, statistical analysis and interpolation, product 2.1-2.2 (Evans et al., 2018a)

Conceptual modelling, product 2.3 (Evans et al., 2018b)

Surface water numerical modelling, product 2.6.1 (Karim et al., 2018a)

Groundwater numerical modelling, product 2.6.2 (Peeters et al., 2018)

Impact and risk analysis, product 3-4 (Lewis et al., 2018)

Compiling water-dependent assets, submethodology M02 (Mount et al., 2015)

Developing a coal resource development pathway, submethodology M04 (Lewis, 2014)

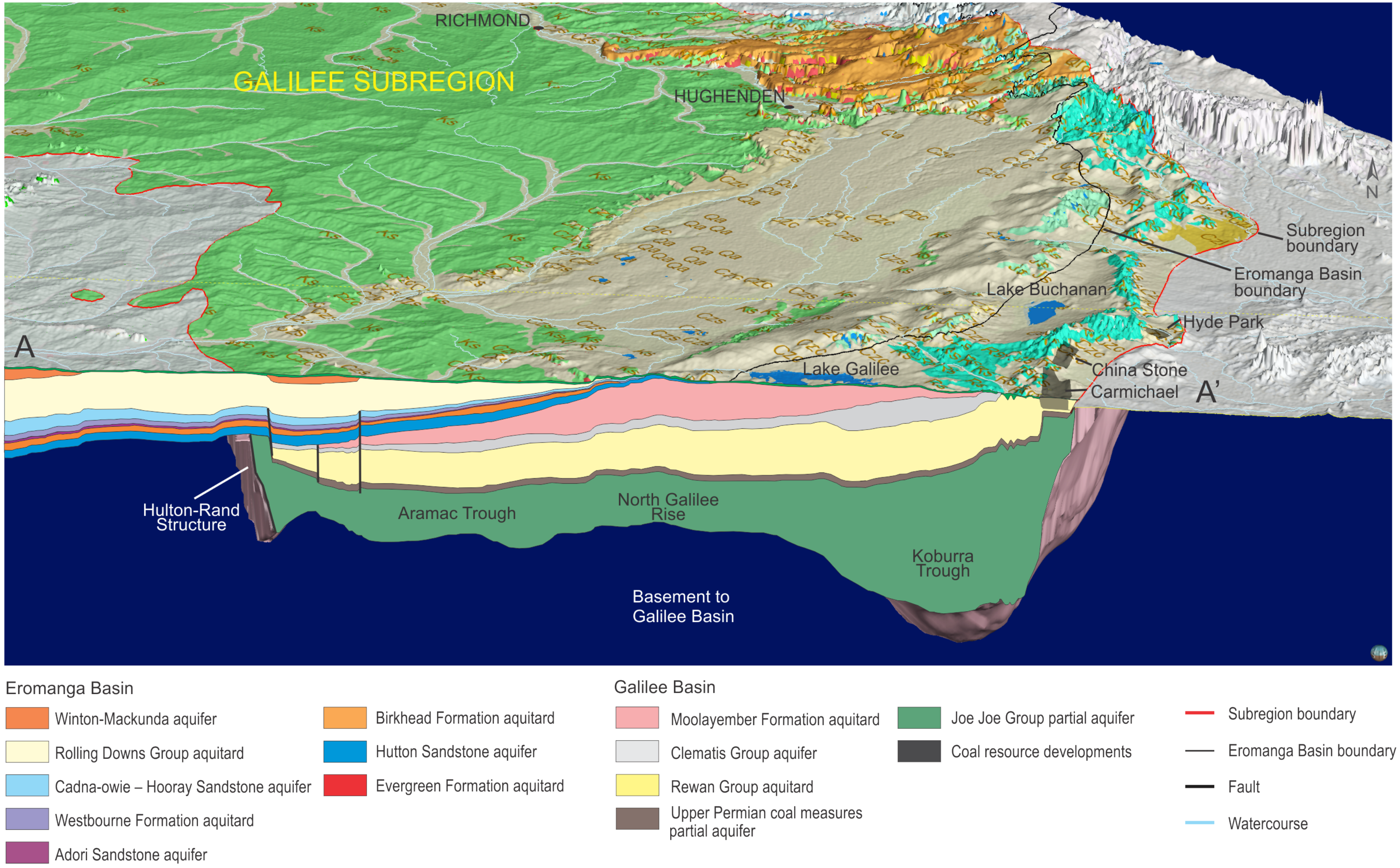

Figure 5 Three-dimensional geological cross-section of the Galilee and Eromanga basins (cross-section A to A', looking north-west)

Location of geological cross-section is in Figure 2. The legend in this figure applies only to the cross-section's underground geological formations. The legend for the surface geology is in Figure 6 in Section 2.3.2 of Evans et al. (2018b).
Data: Bioregional Assessment Programme (Dataset 10)

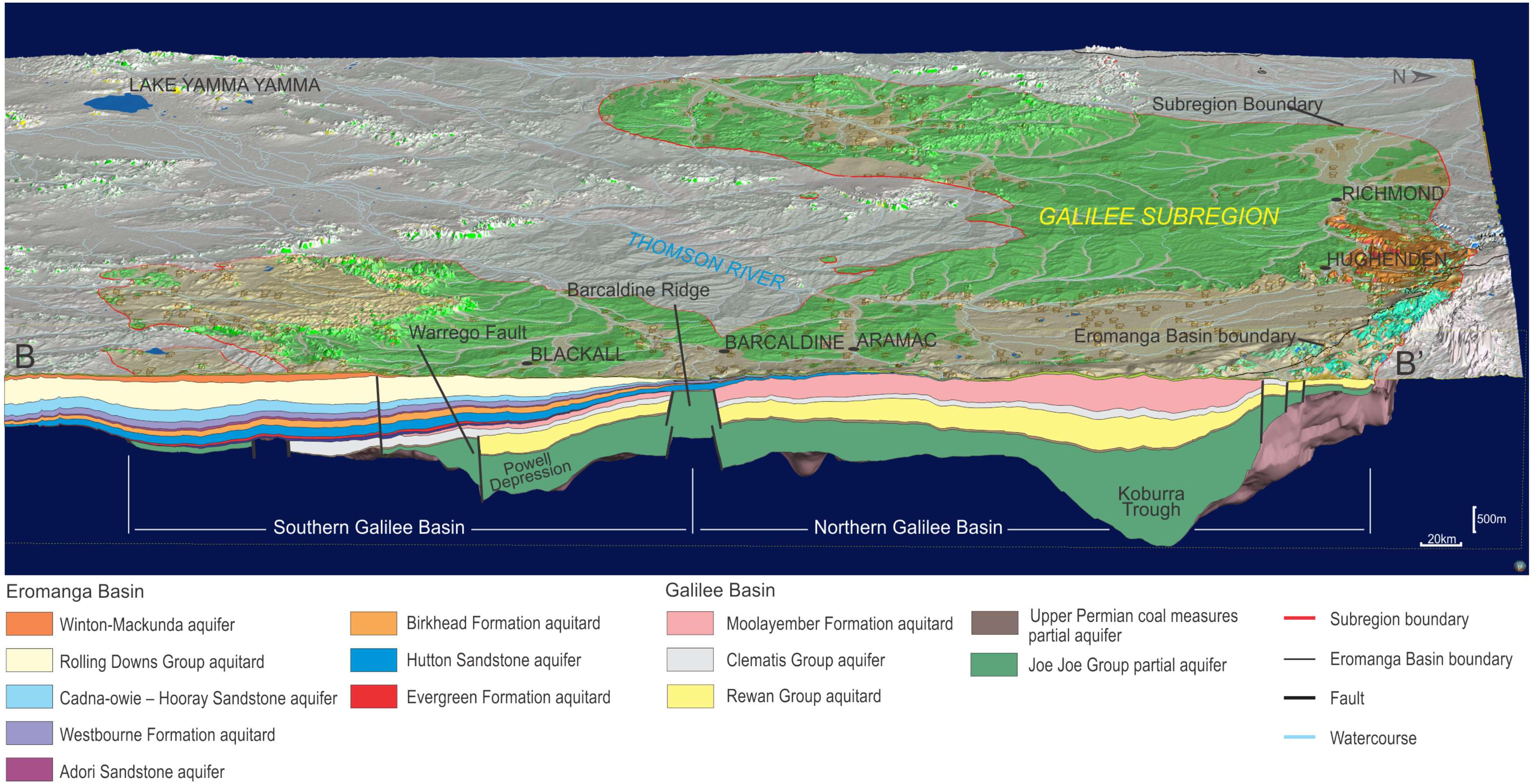

Figure 6 Three-dimensional geological cross-section of the Galilee and Eromanga basins (cross-section B to B', looking west)

Location of geological cross-section is in Figure 2. The legend in this figure applies only to the cross-section's underground geological formations. The legend for the surface geology is in Figure 6 in Section 2.3.2 of Evans et al. (2018b).
Data: Bioregional Assessment Programme (Dataset 10)

How could coal resource development result in hydrological changes?

The assessment identified potential hazards (Dataset 11) associated with coal resource development that could result in hydrological changes, such as aquifer depressurisation due to groundwater extraction. The hazard analysis, including a description of the top 30 ranked hazards identified for coal mining and CSG developments, is presented in Section 2.3.5 of Evans et al. (2018b). Hazards in scope were further assessed by first estimating relevant hydrological changes through hydrological modelling and then identifying potential impacts on, and risks to, water-dependent ecosystems and assets (as described in the following sections).

In the bioregional assessment context, four causal pathway groups summarise the chains of events that commonly arise from coal resource development activities (letters A to D in the list below correspond to those shown in Figure 7):

A. **'Subsurface depressurisation and dewatering'** is triggered by extraction of groundwater to enable CSG extraction, and mine dewatering of open-cut pits and underground operations. This directly affects the local and regional groundwater systems, and indirectly affects surface water – groundwater interactions. Potential effects are likely to be in the short term (less than 5 years) for groundwater pressure changes, to long term (10 to 100s of years) for changes in groundwater movement or quality.

B. **'Subsurface physical flow paths'** are initiated by activities that cause physical changes to the rock mass or geological layers (such as underground coal mining), resulting in new physical paths that water may potentially gain access to and flow along. Potential effects are in the medium (5 to 10 years) to long term and are likely to be restricted to aquifer or aquifer outcrop areas, but can also affect connected watercourses within and downstream of mines.

C. **'Surface water drainage'** is triggered by activities that physically disrupt the surface and near-surface materials (vegetation, topsoil, weathered rock). Medium- to long-term cumulative effects are possible for watercourses within and downstream of development. Activities may include construction of diversion walls and drains, interception of surface runoff, realignment of streams, and groundwater extraction for CSG production or underground coal mining leading to subsidence of the land surface.

D. **'Operational water management'** is triggered by modification of surface water systems to allow storage, disposal, processing and use of extracted water. Potential effects are likely to be in the medium to long term and include impacts on watercourses within and downstream of operations.

Many activities related to coal resource development may also cause more localised or on-site changes to surface water or groundwater. These are not considered explicitly in bioregional assessments because they are considered to be adequately managed by site-based risk management and mitigation procedures (for example, licence conditions accompanying environmental approvals), and are unlikely to result in regional-scale cumulative impacts.

FIND MORE INFORMATION

Conceptual modelling, product 2.3 (Evans et al., 2018b)

Surface water numerical modelling, product 2.6.1 (Karim et al., 2018a)

Groundwater numerical modelling, product 2.6.2 (Peeters et al., 2018)

Developing the conceptual model for causal pathways, submethodology M05 (Henderson et al., 2016)

Systematic analysis of water-related hazards associated with coal resource development, submethodology M11 (Ford et al., 2016)

Impact Modes and Effects Analysis for the Galilee subregion (Dataset 11)

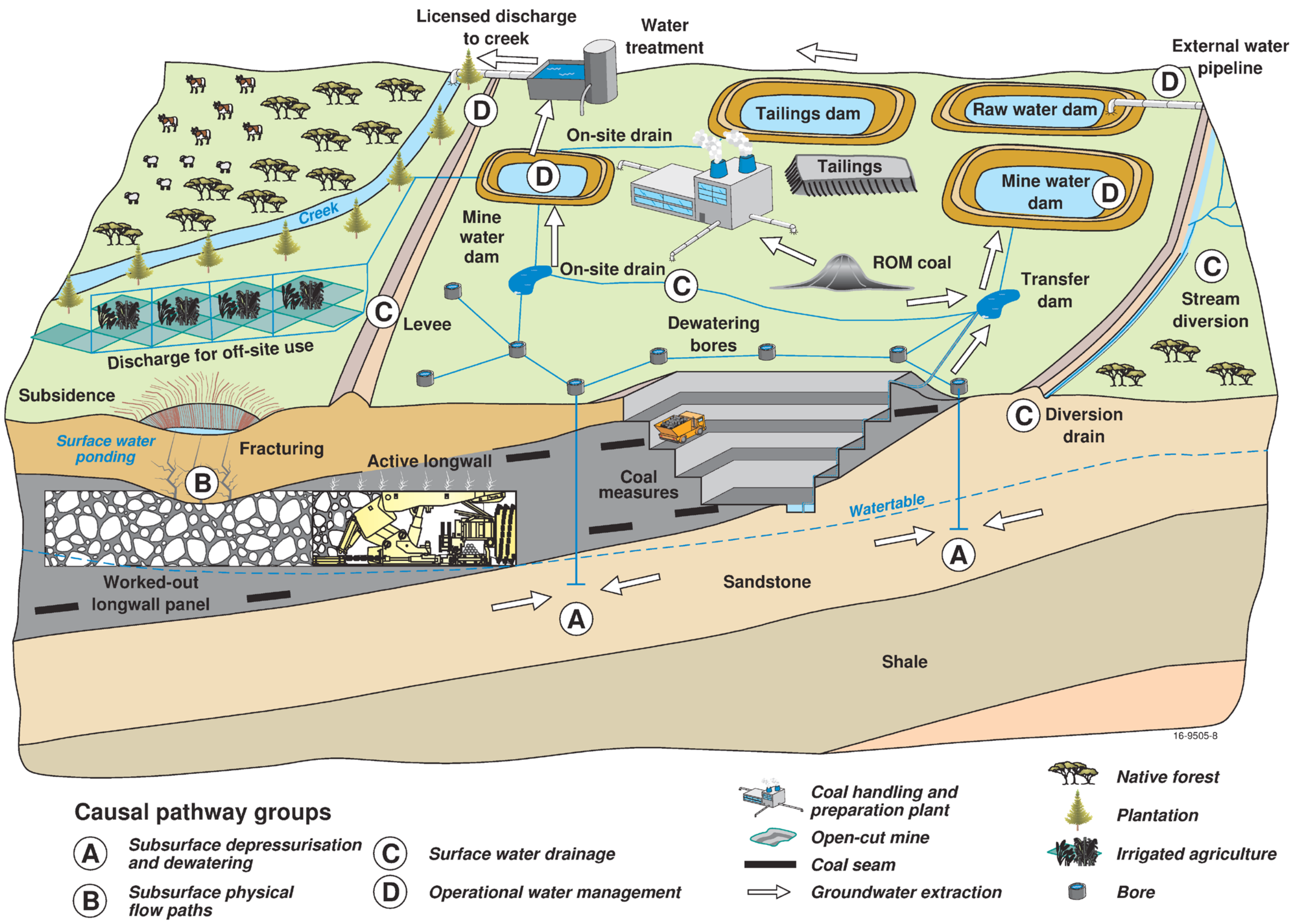

Figure 7 Conceptual diagram of the causal pathway groups that are associated with generic underground and open-cut coal mines

This schematic diagram is not drawn to scale. This generic diagram does not specifically relate to any proposed coal mines in the Galilee subregion, nor does it represent any specific geographic features, geological units or land uses in the subregion. Rather, the mining operation shown here illustrates examples of the four causal pathway groups defined in bioregional assessments (see Section 2.3.5 of Evans et al. (2018b)). The underground arrows refer to groundwater extraction, whereas above-ground arrows illustrate various aspects of mine water management, which may include transferring extracted groundwater around the mine site.
ROM = run of mine

What are the potential hydrological changes?

Potential hydrological changes were modelled for seven coal mines using regional-scale surface water and groundwater models. Potential impacts to water-dependent ecosystems and assets that rely on access to the near-surface aquifer are limited to the zone of potential hydrological change (Figure 1 and Box 5). Modelling indicates that potential impacts to two deeper (confined) groundwater layers extend beyond the zone, and may affect some bores associated with two economic assets (see page 30).

Key finding 2: The zone of potential hydrological change covers an area of 14,030 km^2 (2% of the assessment extent) and includes 6,285 km of streams. The zone occurs mainly in the Belyando river basin, a headwater catchment of the larger Burdekin River.

Key finding 3: Cumulative hydrological changes in the Belyando river basin are *very likely* (Figure 8). These changes affect a larger area of groundwater drawdown in the near-surface aquifer, and total length of streams, than previously predicted from any individual mine-scale impact assessments.

Groundwater

The assessment investigated drawdown due to additional coal resource development in the three main aquifer systems of the central-eastern Galilee Basin (Box 3). These are the near-surface Quaternary alluvium and Cenozoic sediment layer, and the deeper Clematis Group aquifer and the upper Permian coal measures. The models provide a range of possible drawdown values for the near-surface aquifer where water-dependent ecosystems and assets may access water, as well as for the two deeper (confined) groundwater systems, where drawdown may affect some bores and springs.

Drawdown in the near-surface aquifer due to the modelled additional coal resource development has a 5% chance of affecting up to 13,364 km^2. Drawdown occurs in two separate areas, located near the central-eastern margin of the Galilee subregion (Figure 8). In these areas, cumulative groundwater changes in the near-surface aquifer may occur over space and time, due mainly to the interaction of dewatering multiple coal mining operations. In particular, Figure 8 clearly indicates that cumulative groundwater drawdown impacts between multiple mining operations are *very likely* (greater than 95% chance) to occur across all four proposed mines in the southern area, and also across the Carmichael and China Stone mines in the north.

Key finding 4: Proposed coal mines at South Galilee, China First, Alpha and Kevin's Corner result in drawdown in the near-surface aquifer exceeding 0.2 m in an area that is *very likely* to exceed 1663 km^2 and *very unlikely* to exceed 7898 km^2.

Further north, the proposed Carmichael, China Stone and Hyde Park coal mines result in drawdown in the near-surface aquifer exceeding 0.2 m in an area that is *very likely* to exceed 1157 km^2 and *very unlikely* to exceed 5466 km^2.

Box 3 Understanding the groundwater model

For this assessment, the hydrological change due to additional coal resource development is probabilistically estimated with a groundwater analytic element model (Peeters et al., 2018). The groundwater model itself is based on a simplified hydrogeological conceptualisation of the main aquifers and aquitards (Section 3.2.3 in Lewis et al. (2018)) that occur in and around the seven modelled coal mines. This modelling approach is well suited to regional-scale cumulative impact analysis, and the fast model run times allow for the evaluation of a very wide range of parameter combinations, and support the assessment's comprehensive uncertainty analysis. The models cover a 90-year period from 2013 to 2102.

The groundwater model is not suitable for highly accurate local-scale predictions of drawdown within the zone of potential hydrological change due to the relatively low-resolution regional-scale conceptualisation that underpins the drawdown predictions.

At some locations, a relatively simple change in the conceptualisation that underpins the analytic element model can produce substantially different results (Peeters et al., 2018). To reveal the extent to which alternative conceptual models can influence drawdown within the zone, the analytic element model was run for two different approaches (see Section 2.6.2.8 in Peeters et al. (2018)). The first approach (original conceptualisation) allows for drawdown and drainage of shallow aquifers that may occur due to excavation of open-cut mine pits through the near-surface layers, as well as drawdown that can propagate laterally from the deeper coal-bearing unit to shallower aquifers through any intervening layers. The alternative conceptualisation assumes that open-cut mine developments have no direct interaction with the near-surface aquifers, except via drawdown propagating vertically upwards from the deeper coal-bearing layer through any intervening aquifers and aquitards.

Throughout this synthesis and the impact and risk analysis, the results from the original groundwater conceptualisation are mostly reported. However, for specific ecological assets, the analysis presented (see Section 3.4 and Section 3.5 of Lewis et al. (2018)) may use the groundwater results from the alternative conceptualisation where the assessment team considers that these results are more locally appropriate. For example, in the 'Springs' landscape group (Section 3.5.2.6 in Lewis et al. (2018)) the results from two groundwater model conceptualisations are compared to better understand the likely groundwater responses for some spring-related assets.

In the near-surface aquifer, modelling suggests that maximum drawdowns exceeding 5 m only occur very close to the mines (within several kilometres), and that this will usually occur sometime after 2050. Beyond about 20 km from the mine sites, the probability of exceeding a drawdown of 0.2 m is small (Figure 8). Drawdowns predicted in the upper Permian coal measures (the main coal-bearing layer targeted for mining) decrease rapidly with increasing distance from the mines, although maximum drawdown is generally in excess of 5 m throughout the area modelled.

Queensland's *Water Act 2000* specifies drawdown thresholds that may trigger management responses for groundwater resources (2 m for unconsolidated aquifers and 5 m for consolidated rock aquifers). Relevant regional-scale modelling results for the near-surface aquifer are as follows:

- Around the proposed South Galilee, China First, Alpha and Kevin's Corner coal mines, the area where additional drawdown is greater than 2 m is *very likely* to exceed 940 km^2 and *very unlikely* to exceed 2623 km^2, with a 50% chance of drawdown exceeding 2 m for an area of 1617 km^2 (Figure 8).
- Around the proposed Carmichael, China Stone and Hyde Park coal mines, the area where additional drawdown is greater than 2 m is *very likely* to exceed 657 km^2 and *very unlikely* to exceed 1803 km^2, with a 50% chance of drawdown exceeding 2 m for an area of 1100 km^2 (Figure 8).

Results from regional-scale groundwater modelling of the near-surface aquifer are reported in Section 3.3 of the impact and risk analysis (Lewis et al., 2018), focusing on three drawdown thresholds of 0.2, 2 and 5 m (Box 3). Further information about modelled drawdowns for the Clematis Group aquifer and upper Permian coal measures are reported in Section 3.4 and Section 3.5 of Lewis et al. (2018). The results for these two deeper aquifers are used to assess potential impacts to some springs, as well as groundwater bores (which are part of various economic assets). Notably, the assessment of potential drawdown impacts for some water-dependent assets that rely on access to the Clematis Group aquifer may use results from an alternative groundwater model conceptualisation (Box 3).

Box 4 Calculating groundwater drawdown

Drawdown is a lowering of the groundwater level, caused, for example, by pumping. The groundwater model (Box 3) predicted drawdown under the coal resource development pathway and drawdown under the baseline (**baseline drawdown**), which in this case, has no development. The difference in drawdown between the coal resource development pathway and baseline (referred to as **additional drawdown**) is due to additional coal resource development. In a confined aquifer, drawdown relates to a change in water pressure and does not necessarily translate to changes in depth to the watertable.

The maximum drawdown over the course of the groundwater model simulation period (from 2013 to 2102) for each 1 km^2 grid cell is expected to occur at different times across the area assessed.

Close to proposed open-cut and underground mines, confidence in the results of the groundwater model is relatively low because of the very steep hydraulic gradients at the mining interface. As a result, a **mine exclusion zone** was defined in this assessment. Groundwater drawdown within this 986 km^2 zone (the total area of all seven mines) is not used to assess ecological impacts. Mine construction and operational activities within the mine exclusion zone, such as land clearing and surface disturbance, are likely to have greater local impacts to ecosystems than the modelled hydrological changes.

Box 5 The zone of potential hydrological change

A **zone of potential hydrological change** (Figure 1) was defined to rule out areas that are *very unlikely* to be impacted. It was derived by combining the **groundwater zone of potential hydrological change** with the **surface water zone of potential hydrological change** (see Figure 20 and Figure 21 in Lewis et al. (2018)). These zones were defined using **hydrological response variables**, which are the hydrological characteristics of the system that potentially change due to coal resource development – for example, groundwater drawdown in an aquifer, or the number of zero-flow days per year in a stream.

The groundwater zone is the area with at least a 5% chance of greater than 0.2 m drawdown (Box 4) in the near-surface aquifer layer due to additional coal resource development. This threshold is consistent with the most conservative minimal groundwater impact thresholds in Queensland's *Water Act 2000*. Groundwater changes in the near-surface aquifer are important to consider as most groundwater-dependent ecological assets source their water requirements from this watertable.

The surface water zone contains those river reaches where there is at least a 5% chance that a change in any one of eight surface water hydrological response variables exceeds specified thresholds (see Table 9 in Lewis et al. (2018)). These thresholds can generally be described as at least a 5% chance of a 1% (or 3 day) or greater change in a flow volume or event frequency.

Water-dependent ecosystems and ecological assets outside of this zone are *very unlikely* to experience any hydrological changes due to additional coal resource development (assuming they do not rely on deeper groundwater systems below the near-surface aquifer). Within the zone, potential impacts may need to be considered further. This assessment used regional-scale receptor impact models (Box 9) to translate predicted changes in hydrology within the zone into a distribution of ecological outcomes that may arise from those changes. However, to take account of local conditions, finer-scale assessments may need to be undertaken.

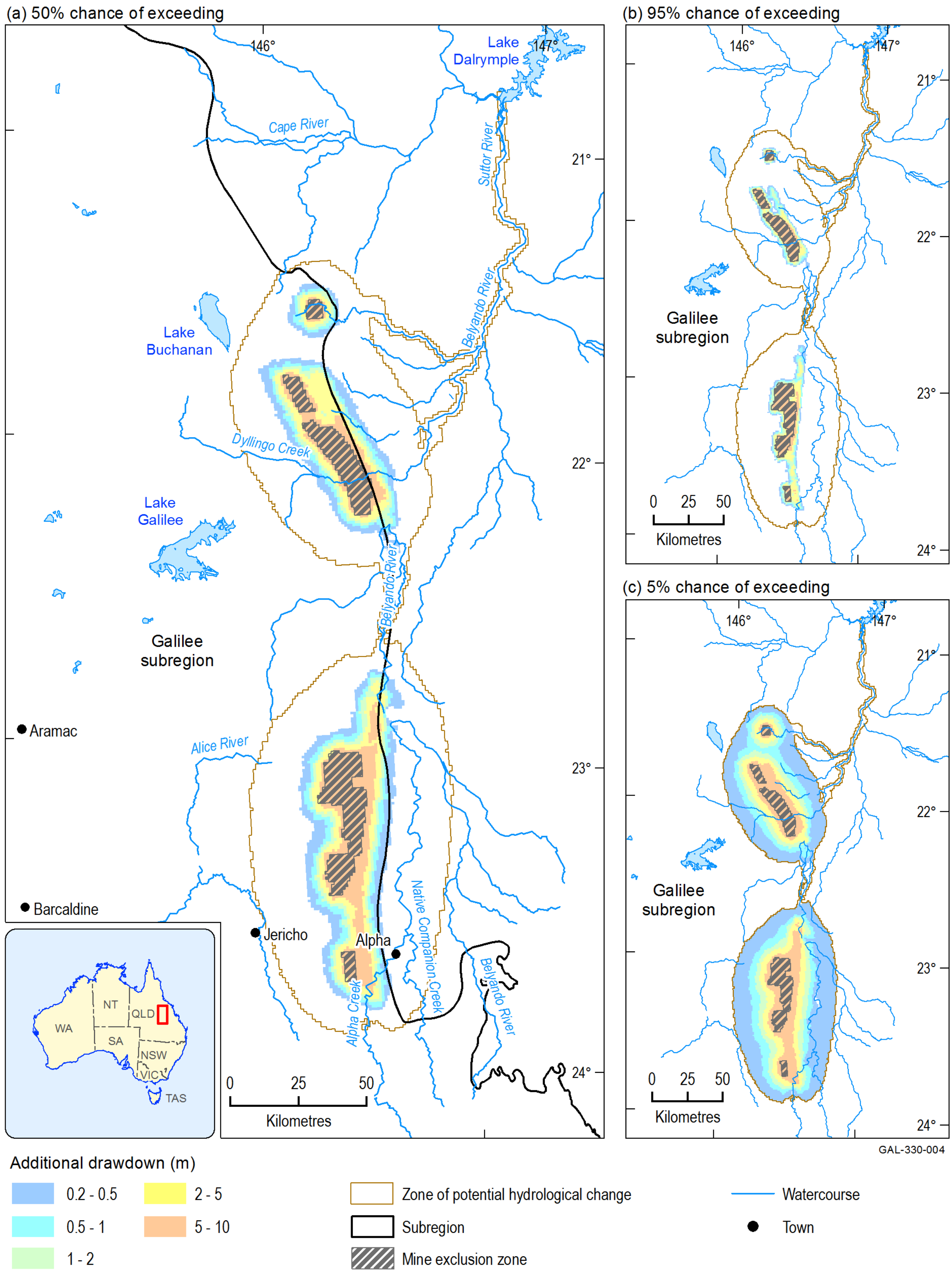

Figure 8 Additional drawdown (m) in the near-surface aquifer (95%, 50% and 5% chance of exceeding given values of drawdown)

Additional drawdown is the maximum difference in drawdown under the coal resource development pathway and the baseline (Box 1 and Box 4). Because there are no coal resource developments in the baseline for the Galilee subregion, the CRDP includes only the additional coal resource development (ACRD). Results are shown as percent chance of exceeding drawdown thresholds (Box 6). These appear in Lewis et al. (2018) as percentiles. The near-surface aquifer includes the Quaternary alluvium and Cenozoic sediments.
Data: Bioregional Assessment Programme (Dataset 1)

Surface water

The surface water zone of potential hydrological change encompasses many of the streams in the Belyando river basin upstream of Lake Dalrymple (including about 60 km of the Suttor River below its junction with the Belyando). Approximately 3012 km of streams occur in the surface water zone, including most of the Carmichael River, Native Companion Creek and Lagoon Creek - Sandy Creek. Much of the potentially impacted stream network coincides with the two areas of the groundwater zone, apart from an approximately 40 km segment of the Belyando River that separates the two groundwater areas, and parts of Bully Creek and the Belyando/Suttor rivers that flow outwards from the northern groundwater zone. Further information about the surface water zone of potential hydrological change is in Section 3.3.1 of Lewis et al. (2018).

The potential changes to surface water flow regimes due to additional coal resource development over the 90-year modelling period (2013 to 2102) were assessed using three **hydrological response variables**:

- maximum change in the annual number of zero-flow days (days when streamflow is less than 1 ML/day over the modelled 90-year period for that stream)
- maximum change in annual number of high-flow days (days when streamflow exceeds the 90th percentile of flow from the simulated 90-year period for that stream)
- maximum percentage change in annual flow volume (GL/year) over the simulated 90-year period.

Changes in other surface water hydrological response variables, such as the number and duration of low-flow spells, can be viewed on the BA Explorer at www.bioregionalassessments.gov.au/explorer/GAL/hydrologicalchanges.

Key finding 5: In the Burdekin river basin, changes in the surface water flow regime due to modelled additional coal resource development are *very unlikely* to propagate further downstream than Lake Dalrymple.

Zero-flow days

Key finding 6: There is a 5% chance that the maximum number of zero-flow days will increase by 200 days per year in the Belyando River downstream of Sandy Creek junction and the Suttor River downstream of its confluence with the Belyando. Such increases are greater than interannual variability and the maximum reduction is most likely to occur in a wet year.

Many reaches of the Belyando and Suttor rivers that have a 5% chance of an additional 200 zero-flow days (Figure 9) do not actually flow for 200 days in most years. This apparent anomalous increase in zero-flow days occurs because, in particularly wet years, modelling indicates that the river can flow for 200 days per year (or more). As bioregional assessments report the maximum change in zero-flow days due to additional coal resource development (over the 90-year period modelled), the reporting is biased towards wet years when these maximum changes can occur.

There is a 50% chance that 1034 km of streams will experience an increase of at least 3 additional zero-flow days per year. A further 1781 km of streams are potentially impacted by increases in zero-flow days, including many streams that will be physically disturbed or diverted as they occur in areas of planned mining operations or mine-site infrastructure. However, these potential impacts could not be quantified for this assessment, as not all stream reaches included in the surface water zone were incorporated in the modelling (Section 3.3.1.2 in Lewis et al. (2018)).

Where changes have been quantified, 1108 km of streams are *very likely* to experience an increase of at least 3 additional zero-flow days per year in the year of maximum change (Figure 9). This includes parts of the Belyando River downstream of where it meets with Sandy Creek to Lake Dalrymple (Burdekin Falls Dam), and the Carmichael River, as well as the east-flowing North and Bully creeks that drain the northern part of the zone of potential hydrological change. It is *very unlikely* that more than 591 km of streams will experience increases of more than 200 zero-flow days per year. There are no streams where it is *very likely* that there will be increases of more than 200 zero-flow days per year (Figure 9).

There is a 50% chance that modelled changes are comparable to interannual variability in the northernmost stretches of the Belyando and Suttor rivers upstream of Lake Dalrymple, particularly for the modelled nodes downstream of the Belyando River junction with the Suttor River. Results also indicate a 5% chance that central and northern stretches of the Belyando River within the zone may experience increases in zero-flow days above interannual variability (Figure 10).

Changes in zero-flow days that are greater than interannual variability indicate that the ecological components of these riverine ecosystems may be less able to adapt to changes in hydrology due to additional coal resource development. However, in some circumstances, even changes that are comparable to or less than interannual variability may still be ecologically important, especially if they occur over a prolonged period.

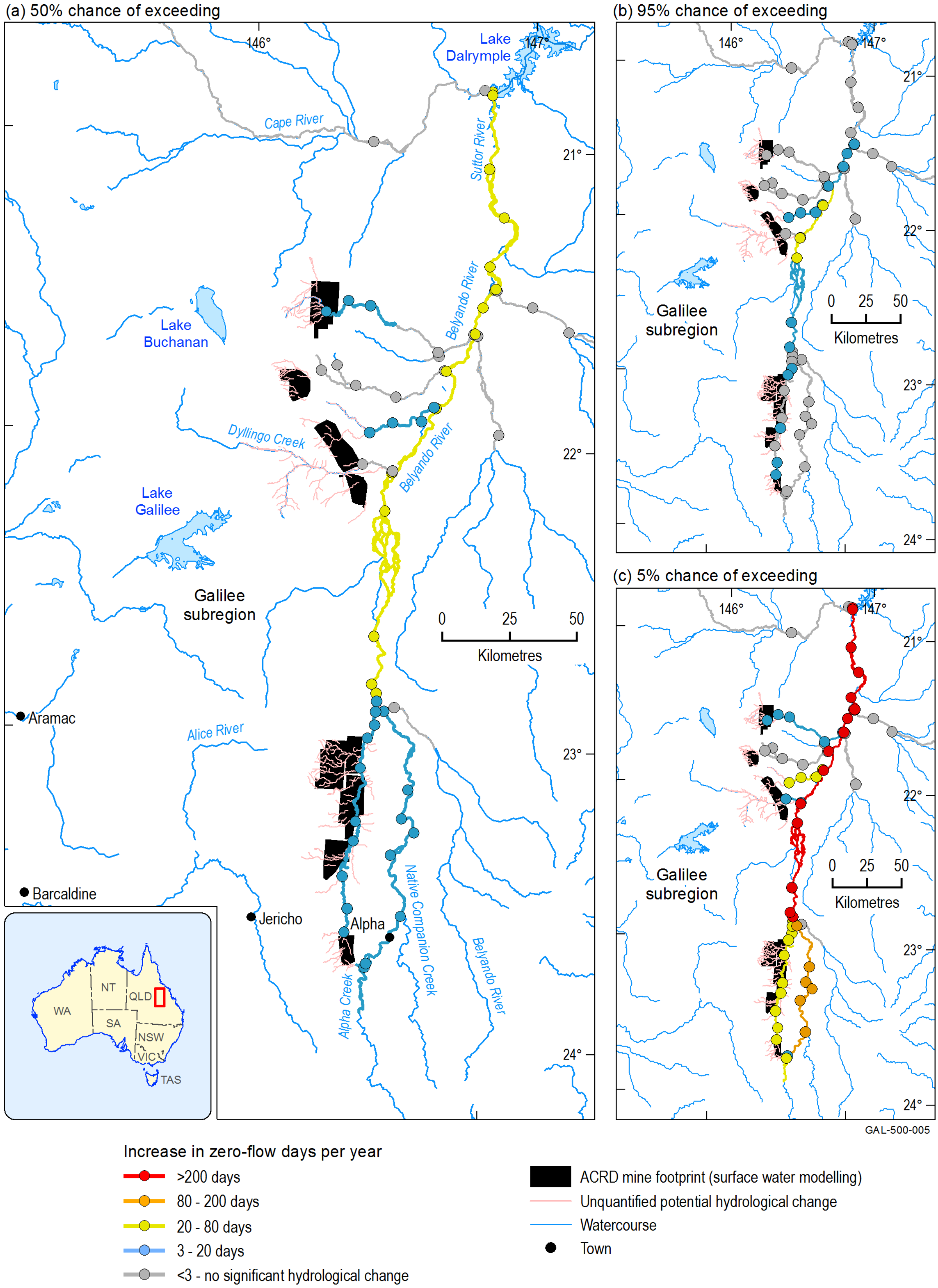

Figure 9 Maximum increase in the number of zero-flow days due to modelled additional coal resource development (95%, 50% and 5% chance of exceeding given values)

The coal resource development pathway (CRDP) includes baseline and additional coal resource developments (ACRD). Because there are no coal resource developments in the baseline for the Galilee subregion, the CRDP includes only the ACRD. The difference in zero-flow days between the CRDP and baseline is due to ACRD. Results are shown as percent chance of exceeding given values of change (Box 6). These appear in Lewis et al. (2018) as percentiles.
Data: Bioregional Assessment Programme (Dataset 1, Dataset 12)

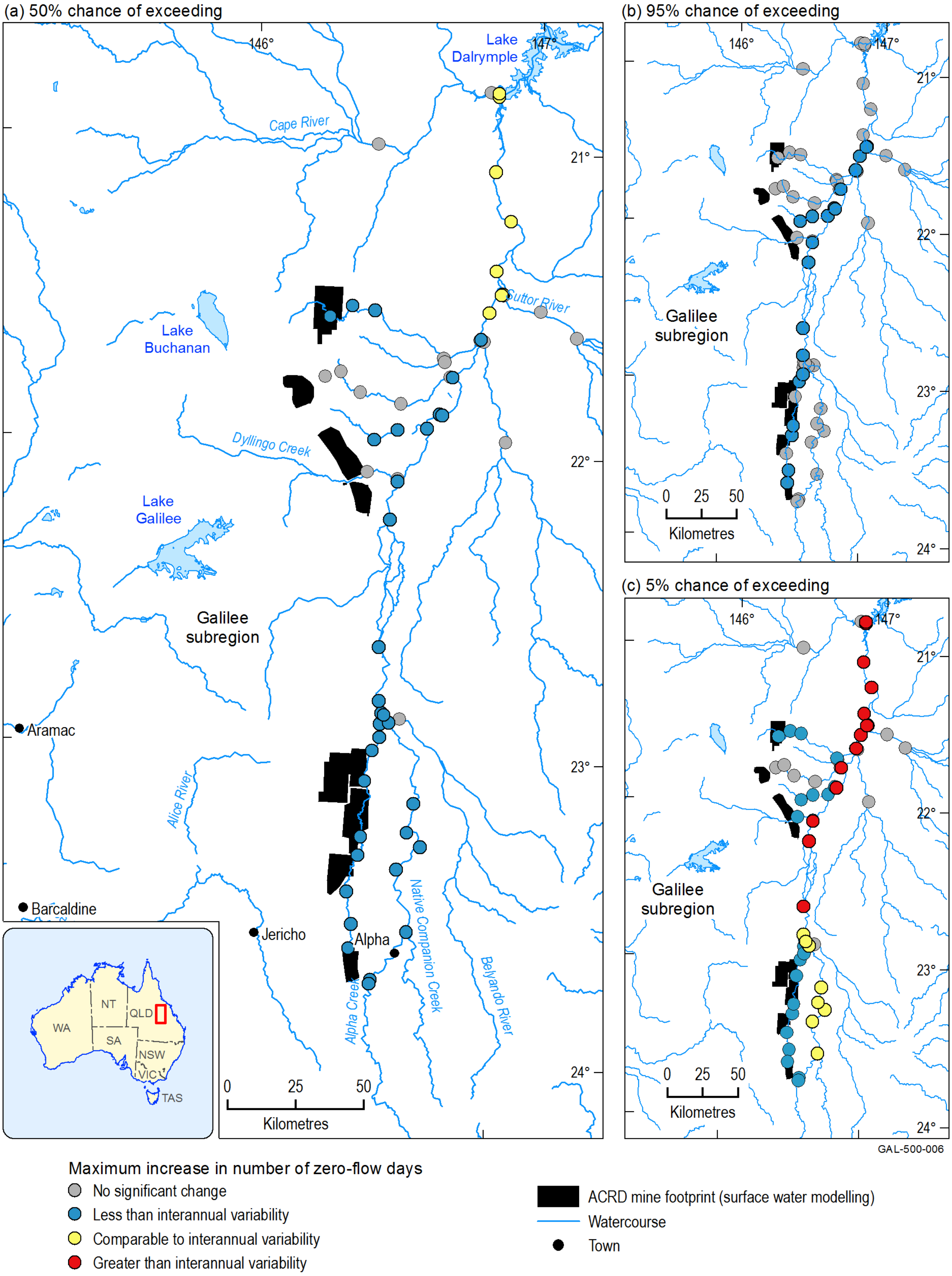

Figure 10 Ratio of maximum increase in number of zero-flow days due to modelled additional coal resource development relative to the interannual variability in the number of zero-flow days (95%, 50% and 5% chance of exceeding given values)

The coal resource development pathway (CRDP) includes baseline and additional coal resource developments (ACRD). The difference in zero-flow days between the CRDP and baseline is due to ACRD. Because there are no coal resource developments in the baseline for the Galilee subregion, the CRDP includes only the ACRD. Results are shown as percent chance of exceeding given values of change (Box 6). These appear in Lewis et al. (2018) as percentiles.

Data: Bioregional Assessment Programme (Dataset 1, Dataset 12)

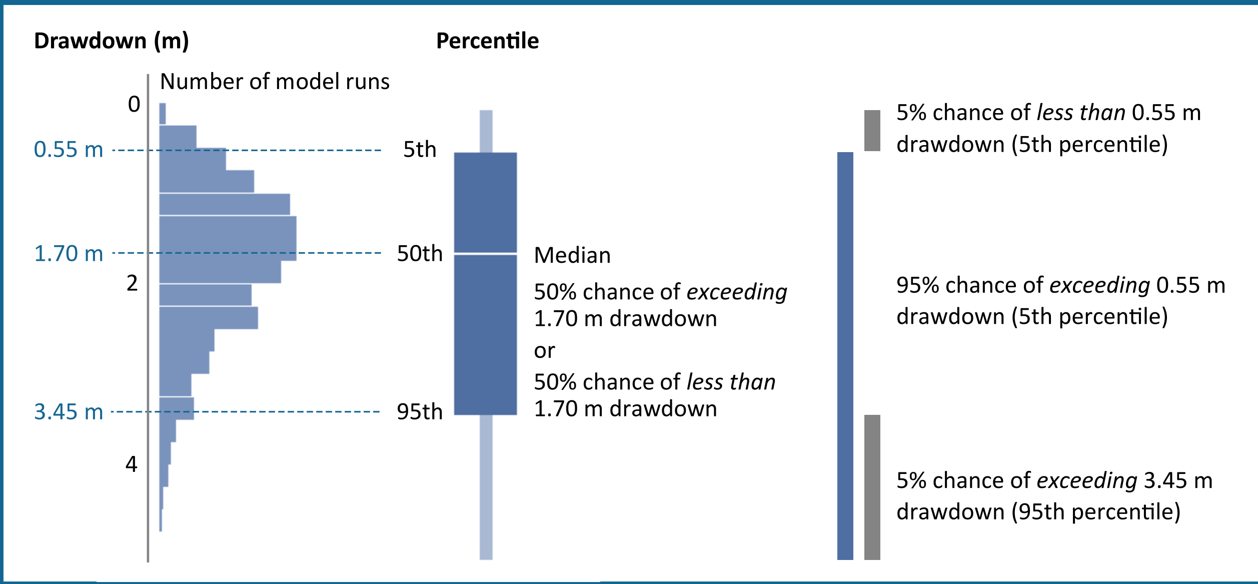

Figure 11 Illustrative example of probabilistic drawdown results using percentiles and percent chance

The chart on the left shows the distribution of results for drawdown in one assessment unit, obtained from an ensemble of thousands of model runs that use many sets of parameters. These generic results are for illustrative purposes only.

Box 6 Understanding probabilities

The models used in the assessment produced a large number of predictions of groundwater drawdown and streamflow characteristics rather than a single number. This results in a range or distribution of predictions, which are typically reported as probabilities – the percent chance of something occurring (Figure 11). This approach allows an assessment of the likelihood of exceeding a given magnitude of change, and underpins the assessment of risk.

Hydrological models require information about physical properties, such as the thickness of geological layers and how porous aquifers are. As it is unknown how these properties vary at every point (both at surface and at depth) in the assessment extent, the hydrological models were run thousands of times using different sets of values drawn from credible ranges of those physical properties. Optimisation of model runs enabled the reproduction of historical observations, such as groundwater level and changes in water movement and volume.

A narrow range of predictions indicates more agreement between the model runs, which enables decision makers to anticipate potential impacts more precisely. A wider range indicates less agreement between the model runs and hence more uncertainty in the outcome.

The distributions created from these model runs are expressed as probabilities that hydrological response variables (such as drawdown) exceed relevant thresholds, as there is no single 'best' estimate of change.

In this assessment, the estimates of drawdown or streamflow change are shown as a 95%, 50% or 5% chance of exceeding thresholds. Throughout this synthesis, the term '*very likely*' is used to describe where there is a greater than 95% chance that the model results exceed thresholds, and '*very unlikely*' is used where there is a less than 5% chance. While models are based on the best available information, if the range of parameters used is not realistic, or if the modelled system does not reflect reality sufficiently, these modelled probabilities might vary from the actual changes that occur in reality. These regional-level models provide a range of evidence to help rule out potential cumulative impacts due to additional coal resource development in the future.

The assessment extent was divided into smaller square assessment units and the probability distribution (Figure 11) was calculated for each. In this synthesis, results are reported with respect to the following key areas (Figure 12):

A. outside the zone of potential hydrological change, where hydrological changes (and hence impacts) are *very unlikely* (defined by maps showing the 5% chance)

B. inside the zone of potential hydrological change, comprising the assessment units with at least a 5% chance of exceeding the threshold (defined by maps showing the 5% chance). Further work is required to determine whether the hydrological changes in the zone translate into impacts for water-dependent assets and ecosystems

C. assessment units with at least a 50% chance of exceeding the threshold (i.e. the assessment units where the median is greater than the threshold; defined by maps showing the 50% chance)

D. assessment units with at least a 95% chance of exceeding the threshold (i.e. the assessment units where hydrological changes are *very likely*; defined by maps showing the 95% chance).

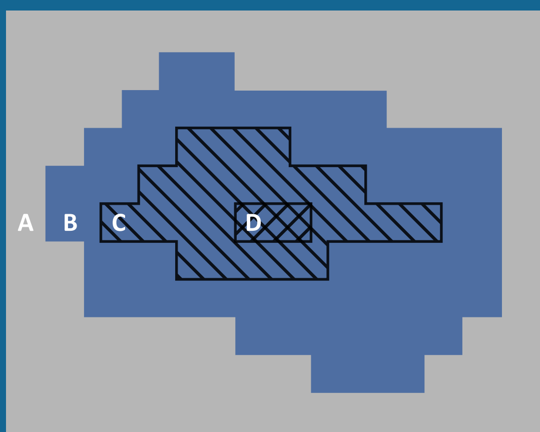

Figure 12 Key areas for reporting probabilistic results

High-flow days

Key finding 7: The maximum changes in high flows and annual flows due to modelled additional coal resource development are smaller than interannual variability, particularly in the Belyando and Suttor rivers, but there is a 5% chance that they are comparable to the interannual variability along Sandy and North creeks, and parts of Bully Creek.

The impact due to modelled additional coal resource development on high-flow days is not as great as it is on zero-flow days. For example, there is a 50% chance that 313 km of modelled streams will have at least a 3-day reduction in high-flow days per year (Table 15 in Lewis et al. (2018)). Reductions in high-flow days of at least 3 days per year are *very likely* along Lagoon Creek and Sandy Creek, where it runs adjacent to the China First, Alpha and Kevin's Corner proposed coal mines in the south, and in the north along North Creek (Figure 31 and Table 15 in Lewis et al. (2018)).

Modelling predicted that it is *very unlikely* that more than 200 km of streams will experience reductions in high-flow days in excess of 50 days per year (Figure 31 and Table 15 in Lewis et al. (2018)), and these are mainly confined to stretches of Sandy Creek in the southern zone, and North Creek in the northern zone. There is a 5% chance that the upper reaches of Bully Creek (which intersect the proposed Hyde Park Coal Mine) may experience reductions of between 20 and 50 high-flow days per year (Figure 31 and Table 15 in Lewis et al. (2018)).

The northern reaches of the Belyando and Suttor rivers above Lake Dalrymple experience a 5% chance of the most substantial increases in zero-flow days of anywhere in the modelled stream network; however, they have relatively minor impacts on high-flow days. This indicates that although large changes in the low-flow regime may accumulate and affect downstream areas, changes in high flow are less likely to accumulate from multiple developments and propagate downstream.

At most modelled locations, the maximum change is relatively small compared to interannual variability (Figure 33 in Lewis et al. (2018)), although there is a 5% chance that some modelled locations may experience changes comparable to interannual variability (Figure 33 in Lewis et al. (2018)).

Annual flow

There is a 50% chance that 833 km of modelled streams are subject to at least a 1% reduction in mean annual flow volume. A further 1442 km of streams are potentially impacted by changes in annual flow, but these could not be quantified for this assessment (see Section 3.3.1.2 in Lewis et al. (2018)).

About 6 km of the modelled streams are *very likely* to experience greater than 20% reduction in annual flow volume, just downstream of the proposed South Galilee Coal Mine on Tallarenha Creek. Similarly, 269 km of the modelled streams are expected to have greater than 5% reduction in annual flow. The streams that are predicted to have the greatest reductions in annual flow are:

- Tallarenha Creek – Sandy Creek, where the stream starts at South Galilee and flows northwards adjacent to the three neighbouring mines in the southern cluster at China First, Alpha and Kevin's Corner
- North Creek, which flows in an easterly direction from the area of the proposed Carmichael and China Stone mines towards the Belyando River
- some segments of Bully Creek just downstream of the Hyde Park Coal Project.

There is a 5% chance that the maximum change in annual flow due to modelled additional coal resource development will be comparable to annual flow variability under the baseline for parts of Sandy Creek, North Creek and Bully Creek (Figure 36 in Lewis et al. (2018)). Reductions in annual flow at all other modelled locations are less than interannual variability.

Water quality

Water quality was not modelled as part of this assessment. However, the implications for water quality in the Galilee subregion are briefly considered in Section 3.3.4 of the impact and risk analysis (Lewis et al., 2018) in light of the modelled hydrological changes due to additional coal resource development.

The groundwater modelling results presented in Peeters et al. (2018) indicated that drawdown due to additional coal resource development will be confined primarily to the upper Permian coal measures, and to a lesser extent the Clematis Group aquifer, and in areas where alluvium and Cenozoic sediments overlie the deeper Galilee Basin aquifers. These conditions largely occur around the central-eastern margin of the Galilee Basin in the vicinity of the proposed coal mines modelled in this assessment. Hence, any groundwater quality changes are unlikely to occur outside of areas where these aquifers may experience drawdown.

The likelihood of off-site water quality impacts to broader surface water systems is reduced through the capture of surface water on mine sites, which is then utilised for various on-site processes. However, as of July 2017, conditions for off-site discharge of any excess water are yet to be finalised for the additional coal resource developments. Discharge requirements will form part of mine approval conditions.

FIND MORE INFORMATION

Explore the hydrological changes in more detail at www.bioregionalassessments.gov.au/explorer/GAL/hydrologicalchanges

Surface water numerical modelling, product 2.6.1 (Karim et al., 2018a)

Groundwater numerical modelling, product 2.6.2 (Peeters et al., 2018)

Impact and risk analysis, product 3-4 (Lewis et al., 2018)

Groundwater modelling, submethodology M07 (Crosbie et al., 2016)

Impacts and risks, submethodology M10 (Henderson et al., 2018)

Impact and risk analysis database (Dataset 1)

Surface water model results (Dataset 13)

Groundwater model results (Dataset 14)

What are the potential impacts of additional coal resource development on ecosystems?

The impact and risk analysis (Lewis et al., 2018) used multiple lines of evidence (Box 7) to investigate how hydrological changes due to additional coal resource development may affect ecosystems in the assessment extent.

These ecosystems are represented by 31 landscape classes (Evans et al., 2018b), which were further aggregated into 11 (bolded) landscape groups (Box 8):

- **'Dryland'**, includes vegetation that depends only on incident rainfall and localised runoff, and so is not considered to be water dependent for purposes of this assessment
- Floodplain environments, include wetlands that are dependent on groundwater (**'Floodplain, wetland GDE'**), wetlands that are disconnected from groundwater (**'Floodplain, disconnected wetland'**) and vegetation outside of wetlands that is groundwater dependent (**'Floodplain, terrestrial GDE'**) or surface water dependent (**'Floodplain, non-wetland'**)
- Non-floodplain environments, include wetlands that are dependent on groundwater (**'Non-floodplain, wetland GDE'**), wetlands that are disconnected from groundwater (**'Non-floodplain, disconnected wetland'**), and vegetation outside of wetlands that is groundwater or surface water dependent (**'Non-floodplain, terrestrial GDE'**)
- Streams, include streams that are dependent on groundwater (**'Streams, GDE'**) and streams that are disconnected from the groundwater system (**'Streams, non-GDE'**). Streams in each landscape group are classified based on water regime (temporary or near-permanent) and landscape position (lowland, upland or estuarine)
- **'Springs'**, include both discharge springs and recharge springs.

Box 7 Analysing impact and risk

Potential impacts to water-dependent ecosystems and assets were assessed using multiple lines of evidence that included:

- water dependence
- hydrological response variables from hydrological modelling
- the overlay of the zone of potential hydrological change (Box 5) on the extent of ecosystems and assets
- qualitative mathematical models derived from consultation with experts
- quantitative receptor impact models and additional discussion of outputs with experts (Box 9), primarily developed for ecosystems not assets.

Impacts to all assets and ecosystems were assessed (as a minimum) by overlaying the extent of ecosystems and assets on the zone of potential hydrological change to identify the hydrological changes that a particular asset or ecosystem might experience.

- **Outside this zone**, ecosystems and assets are ***very unlikely* to be impacted** by hydrological changes due to additional coal resource development.
- **Within this zone**, ecosystems and assets are **potentially impacted**, unless there is clear evidence to rule out impact. This evidence might come from hydrological modelling, regional-scale qualitative mathematical models and/or receptor impact models applied to some ecosystems. The impact depends on an ecosystem's or asset's reliance on groundwater and/or surface water, the magnitude and likelihood of the change and the extent of the ecosystem or asset exposed to the change. Although hydrological changes may be small, where the effects are sustained over a prolonged period there may be potential for substantial ecological impacts.

For ecological assets, the assessment considered the potential impact to the habitat of species, not to the species themselves.

Ecosystems and assets that fall within the mine exclusion zone are likely to be impacted, but as estimates of drawdown are unreliable, quantification of the impact is not possible. Similarly, surface water modelling near mine pits cannot quantify the impact on some streams.

The greatest confidence in results is in those areas that are *very unlikely* to be impacted. Where potential impacts have been identified, further local-scale modelling using higher resolution data may be required to determine the presence and magnitude of impacts.

Potential impacts on ecosystems were assessed by first overlaying their extent on the **zone of potential hydrological change** (Box 5, Figure 13). Assessing potential impacts for the 'Springs' landscape group also used other drawdown zones relevant to individual spring source aquifers (such as the Clematis Group aquifer for the Doongmabulla Springs complex).

For the potentially impacted ecosystems within the zone (Table 2), **receptor impact modelling** (Box 9) was used to translate predicted changes in hydrology into a distribution of ecological outcomes that may arise from those changes. These models used indicators of the health of the ecosystem, such as the annual percent foliage cover for selected tree species, to infer the potential ecological impacts of hydrological changes.

The relative risk to ecosystems is reported using categories defined in Box 10.

Table 2 Extent of each landscape group in the Galilee assessment extent and the zone of potential hydrological change

The extent of each landscape group is either an area of vegetation (km^2), length of streams (km) or number of springs. The landscape groups that have qualitative and/or receptor impact models are also shown.

Landscape group	Extent in assessment extent	Extent in zone of potential hydrological change	Qualitative model	Receptor impact model
Dryland (km^2)	419,657	8,134	No	No
Floodplain, disconnected wetland (km^2)	6,558	19.0	No	No
Floodplain, non-wetland (km^2)	72,016	2,098	No	No
Floodplain, terrestrial GDE (km^2)	79,229	2,433	Yes	Yes
Floodplain, wetland GDE (km^2)	4,949	153	No	No
Non-floodplain, disconnected wetland (km^2)	8,784	3.6	No	No
Non-floodplain, terrestrial GDE (km^2)	20,800	1,189	Yes	Yes
Non-floodplain, wetland GDE (km^2)	258	0.2	No	No
Springs (number)	1,559	200	Yes	No
Streams, GDE (km)	48,538	2,801	Yes	Yes
Streams, non-GDE (km)	344,916	3,484	Yes	Yes
Total area (km^2)	**612,252**	**14,030**		
Total springs (number)	**1,559**	**188**		
Total stream length (km)	**393,455**	**6,285**		

Definitions for landscape classes and landscape groups for the Galilee subregion are available online at environment.data.gov.au/def/ba/landscape-classification/galilee-subregion.
Due to rounding, some totals may not equal the sum of the individual numbers.
GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 1, Dataset 15)

Box 8 Understanding the landscape classification

The natural and human-modified ecosystems in the subregion were classified into 31 landscape classes (Section 3.4 in Lewis et al. (2018)) to enable a systematic and comprehensive analysis of potential impacts on, and risks to, the water-dependent assets nominated by the community. The landscape classification was based on the subregion's geology, geomorphology, hydrogeology, land use and ecology. These landscape classes were aggregated into 11 landscape groups based on their likely response to hydrological changes. Definitions for landscape classes and landscape groups for the Galilee subregion are available online at environment.data.gov.au/def/ba/landscape-classification/galilee-subregion.

About 6% of the zone of potential hydrological change, along the far eastern edges, does not have landscape classes or groups mapped, as this part of the zone extends beyond the margins of the assessment extent. This recognised limitation may mean that specific results reported in this synthesis for potentially impacted areas, lengths and proportions of some ecosystems may be slightly underestimated or overestimated. Despite this minor limitation, the main findings of the landscape group analysis are unlikely to be substantially different, as most ecosystems in the zone are well mapped (particularly in areas predicted to experience the greatest hydrological changes), and the majority of the unmapped area is likely to be 'Dryland' or 'Floodplain, non-wetland' ecosystems, both of which do not rely on access to groundwater or streams.

Ecosystems

Which ecosystems are *very unlikely* to be impacted?

Ecosystems outside the zone of potential hydrological change are *very unlikely* to be impacted, including:

- 526,658 km^2 of remnant vegetation and 71,563 km^2 of non-remnant vegetation. This includes 101,460 km^2 of groundwater-dependent vegetation and 20,373 km^2 of wetland vegetation
- 387,170 km of streams that are groundwater dependent and 341,433 km of streams that are not groundwater dependent. Streams outside of the zone predominantly have an intermittent or ephemeral water regime (386,468 km) rather than a perennial or near-perennial water regime (552 km)
- 8133 km^2 of saline wetlands and 290 km of estuarine streams that cover less than 0.1% of the assessment extent.

Within the zone, most (73%) of the ecosystems are categorised as dryland vegetation (8134 km^2) or floodplains not connected to wetlands (2098 km^2) (Table 2 and Figure 13). These are ruled out as they depend on incident rainfall and localised runoff, rather than groundwater or streams.

Key finding 8: It is *very unlikely* that the source aquifers of any of the Great Artesian Basin springs in the Eromanga Basin will be impacted by the modelled additional coal resource developments.

Assessing potential impacts to springs uses drawdown zones relevant to the source aquifer for each spring, and these may differ from the zone of potential hydrological change (which relates to the near-surface aquifer). Several spring clusters in the zone defined by the near-surface aquifer, including the Doongmabulla Springs complex, rely on groundwater sourced from deeper (confined) aquifers of the Clematis Group and upper Permian coal measures.

Box 9 Receptor impact models

Receptor impact models translate predicted changes in hydrology into ecological outcomes that may arise from those changes. Applying receptor impact models across ecosystems assists in identifying where changes in hydrology may result in ecosystem changes, and consequently where additional local-scale information and further investigation may be warranted.

To assess potential ecological outcomes experts identified **receptor impact variables**, characteristics that serve as indicators of the ecological condition of an ecosystem, and which are also likely to respond to hydrological changes as well as being within the expertise of the available experts. These variables were specifically chosen to be representative of a landscape group in the Galilee subregion and include the following indicators:

- percent foliage cover of woody riparian vegetation
- density of a mayfly species (nymphs), 3 months after the end of the wet season
- percent foliage cover of woody vegetation.

One or more hydrological response variable(s) that affect each indicator were identified with ecological experts. Receptor impact models, which take the form of statistical models, were then developed to represent the relationship between each indicator and its important hydrological response variables. Details are found in Ickowicz et al. (2018).

Hydrological models were used to quantify changes in the related hydrological response variable(s). Predictions of an ecological indicator at a specific location were made by applying the receptor impact model for that indicator to the predicted hydrological response variable(s) at that location.

Receptor impact models were used to predict changes in the indicator for a landscape group that result from changes in the hydrological response variable(s). The changes in the indicator reflect the magnitude of potential ecological impacts for that ecosystem. The indicators provide a relative measure of the risk to the ecosystem, rather than a prediction about (for example) densities of mayfly nymphs *per se*.

For the Galilee subregion, the impact and risk analysis focused on ecosystems represented by five landscape groups. Four receptor impact models were developed, representing four of the landscape groups. In addition, 12 qualitative mathematical models were developed for the five landscape groups. The ‘Springs’ landscape group only had qualitative mathematical models built, as it was not possible to develop a receptor impact model. Results from applying receptor impact models are described in Section 3.4 of Lewis et al. (2018).

Importantly, receptor impact models were not used in isolation but were applied along with other lines of available evidence, including expert advice, hydrological modelling results and other existing data and knowledge, to assess potential ecological impacts.

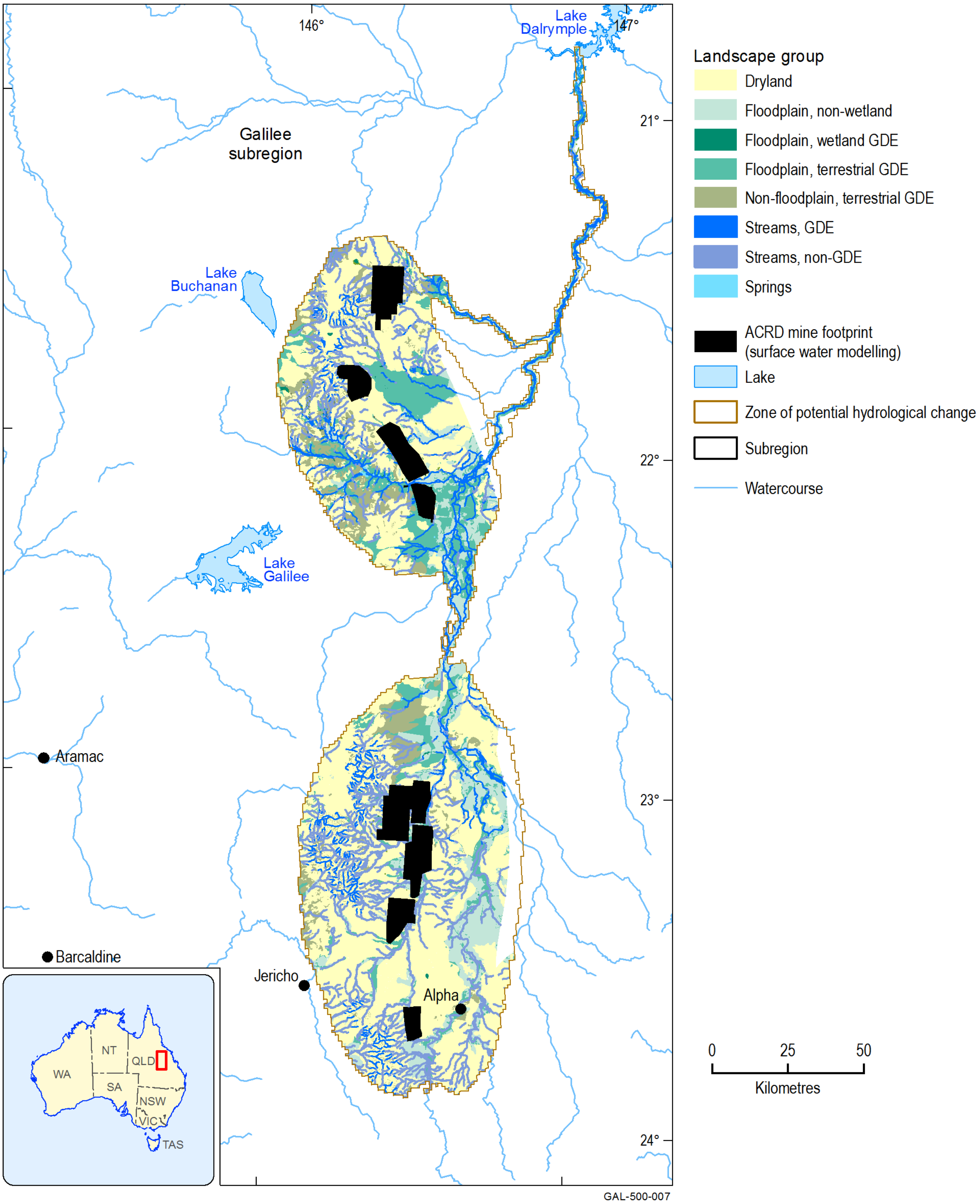

Figure 13 Landscape groups within the zone of potential hydrological change

The coal resource development pathway (CRDP) includes baseline and additional coal resource developments (ACRD).
GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 12, Dataset 15)

Using the relevant drawdown zones for different spring groups in the Galilee assessment extent shows that 1359 springs are *very unlikely* to be impacted due to modelled additional coal resource development. This includes 6 springs in the Doongmabulla Springs complex and 1353 GAB springs that are sourced from aquifers of the Eromanga Basin (which partly overlies the older Galilee Basin, Figure 5 and Figure 6). Potential impacts to the GAB (Eromanga) springs, which occur over 50 km west of the seven mines, are ruled out as the groundwater modelling for this assessment indicated that drawdown due to modelled additional coal resource development will not affect any aquifers of the Eromanga Basin (Peeters et al., 2018). This is due to the very thick Moolayember Formation (400 to 1000 m thick), a low permeability regional aquitard layer, that separates the Eromanga Basin aquifers from the underlying Clematis Group aquifer (in areas where greater than 0.2 m drawdown in the Clematis Group is *very unlikely*).

Which ecosystems are potentially impacted?

Ecosystems that intersect the zone of potential hydrological change (Box 5, Figure 13) are potentially at risk of impact due to additional coal resource development (Table 2, Figure 13).

Key finding 9: At the Doongmabulla Springs complex near the Carmichael River, there is a 5% chance that additional drawdown in the Clematis Group source aquifer will exceed 0.2 m for 181 of 187 springs. Thus, potential ecological impacts cannot be ruled out, although local-scale information is needed to improve the understanding of impacts to these springs.

It is *very likely* that at least five of the seven springs sourced from the upper Permian coal measures will be affected by greater than 5 m of additional drawdown.

Springs

Three clusters of springs are within the zone: the Doongmabulla Springs complex, Permian springs cluster and Triassic springs cluster. Springs are not explicitly incorporated in the groundwater model, with drawdown at each spring estimated for the model layer interpreted as the source aquifer (e.g. Clematis Group aquifer). However, the regional-scale modelling in this assessment is not well suited to accurate point-scale drawdown estimates, such as for individual springs. This means that more detailed modelling user higher resolution local-scale data is necessary to better understand impacts on springs.

The available hydrogeological evidence to characterise the source aquifers for the springs within the zone is discussed in Section 3.4 of Lewis et al. (2018). The Permian springs are sourced from the upper Permian coal measures (layer 5 in the Galilee groundwater model), whereas the Triassic springs are 'recharge springs' disconnected from the regional groundwater system and likely sourced from local sedimentary rock aquifers of Triassic age (such as the Dunda beds, which are not included in the model).

As outlined in Section 3.4.3.1 of Lewis et al. (2018), two different interpretations have been presented by previous researchers for the source aquifer of the Doongmabulla Springs complex; one interpretation favours the Clematis Group as the primary source aquifer, whereas the other proposes the upper Permian coal measures. Appraisal of the available hydrogeological evidence for this assessment, including the regional groundwater flow directions of different aquifers and the topographic location of the springs, suggests that most of the Doongmabulla Springs complex is sourced from the Clematis Group. This means that the drawdown predictions from the Galilee groundwater model for the Clematis Group layer can be used to estimate potential groundwater impacts at Doongmabulla.

Box 10 Categorising risk for ecosystems

Parts of some ecosystems were deemed at greater risk of ecological and hydrological changes relative to other parts of that ecosystem. Three categories were defined: 'more at risk of ecological and hydrological changes', 'at some risk of ecological and hydrological changes' and 'at minimal risk of ecological and hydrological changes'. Categorisation assists the rule-out process and in identifying where further local-scale assessment is warranted.

Assessment units that overlap with a landscape group or class are categorised based on the degree that modelled ecological changes exceed thresholds of risk. These bioregion-specific thresholds are based on expert opinion and defined using receptor impact variables listed in Box 9 (see Section 3.4 of Lewis et al. (2018) for more details on the thresholds).

The geological structure used in the groundwater model, and the way in which the proposed coal mine operations may affect groundwater levels for each modelled aquifer, was developed to provide the greatest utility and spatial coverage to define the zone of potential hydrological change. However, there are some areas in the zone where both the model structure and the effects of mine dewatering will potentially cause the amount of drawdown to be over-estimated (see Section 3.3 in Lewis et al. (2018) for further information). This will mainly affect areas where the Quaternary alluvium and Cenozoic sediment layer does not occur, such as in the upland regions west of the proposed mines in the zone.

To better understand the likely overestimation of drawdown in these areas, an alternative groundwater model conceptualisation was used to predict drawdown impacts at some specific points. This alternative model provides more robust drawdown predictions in areas of outcropping Triassic rocks in the zone, particularly for the Clematis Group aquifer. The variations between the two model conceptualisations, including discussion of why the alternative approach is more scientifically valid for making drawdown predictions at the Doongmabulla Springs complex, is outlined in Box 3 and explained in detail in Lewis et al. (2018) and Peeters et al. (2018).

The alternative model predictions are better suited to evaluating drawdown for the Doongmabulla Springs complex, and these generally project lower levels of drawdown for the springs than the results from the original groundwater conceptualisation. For example, the drawdown estimated at one of the springs in the Doongmabulla Springs complex is 0.88 m (with a 50% chance) using the original conceptualisation, but is 0.18 m using the alternative approach. Although model results from both of the conceptualisations indicate that 181 of the 187 individual springs in the Doongmabulla Springs complex have at least a 5% chance of more than 0.2 m of drawdown, there are no springs with a 50% chance of exceeding 0.2 m drawdown under the alternative conceptualisation (Table 20 in Lewis et al. (2018)).

Estimates of expected water level reductions due to modelled additional coal resource development within the source aquifers to the various springs indicate that there is some potential for ecosystem impact. This was investigated in this assessment using qualitative models to show the ecological relationships within aquatic communities (see Section 2.7.3 in Ickowicz et al. (2018)). The following ecosystem impacts for the different spring clusters were predicted:

- **Doongmabulla Springs complex:** Changes in water flows and a decrease in water availability to GDEs are predicted; however, the long-term impact on the springs and spring wetlands and related organisms is unclear (Figure 14, and Section 3.4.3.3 in Lewis et al. (2018)).
- **Triassic springs cluster:** Drawdown for the 12 springs in the Triassic springs cluster cannot be reliably estimated by the groundwater model used in this assessment, but is likely to fall within the range predicted for the Clematis Group model layer (Figure 14, and Section 3.4.3.3 in Lewis et al. (2018)).
- **Permian springs cluster:** It is *very likely* that at least five springs and *very unlikely* that more than seven springs will experience drawdown in excess of 5 m in the upper Permian coal measures due to modelled additional coal resource development. Potentially affected springs include the Albro, Lignum, Storys and Mellaluka springs. Hydrological changes will potentially result in the loss of ecological functioning of these springs (Figure 14, and Section 3.4.3.3 in Lewis et al. (2018)).

Groundwater-dependent streams

The Galilee subregion includes the headwaters of six major surface water catchments: Cooper Creek-Bulloo, Diamantina-Georgina, Flinders-Norman, Darling, Burdekin and Fitzroy (Figure 2). About 12% of all streams in the assessment extent are groundwater dependent (Table 19 in Lewis et al. (2018)).

Almost half (2801 km) of the 6285 km of streams in the zone of potential hydrological change are groundwater dependent (Table 2) and most have a temporary water regime (2541 km of these 2801 km).

Potential hydrological impacts to groundwater-dependent streams include additional drawdown in excess of 5 m, an increase in the number of low-flow days (averaged over 30 years), increased low-flow spells and decreased overbank flows.

Key finding 10: There is some level of risk of ecological and hydrological changes in 8% of the 2801 km of groundwater-dependent streams in the zone of potential hydrological change. This includes parts of Native Companion, North and Sandy creeks, and the Belyando and Carmichael rivers.

This is based on expert opinion, modelled hydrological changes and changes to the chosen ecological indicators (Box 9); more detail in shown in Figure 51 in Lewis et al. (2018).

Temporary, upland groundwater-dependent streams are located along the western edge of the zone, upstream of the proposed Hyde Park and China Stone mines in the north, and upstream of the proposed Kevin's Corner, Alpha and South Galilee mines in the south. Temporary, lowland groundwater-dependent streams intersect and flow downstream of the seven proposed mines in the northern and southern parts of the zone of potential hydrological change. It is *very unlikely* that additional drawdown in excess of 0.2 m will affect more than 1597 km of temporary, lowland groundwater-dependent streams and 466 km of temporary, upland groundwater-dependent streams (Figure 45 and Table 21 of Lewis et al. (2018)). Additional drawdown in excess of 5 m is *very unlikely* to affect more than 173 km of groundwater-dependent streams.

Modelled changes in the flow regime of the Belyando River below Sandy Creek and the Suttor River below the confluence with the Belyando River do not appear to lead to hydrological changes that are considered to put these streams and their ecosystems at risk.

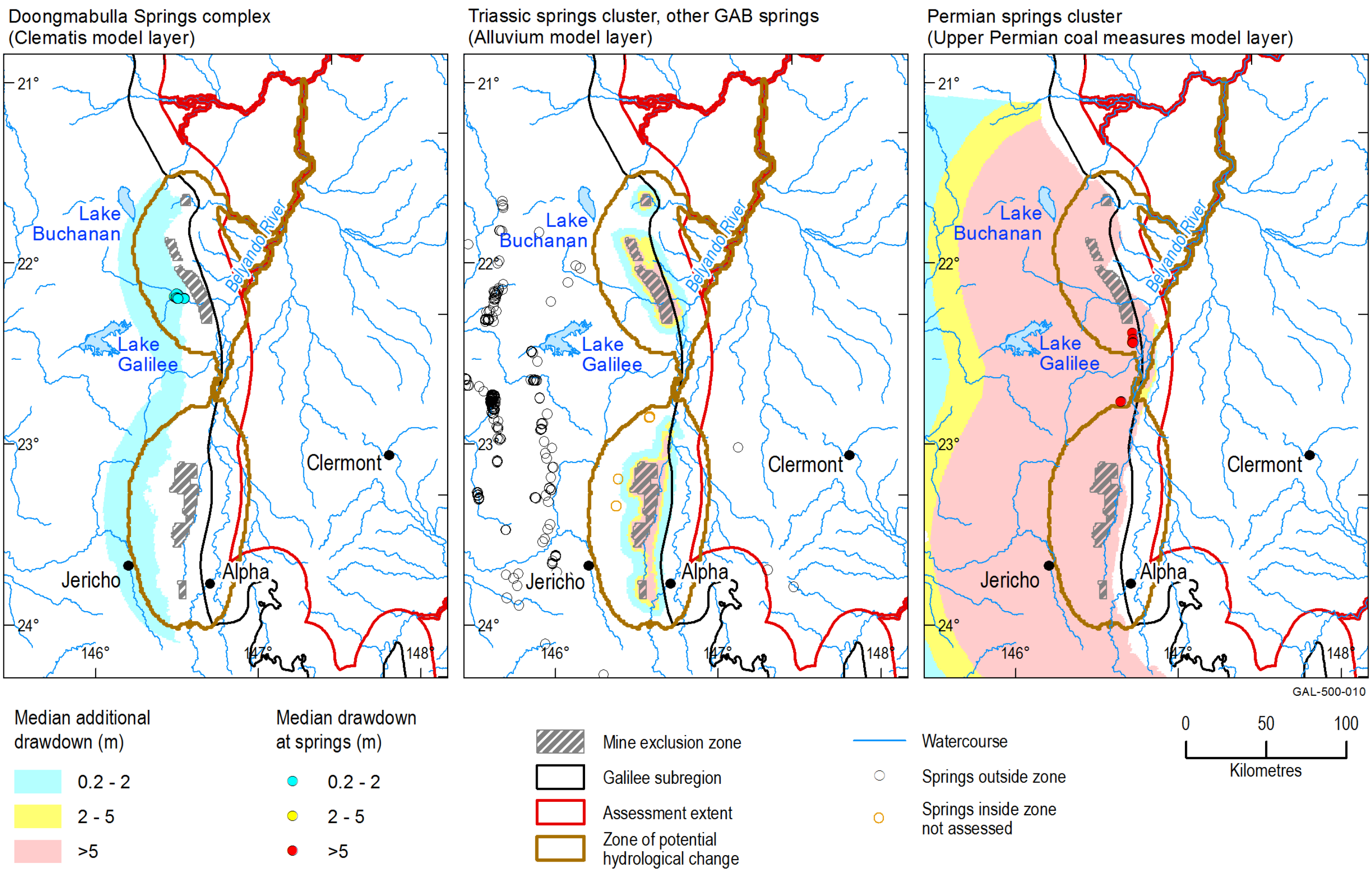

Figure 14 Additional drawdown (m) in the source aquifers of springs in the zone of potential hydrological change (50% chance of exceeding given values of drawdown)

The groundwater component of the zone of potential hydrological change (brown line) was defined by drawdown in the near-surface aquifer (see Box 5). Springs, however, may source water from different deeper layers. Being in or out of the zone defined by the near-surface aquifer therefore does not necessarily signify impacts – rather potential impacts are indicated by drawdown in the relevant source aquifer for that spring. Additional drawdown is the maximum difference in drawdown under the coal resource development pathway and the baseline (Box 1 and Box 4). Because there are no coal resource developments in the baseline for the Galilee subregion, the CRDP includes only the additional coal resource development (ACRD). Results are shown as percent chance of exceeding drawdown thresholds (Box 6). These appear in Lewis et al. (2018) as percentiles.

Data: Queensland Herbarium (Dataset 16); Bioregional Assessment Programme (Dataset 17)

Non-groundwater-dependent streams

The remaining streams in the zone of potential hydrological change are not groundwater dependent (3484 km) and so are unlikely to be affected by groundwater drawdown (Table 2). This includes most of the temporary streams (1028 km) in the zone that are potentially impacted but not represented in the surface water model (due to absence of model nodes on these streams), including parts of Bully, Lagoon, North, Sandy and Tomahawk creeks and Carmichael River. Future opportunities to improve the surface water modelling, which include increasing the density of modelling locations on the stream network, are further explained in the 'Building on this assessment' section (page 38).

Potential hydrological changes include increased number of low-flow days (averaged over 30 years) and low-flow spells along up to 177 km of temporary streams in the zone. The analysis of potential ecosystem impacts indicates that less than 1% of non-groundwater-dependent streams are 'at some risk of ecological and hydrological changes' (relative to other streams in the zone) (Box 10) (Figure 56 in Lewis et al. (2018)). These potential changes mainly affect isolated segments of the Belyando and Suttor rivers, just upstream of Lake Dalrymple.

Floodplain, terrestrial groundwater-dependent ecosystems

Key finding 11: On floodplains, 3% of the 2433 km^2 of groundwater-dependent vegetation is 'at some risk of ecological and hydrological changes' due to additional drawdown and decreased overbank flow along parts of Alpha, North, Sandy and Tallarenha creeks, and the Belyando and Carmichael rivers.

Outside of floodplains or wetlands, 5% of the 1189 km^2 of groundwater-dependent vegetation is 'at some risk of ecological and hydrological changes'. These areas are near the proposed coal mines, where additional drawdown is greatest.

Floodplain, terrestrial GDEs typically occur in areas that are water limited, with low annual rainfall and high evaporation rates (Evans et al., 2014a). In this subregion, most groundwater-dependent remnant vegetation in the zone of potential hydrological change occurs on floodplains (2358 km^2 or 62% of groundwater-dependent vegetation in the zone). Vegetation classified as 'Floodplain, terrestrial GDE' is located along the western edge of the zone, upstream of the proposed Hyde Park and China Stone mines in the north and upstream of the proposed Kevin's Corner, Alpha and South Galilee mines in the south (Figure 58 in Lewis et al. (2018)).

More than half of the groundwater-dependent vegetation (716 km^2) in the zone is located on floodplains intersected by temporary streams that are potentially impacted but not represented in the surface water model. Potential hydrological changes include decreased overbank flows that may affect up to 355 km^2 of floodplain vegetation and additional drawdown in excess of 5 m that may affect up to 296 km^2 of groundwater-dependent vegetation on floodplains. Within large uncertainty bounds, up to 3% of groundwater-dependent vegetation on floodplains is 'at some risk of hydrological and ecological changes' due to additional drawdown and decreased overbank floods along parts of Alpha, North, Sandy and Tallarenha creeks, and the Belyando and Carmichael rivers (Figure 61 in Lewis et al. (2018)).

Non-floodplain, terrestrial groundwater-dependent ecosystems

About one-third of GDEs in the zone (1189 km^2) rely on groundwater associated with clay plains, loamy and sandy plains, inland dunefields, and fine-grained and coarse-grained sedimentary rocks. Additional drawdown in excess of 5 m is *very unlikely* to affect more than 68 km^2 (2%) of GDEs that do not occur on floodplains in the zone. As this landscape group is not associated with streams, it is unaffected by changes to surface water flow. Up to 5% of non-floodplain terrestrial GDEs in the zone are 'at some risk of ecological and hydrological changes', and these occur where additional drawdown is greatest (Figure 65 in Lewis et al. (2018)).

FIND MORE INFORMATION

Explore potential impacts on ecosystems in more detail on the BA Explorer, available at www.bioregionalassessments.gov.au/explorer/GAL/landscapes

Conceptual modelling, product 2.3 (Evans et al., 2018b)

Receptor impact modelling, product 2.7 (Ickowicz et al., 2018)

Impact and risk analysis, product 3-4 (Lewis et al., 2018)

Receptor impact modelling, submethodology M08 (Hosack et al., 2018)

Impacts and risks, submethodology M10 (Henderson et al., 2018)

Summary of groundwater drawdown by assessment unit (Dataset 1)

Landscape classification (Dataset 15)

Landscape class spatial overlay by assessment unit (Dataset 1)

Receptor impact model (Dataset 18)

Results from applying receptor impact models (Dataset 19)

What are the potential impacts of additional coal resource development on water-dependent assets?

The impact and risk analysis (Box 7) used multiple lines of evidence to investigate how hydrological changes due to additional coal resource development may affect water-dependent assets, such as bores, heritage sites, or habitats of species.

More than 4200 assets were listed for the Galilee subregion, comprising more than 800,000 individual elements (Sparrow et al., 2015; Bioregional Assessment Programme, 2017; Dataset 3). Many of these assets are large, such as the Diamantina National Park in south-west Queensland, which covers an area of 5070 km^2.

A total of 4262 assets were assessed as being water dependent, including:

- **3982 ecological assets,** of which 241 are in the zone of potential hydrological change
- **129 economic assets,** comprising 5012 surface water and groundwater access entitlements, which are aggregated into 96 groundwater economic assets and 33 surface water economic assets
- **151 sociocultural assets**, including historical places associated with the ill-fated 19th century expedition of Burke and Wills, and Indigenous assets of cultural significance.

Potential impacts on most water-dependent assets were assessed by overlaying their extent on the zone of potential hydrological change (Box 5, Figure 1), defined using the near-surface aquifer and some streams. However, the potential impacts to some groundwater economic assets sourced from the confined aquifer of the Clematis Group were assessed using the area with at least a 5% chance of 0.2 m of drawdown in the deeper Clematis Group model layer.

The assessment identified potential impacts if an asset or any part of it is within the zone. Assets with areas that exceed thresholds of hydrological change (defined in Box 11) are identified as 'more at risk of hydrological changes' relative to other assets.

Ecological changes were not predicted for assets, because receptor impact models (Box 9) were developed for landscape groups and not individual assets. However, an example of a more detailed analysis of a specific asset ('potential distribution of Black Ironbox (*Eucalyptus raveretiana*)') is provided in Lewis et al. (2018) to illustrate the type of approach that could be used to assess impacts at a finer level of detail.

Ecological assets

Which ecological assets are *very unlikely* to be impacted?

Key finding 12: Of the 3982 ecological water-dependent assets in the Galilee assessment extent, 3741 (94%) are outside the zone of potential hydrological change and thus are *very unlikely* to be impacted.

None of the ecological assets outside of the zone are interpreted to source water from either of the deeper aquifers modelled for this assessment (Clematis Group and upper Permian coal measures aquifers), as they are too deeply buried and overlain by a significant thickness of sedimentary rocks (400 to 1200 m), including regional aquitard layers such as the Moolayember Formation.

For more details see Table 30 in Section 3.5.2 of Lewis et al. (2018).

Box 11 Categorising risk for assets

Parts of some assets were deemed 'more at risk of hydrological changes' relative to other parts of that asset. Categorisation assists the rule-out process and in identifying where further local-scale assessment is warranted.

Assessment units that overlap with an asset are categorised as 'more at risk' based on the degree that modelled hydrological changes exceed thresholds of risk. These bioregion-specific thresholds are based on expert opinion and defined using hydrological response variables (see Section 3.5 of Lewis et al. (2018) for more details on the thresholds).

Which ecological assets are potentially impacted?

Of the 241 ecological assets in the zone, the majority (67%) is groundwater-dependent vegetation, distributed along streams such as Cape River, Carmichael River, Cattle Creek, Dyllingo Creek, Fox Creek, Lagoon Creek, Native Companion Creek, North Creek, Sandy Creek, Suttor River and Tomahawk Creek.

Key finding 13: Of the 241 water-dependent ecological assets in the zone of potential hydrological change, 148 are 'more at risk of hydrological changes' (Box 11). Most of these assets are groundwater-dependent ecosystems or potential habitat of threatened species.

The assets that are 'more at risk of hydrological changes' include 106 GDEs as well as potential habitat for 12 threatened species listed under the EPBC Act, including:

- two endemic spring wetland plants: the blue devil and the salt pipewort (Figure 67 in Lewis et al. (2018))
- three species of seed-eating birds: the black-throated finch (southern), star finch (eastern) and squatter pigeon (southern) (Figure 68 in Lewis et al. (2018))
- the koala
- four reptile species.

Two EPBC Act-listed threatened ecological communities, seven regional ecosystems listed under Queensland's *Nature Conservation Act 1992,* and four parks and reserves are also deemed 'more at risk of hydrological changes'.

Of all ecological assets in the zone, 48 (20%) are in the 'Springs' landscape group, mostly in the Doongmabulla Springs complex. The 200 springs in this landscape group occupy less than 1% of the area of the zone.

Two alternative groundwater model conceptualisations applied in this assessment predict that 181 of the 187 springs in the Doongmabulla Springs complex both have a 5% chance of experiencing additional groundwater drawdown in excess of 0.2 m (for the Clematis Group aquifer which is interpreted to be the source aquifer for these springs). Expert ecological knowledge suggests that this level of drawdown is predicted to impact the ecological functioning of some ecological assets; however, there will be considerable variation in response across springs and spring complexes. Higher resolution modelling using local-scale information is needed to improve the assessment of potential impacts and risks to springs in the zone.

Section 3.6 of Lewis et al. (2018) provides a qualitative assessment of potential impacts to water-dependent ecosystems and assets due to the ten non-modelled additional coal resource developments in the CRDP (seven coal mine projects and three CSG extraction projects).

Economic assets

The groundwater and surface water resources in the central-eastern Galilee subregion are used for a variety of economic purposes: town water supplies, stock and domestic use, and minor irrigation. Find out more about the subregion's water use in Evans et al. (2015). Many bores in the GAB extract groundwater from deeper confined aquifers (i.e. not the near-surface aquifer), and most of the water-dependent economic assets in the Galilee assessment extent are associated with the GAB. Therefore, the impact analysis of economic assets is based on the framework of groundwater management areas and units defined in the *Water Plan (Great Artesian Basin) 2006* (although this plan was superseded in September 2017 by the new *Water Plan (Great Artesian Basin and Other Regional Aquifers) 2017*).

The groundwater model (Box 3) estimated drawdown due to additional coal resource development for three aquifer layers:

- **Quaternary alluvium and Cenozoic sediments** – the geologically young, near-surface aquifer that mainly hosts the watertable within the zone of potential hydrological change (Figure 15)
- **Clematis Group aquifer** – outcropping west of the seven modelled mines, this unit forms a deeper confined aquifer that provides water for stock and domestic bores in the Barcaldine North 3 and Barcaldine East 4 groundwater management units
- **Upper Permian coal measures** – the main geological unit that contains the coal resources targeted for mining in the CRDP.

The Clematis Group is the main aquifer associated with groundwater economic assets that are potentially impacted due to modelled additional coal resource development. For this aquifer, the area with at least 5% chance of exceeding 0.2 m drawdown extends further west than the boundary of the zone of potential hydrological change, defined for the near-surface aquifer (Figure 16).

Which economic assets are *very unlikely* to be impacted?

About 95% of the 129 economic assets in the Galilee assessment extent are outside the zone of potential hydrological change. In addition, most economic assets that source groundwater from the deeper confined aquifer of the Clematis Group are also outside the area of the Clematis Group drawdown zone (defined using a similar threshold of a 5% chance of 0.2 m drawdown for the Clematis Group). No economic assets source groundwater from the deeper upper Permian coal measures layer. Economic assets that are *very unlikely* to be impacted include:

- all of the economic assets associated with eight of the ten groundwater management areas of the GAB that intersect the subregion, including the Barcaldine North, Barcaldine South and Flinders groundwater management areas
- all 25 of the surface water access rights that intersect with the assessment extent, including the 2 water access rights associated with the *Water Plan (Burdekin Basin) 2007*.

Which surface water economic assets are potentially impacted?

Key finding 14: One basic water right on the Belyando and Suttor rivers is the sole surface water economic asset in the zone of potential hydrological change. There is a 5% chance of annual flows reducing by around 1% and of zero-flow days increasing by a maximum of between 152 and 260 days per year at the three extraction points associated with this water right.

The basic surface water right has three water extraction locations in the zone: two on the Belyando River and one on its headwater tributary, Native Companion Creek (Figure 15). This is the single surface water economic asset managed under the *Water Plan (Burdekin Basin) 2007*. The extraction point on Native Companion Creek is not expected to experience significant changes in annual flow volume, as all predictions are below the 1% threshold. However, there is potential for large increases in the number of zero-flow days at this location. It is *very likely* that zero-flow days will increase by a maximum of at least 2 days per year, and *very unlikely* that they will exceed a maximum increase of 152 days (with a 50% chance of a 14-day increase).

At the two locations on the Belyando River, the hydrological changes are greater. Reductions in annual flow remain relatively low, only just exceeding 1% (with a 50% chance), but zero-flow days are expected to increase at both sites, with a 50% chance of a maximum increase of more than 50 days per year. There is a 5% chance of very large increases of similar magnitude (around 260 days) in both cases.

Which groundwater economic assets are potentially impacted?

Preliminary spatial analysis of bores in and near to the zone of potential hydrological change indicated two groundwater management areas of the GAB that are potentially most affected by drawdown due to modelled additional coal resource development, Barcaldine East Groundwater Management Area and Barcaldine North Groundwater Management Area.

The Clematis Group aquifer is the main hydrogeological unit managed in both these groundwater management areas under the *Water Plan (Great Artesian Basin) 2006* and is potentially impacted by drawdown (Table 3).

Key finding 15: Five groundwater economic assets are potentially affected by additional drawdown, including three associated with the Clematis Group aquifer, and one associated with the Jericho town water supply. It is *very unlikely* that there will be drawdown greater than 2 m in any economic assets that rely on the Clematis Group aquifer.

Three economic assets specifically associated with the Clematis Group aquifer are potentially affected by drawdown due to modelled additional coal resource development in the subregion:

- a basic water right in Barcaldine East 4 Groundwater Management Unit
- a basic water right in Barcaldine North 3 Groundwater Management Unit
- a water access right in Barcaldine North 3 Groundwater Management Unit.

A basic water right is the right to take water for domestic and stock purposes only, whereas a water access right requires a licence both for the works and the extraction of water for irrigation, mining and intensive agriculture (see Section 2.2 in Mount et al. (2015) and Section 1.3.1.2.2 in Sparrow et al. (2015)).

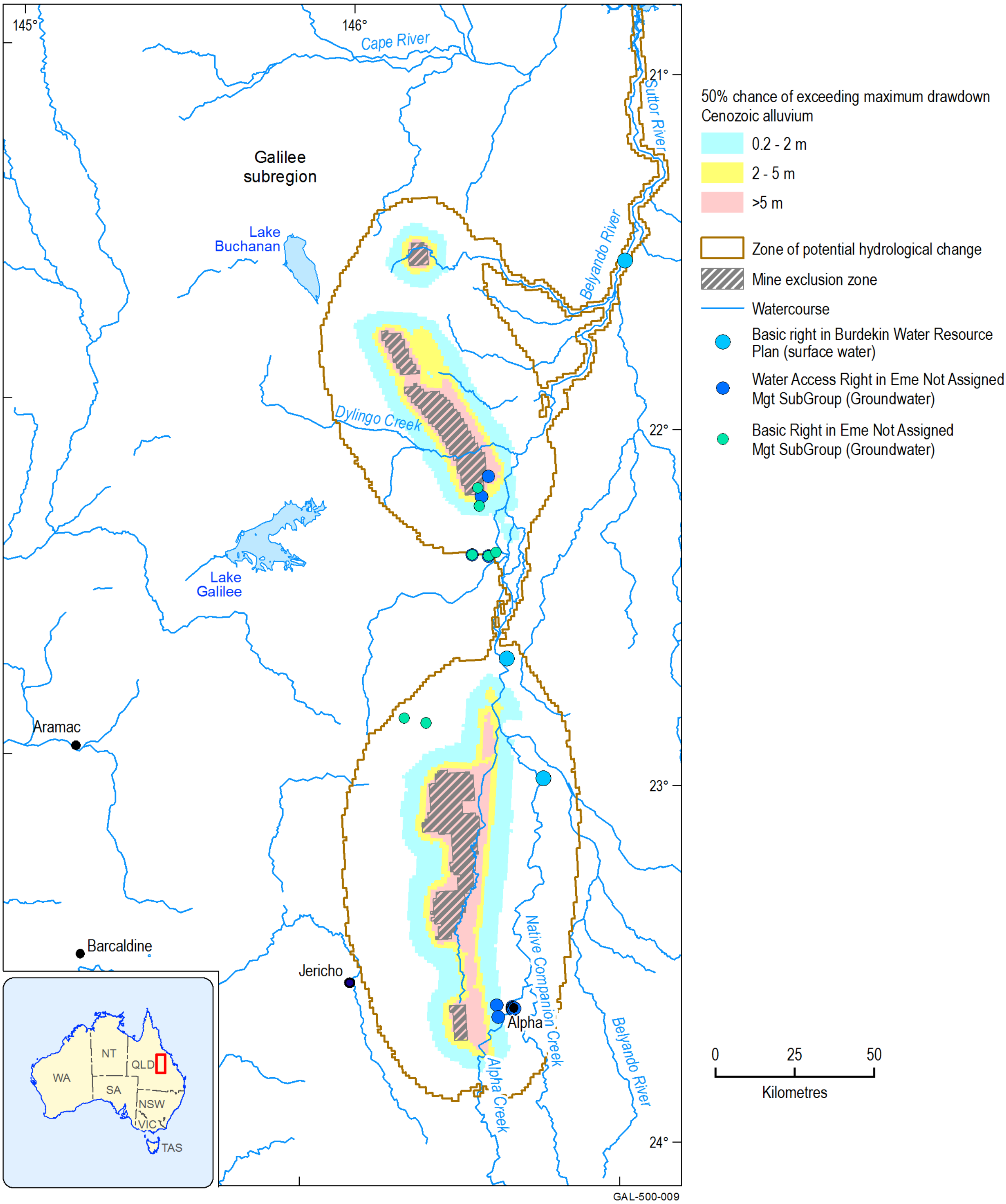

Figure 15 Individual extraction points associated with the only surface water economic asset in the zone of potential hydrological change, and bores associated with the two unassigned groundwater economic assets in the zone

The surface water economic asset has three separate water extraction points shown, whereas the two unassigned groundwater economic assets have multiple bore locations. The term 'Eme' in the name of the two economic assets refers to Emerald, the location of the nearest regional office that is responsible for management of the Queensland Groundwater Database (DNRM, 2015).
Data: Bioregional Assessment Programme (Dataset 1, Dataset 3, Dataset 17)

No asset-related bores associated with these groundwater management units are expected to experience greater than 2 m of drawdown due to modelled additional coal resource development. Only a relatively small area to the west of China Stone and Carmichael has a 5% chance of experiencing more than 2 m of drawdown in the Clematis Group aquifer, but no economic assets are identified for this location. This area of greater than 2 m drawdown in the Clematis Group aquifer is shown in yellow in Figure 16c.

The other two potentially impacted groundwater economic assets are not assigned to a specific management unit and include one water access right and one basic water right (for bore locations see Figure 15). Several bores in the water access right economic assets are associated with the Jericho town water supply. These bores source groundwater from the Clematis Group aquifer and it is *very unlikely* that any will experience more than 2 m of drawdown.

Not all groundwater bores recorded in the Queensland bore database (Queensland Government, 2018) are associated with the groundwater economic assets in the water-dependent asset register (Bioregional Assessment Programme, 2017; Dataset 3). For example, there may be some bores drilled after the register was compiled, and other bores owned by various mining companies in the Galilee subregion were not initially available for inclusion. Find out more in Section 3.5 of the impact and risk analysis (Lewis et al., 2018).

Table 3 Impacts of modelled additional coal resource development on groundwater-dependent economic assets that source the Clematis Group aquifer (95%, 50% and 5% chance of exceeding given values of drawdown)

Asset ID	Asset name	Total number of bores in assessment extent	Managed aquifers	Number of bores with additional drawdown 0.2–2 m			Maximum additional drawdown (m)		
				95%	50%	5%	95%	50%	5%
2217	Basic water right in Barcaldine East 4	92	• Moolayember Formation • Warang Sandstone • Clematis Group • Rewan Formation	5	14	22	0.26	0.73	1.36
2220	Basic water right in Barcaldine North 3	162	• Moolayember Formation • Clematis Group	7	49	93	0.26	0.70	1.49
2276	Water access right in Barcaldine North 3	2	• Moolayember Formation • Clematis Group	0	1	1	0.14	0.36	0.69

Additional drawdown is the maximum difference in drawdown under the coal resource development pathway and the baseline (Box 1 and Box 4). Because there are no coal resource developments in the baseline for the Galilee subregion, the CRDP includes only the additional coal resource development (ACRD). Results are shown as percent chance of exceeding drawdown thresholds (Box 6). These appear in Lewis et al. (2018) as percentiles.
Although multiple aquifers are managed under each of the management units listed here, the groundwater modelling for this assessment only generated results for the Clematis Group aquifer. There is one water access right in the Barcaldine North 3 Groundwater Management Unit that occurs within the area of predicted drawdown greater than 0.2 m in the Clematis Group aquifer.
Data: Bioregional Assessment Programme (Dataset 1)

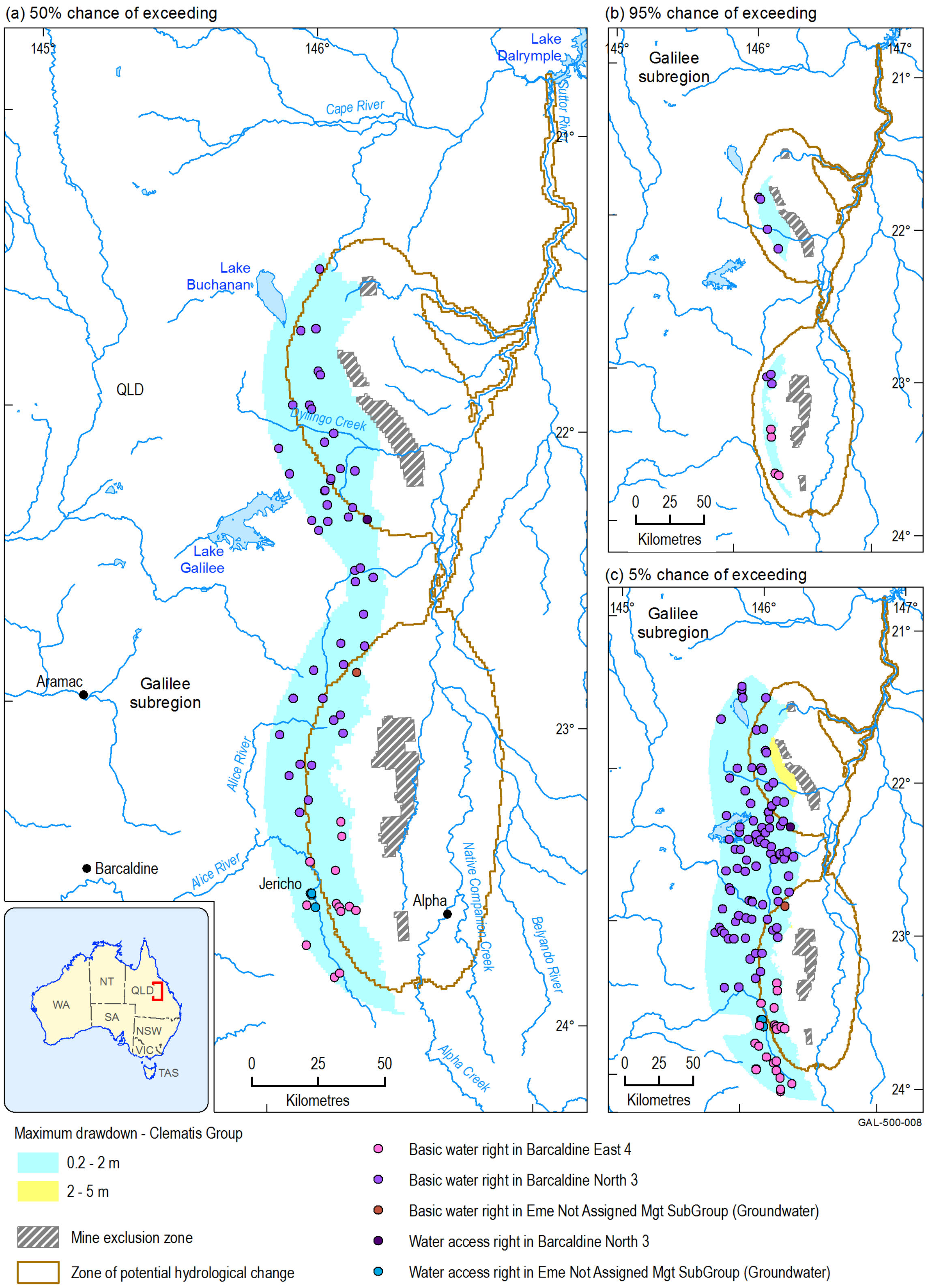

Figure 16 Variation in the extent and magnitude of additional drawdown in the Clematis Group aquifer near the central-eastern margin of the Galilee subregion, overlain with individual groundwater bores that belong to groundwater-related economic assets within the drawdown extent

The groundwater component of the zone of potential hydrological change (brown line) was defined by drawdown in the near-surface aquifer (see Box 5), not the deeper Clematis Group aquifer.

Additional drawdown is the maximum difference in drawdown under the coal resource development pathway and the baseline (Box 1 and Box 4). Because there are no coal resource developments in the baseline for the Galilee subregion, the CRDP includes only the additional coal resource development (ACRD). Results are shown as percent chance of exceeding drawdown thresholds (Box 6). These appear in Lewis et al. (2018) as percentiles.

The term 'Eme' as used in the name of the two economic assets that are not assigned to a specific groundwater management unit refers to the location of the nearest regional office to these bores (which is situated in the town of Emerald) that is responsible for management of the Queensland Groundwater Database (DNRM, 2015).

Data: Bioregional Assessment Programme (Dataset 1, Dataset 3, Dataset 17)

Bores where 'make good' provisions might apply

In Queensland, 'make good' obligations for groundwater bores affected by coal resource extraction (as well as other types of extractive industries) apply under Queensland's *Water Act 2000* (see Section 3.5.3.3.2 of Lewis et al. (2018)).

None of the groundwater-dependent economic assets sourced from the Clematis Group aquifer are predicted to experience drawdown greater than 2 m (Table 3). As the Clematis Group is a consolidated rock aquifer, the relevant bore trigger threshold under Queensland legislation is a decline in the aquifer water level of 5 m. Consequently, none of the economic assets associated with the Barcaldine North and Barcaldine East groundwater management areas are expected to be impacted at a level that would trigger the need for 'make good' provisions to be negotiated.

The town water supply bores for Jericho, classed as part of an unassigned economic asset for this assessment, are sourced from the Clematis Group aquifer. They occur in an area where all modelling results show a 5% chance of a maximum drawdown of about 0.6 m. This suggests that any groundwater impacts at the Jericho town water supply due to modelled additional coal resource development are unlikely to exceed specified bore trigger thresholds.

The town water supply bores at Alpha also occur within the zone of potential hydrological change (for the near-surface aquifer). However, groundwater modelling outputs for this assessment were not able to accurately predict water level changes for these bores, as their alluvial source aquifer is interpreted to be in direct connection with the basal Joe Joe Group of the Galilee Basin. As this hydrogeological connection is not represented in the groundwater model for the Galilee subregion, it is not possible to evaluate the potential for groundwater bore impacts to adversely affect the Alpha town water supply (see Section 3.5.3 of Lewis et al. (2018)). As potential impacts cannot be ruled out on basis of this assessment, further local-scale hydrogeological investigations are needed to develop an appropriate management response for the Alpha town water supply.

Sociocultural assets

The water-dependent asset register for the Galilee subregion lists 151 sociocultural assets with some level of dependency on either groundwater and/or surface water resources. All are either classed as heritage sites or Indigenous sites.

Most sociocultural assets in the Galilee assessment extent are from the Register of the National Estate, although there are also some assets from the National Heritage List and a single entry from the World Heritage List (Great Barrier Reef World Heritage Area).

The water-dependent asset register for the Galilee subregion is available at Bioregional Assessment Programme (2017). The register includes 69 culturally significant Indigenous sites or species within the Galilee assessment extent that were added following consultation with local Indigenous groups. This included 24 species of fauna and flora that are of critical cultural heritage value, all of which may be water dependent. However, as there was no spatial information associated with these assets, it was not possible to determine if they occur within the zone of potential hydrological change (see Section 3.5.4 in Lewis et al. (2018)).

The results of the Indigenous assets consultation are documented in a separate report (Constable and Love, 2014).

Which sociocultural assets are *very unlikely* to be impacted?

More than 95% of the sociocultural assets in the water-dependent asset register are not in the zone of potential hydrological change, indicating that impacts are *very unlikely*. These include notable sites such as the Great Barrier Reef World Heritage Area and the national heritage-listed icons of the Simpson Desert and the Birdsville and Strzelecki Tracks Area.

Which sociocultural assets are potentially impacted?

Parts of four heritage or Indigenous sites are in the zone of potential hydrological change:

- **Doongmabulla Springs** – natural indicative place (Register of the National Estate)
- **Lake Buchanan and catchment** – natural registered place (Register of the National Estate)
- **Old Bowen Downs Road** – historic indicative place (heritage site) listed on the Register of the National Estate
- **Cape River** – surface water feature specified as an Indigenous site during consultation with Indigenous people about water values in the Galilee subregion.

Potential impacts on Doongmabulla Springs are discussed in the ecosystem and ecological assets sections of this synthesis (page 21 and page 29, respectively), Lake Buchanan is discussed in Section 3.5.4.2 in Lewis et al. (2018), and impacts on the Old Bowen Downs Road are assessed as being minimal, with modelled predictions suggesting a minor reduction in the number of high-flow days at the river crossings (Section 3.5.4.3 in Lewis et al. (2018)). The Cape River Indigenous asset is only included here, as 1.4 km of the Cape River occurs in the zone of potential hydrological change at its most downstream junction with the Suttor River. However, surface water modelling for this assessment confirmed that modelled additional coal resource development is *very unlikely* to impact the Cape River.

FIND MORE INFORMATION

Explore potential impacts on water-dependent assets in more detail on the BA Explorer, available at www.bioregionalassessments.gov.au/explorer/GAL/assets. It is important to note that when viewing impacts to economic assets using the BA Explorer, drawdown is shown only for the near-surface aquifer and not the deeper confined aquifers that may be the source of water for some bores and springs.

Description of the water-dependent asset register, product 1.3 (Sparrow et al., 2015)

Water-dependent asset register (Bioregional Assessment Programme, 2017)

Impact and risk analysis, product 3-4 (Lewis et al., 2018)

Compiling water-dependent assets, submethodology M02 (Mount et al., 2015)

Impacts and risks, submethodology M10 (Henderson et al., 2018)

Asset database (Dataset 3)

Landscape classification (Dataset 15)

How to use this assessment

Findings from this bioregional assessment can help governments, industry and the community provide better-informed regulatory, water management and planning decisions.

Assessment results flag where future efforts of regulators and proponents can be directed. This is emphasised through the rule-out process, which directs focus onto areas where hydrological changes are predicted. This process has identified areas, and consequently water resources and water-dependent assets, that are *very unlikely* to experience hydrological change or impact due to additional coal resource development.

This assessment predicts the likelihood of exceeding levels of potential hydrological change at a regional scale and also considers cumulative changes from multiple coal resource developments. It provides important context to identify potential issues that may need to be addressed in local-scale environmental impact assessments of new coal mines. It should help project proponents to meet legislative requirements to describe the environmental values that coal resource development may affect, and to adopt strategies to avoid, mitigate or manage the predicted impacts, including those that overlap with other future coal resource developments. These assessments did not investigate the social, financial or human health impacts of coal resource development, nor did they consider risks of fugitive gases and non-water related impacts.

Bioregional assessments are not a substitute for careful assessment of individual coal mine or CSG extraction projects under Australian or state environmental law. Such assessments may use finer-scale groundwater and surface water models and consider impacts on matters other than water resources and interactions with neighbouring developments. However, the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (a federal government statutory authority established in 2012 under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999*) can use these assessment results to help formulate their advice on proponent's proposals for coal resource development projects, and on addressing cumulative impacts with other developments.

Data access

The full suite of information, including information for individual assets, is provided at www.bioregionalassessments.gov.au. Access to underpinning datasets, including geographic data and modelling results, can assist decision makers at all levels to review the work undertaken to date; to explore the results using different thresholds; and to extend or update the assessment if new models or data become available. Additional guidance about how to apply the Programme's methodology is also documented in 11 detailed scientific submethodologies (as listed in 'References and further reading' on page 42).

The Programme's rigorous commitment to data access is consistent with the Australian Government's principles of providing publicly accessible, transparent and responsibly managed public sector information.

Building on this assessment

Bioregional assessments have been developed with the ability to be updated, for example, incorporating new coal resource developments in the groundwater or surface water modelling. Components such as the water-dependent asset register (Bioregional Assessment Programme, 2017; Dataset 3) will remain relevant for future assessments. If new coal resource developments emerge in the future, the data, information, analytical results and models from this assessment provide a comprehensive basis for bioregion-scale re-assessment of potential impacts under an updated CRDP. It may also be applicable for other types of resource development, such as agriculture or shale gas.

The Galilee Basin hydrogeological (GBH) model is a regional-scale numerical groundwater flow model developed utilising data and interpretations compiled to support the bioregional assessment of the Galilee subregion (Turvey et al., 2015). The GBH model provides a more sophisticated representation of the hydrogeology of the Galilee and Eromanga basins and mine developments, and could provide the basis for future cumulative impact assessments, building upon the initial work undertaken for this assessment. Peeters et al. (2018) provided an overview of the GBH model as well as a summary of its strengths and current limitations.

The assessment provides information about potential cumulative impacts of coal mining and CSG developments on water resources and water-dependent assets. It did not assess potential impacts from rail development or coal handling and processing facilities at coal terminals or ports.

Non-modelled coal resource developments

The main focus of the impact and risk analysis for the Galilee subregion is in the central-east, where the initial seven proposed coal mines are most likely to begin operations. However, a further seven potential coal mine projects and three CSG projects were included in the CRDP for this assessment, though these were not modelled.

Most of these later-stage coal resource developments will occur in parts of the subregion away from the area where the modelling analysis was undertaken for this assessment. This includes a suite of five potential coal mines near the northern edge of the Galilee Basin, and a stand-alone operation in the southern part of the subregion (near Blackall) targeting geologically younger coal from the Eromanga Basin. The seven non-modelled coal mine projects in the CRDP are (from north to south) Clyde Park, Hughenden, Pentland, West Pentland, Milray, Alpha West and Blackall (Figure 2).

The most likely area for future CSG development spans the central part of the basin, from the Glenaras Gas Project in the west, across to the Gunn Project in the east. All of the subregion's CSG projects remain at exploration and early appraisal stages, with no clear understanding yet as to the timing, scale and longevity of any CSG production fields. The areas of most interest for CSG development in the Galilee subregion all occur within the Cooper Creek – Bulloo river basin.

More information on the non-modelled coal resource developments is available in Section 3.6 of Lewis et al. (2018), which describes:

- the most likely areas for subsequent phases of coal resource development
- information about non-modelled coal mine and CSG projects, to assist any future assessment of cumulative impacts across the wider Galilee Basin
- qualitative analyses of the potential for impacts on the water-dependent landscape groups and assets that are near these sites, including any overlap with hydrological changes caused by the seven coal mines that were modelled for this assessment.

This information will assist users of the assessment to understand where subsequent stages of coal resource development may potentially occur in different areas of the Galilee Basin, as well as a flag for the key ecosystems and assets that are near these later-stage developments. This information may assist future planning and management of potential water-related impacts and risks in the Galilee subregion.

Future opportunities

Section 3.7.4 in Lewis et al. (2018) details data gaps and future opportunities to build upon the work of this assessment and further improve knowledge in key areas such as geology and hydrogeology, hydrological modelling, assessing impacts on ecosystems, water quality considerations and incorporating other climate change and land use impacts.

Geology and hydrogeology

An opportunity exists to improve the surface geological and structural mapping along the central-eastern margin of the Galilee Basin, which would address some notable discrepancies in the current mapping (across different scales). New mapping efforts should ideally incorporate as much information as possible from recent geophysical surveys as well as any available finer-scale mapping or geological modelling that may have been completed (e.g. to aid coal exploration or resource evaluation activities). Information such as this could then be used to refine knowledge of the three-dimensional geological architecture within this area of interest, potentially leading to more robust and reliable hydrogeological conceptualisations to underpin subsequent local-scale modelling.

Hydrogeological interpretation of spring source aquifers within the zone of potential hydrological change (a noted point of current scientific debate as outlined in Section 3.4 of Lewis et al. (2018) and references therein) would benefit from additional field-based measurements and data collection, for example, using suitable environmental tracers, geophysical data and application of local-scale geological mapping and groundwater modelling. Also, determining the source aquifer for bores in the zone with missing screen depths will improve estimates of water take from different aquifers, decreasing uncertainty around potential impacts of groundwater drawdown on these bores.

Hydrological modelling

Future iterations of surface water and groundwater modelling to support management or planning decisions in the Galilee subregion should revisit the choice of individual coal resource developments in the CRDP, and their proposed operational characteristics, and assess if any updates or changes are required. This could be done on a regular basis, such as every 3 to 5 years, to ensure that the CRDP is aligned with any possible changes to the number of likely developments and their proposed timing.

Consideration could also be given to evaluating multiple potential development scenarios for the Galilee subregion within the hydrological models. Additionally, future modelling iterations could evaluate the potential for hydrological interaction between coal mining operations and CSG development in the basin's most prospective central area.

The distribution of surface water model nodes in this assessment did not enable a comprehensive extrapolation to all network reaches, and resulted in identification of some 'potentially impacted' stream reaches where hydrological changes could not be quantified. A higher density of surface water modelling nodes and gauging information, located immediately upstream of major stream confluences as well as upstream and downstream of mining operations, would allow the point-scale information to be interpolated to a larger proportion of the stream network. More extensive quantification of hydrological changes along the stream network would enable better spatial coverage of the results of the receptor impact modelling.

A more detailed understanding of all water balance components, including recharge, evapotranspiration, inter-aquifer leakage and groundwater fluxes between the Galilee and Eromanga basins would decrease uncertainty and improve future updates to this assessment. This work would build upon the higher-level water balance reporting presented for this bioregional assessment (Karim et al., 2018b), and include revised estimates of mine water extraction, on-site use and any potential stream releases (if appropriate). Improved understanding of the dynamic interaction between components of the water balance for key assets such as the Doongmabulla Springs complex could be gained through analysis of baseline time-series remote sensing datasets.

As mentioned above, further investments to improve the structure and robustness of the GBH numerical groundwater model (Turvey et al., 2015) would provide a strong foundation for assessing cumulative impacts of coal resource development on groundwater systems into the future.

Assessing impacts on ecosystems

Extending this bioregional assessment should focus on improving confidence in assessing impacts in the landscape through more mapping of groundwater depths, vegetation communities and their water requirements, and identification of GDEs.

Improved knowledge of surface water – groundwater interactions would provide a better understanding of the separation between groundwater-dependent and surface water-dependent wetlands for future assessments. In particular, the impact assessment would benefit from better characterisation of surface water – groundwater interactions along the Belyando and Carmichael rivers (and their tributaries) with adjacent Cenozoic aquifers, and an improved understanding of potential for connectivity between aquifers in Cenozoic sediments and deeper aquifers in the Galilee Basin.

The remote sensing techniques applied for this assessment (see Section 3.5.2 in Lewis et al. (2018) for further details) demonstrate the potential for multi-decadal earth observation data to provide insight and baseline information for assessing dynamics of vegetation and wetlands. However, further quantitative analysis could be undertaken to determine the relative contributions of rainfall, streamflow and groundwater to water-dependent features. Better understanding of the hydrological contributions from different sources will assist with management and improve understanding around potential impact pathways from future development.

There is also a major data gap in the understanding of water thresholds for ecosystems associated with springs and other key water assets. In part, this results from the lack of bores available to provide meaningful time-series groundwater level data. Some examples of these data gaps appear in the discussion of the functioning of springs in the Doongmabulla Springs complex (see Lewis et al. (2018) for further details).

Subsurface GDEs have not been adequately surveyed within the assessment extent and are not well represented in this landscape classification. A consequence of this gap is uncertainty in the understanding of the water dependency of these GDEs, although most would be expected to have a high degree of reliance on groundwater for their survival.

Water quality

The potential large yearly variations in streamflow in the Belyando river basin mean that hydrological changes due to modelled additional coal resource development may not lead to substantial changes in water quality parameters such as salinity at the regional (or basin) scale, at least beyond the natural annual variability that these streams may already experience. However, there are scant baseline water quality data available, and hence there are opportunities to better characterise the natural range of water quality parameters, to develop an improved regional baseline. This would assist in better understanding potential water quality changes that could occur due to coal resource development, for example, due to variations in the relative contributions of surface runoff and (groundwater) baseflow to streams. Likewise, available groundwater quality data are also sparse within the zone of potential hydrological change, and additional knowledge of groundwater quality parameters would greatly assist in characterising the regional baseline for key aquifers. There is also a future opportunity to integrate any updated understanding of regional water quality in the zone with the quantitative outputs derived from the surface water and groundwater modelling developed for this assessment.

Climate change and land use

In comparing results under two different futures in this assessment, factors such as climate change, land use and other types of water extraction and usage are held constant. Future assessment iterations could include these and other stressors to more fully predict cumulative impacts at a landscape scale.

Future monitoring

Future monitoring to confirm predictions made in this assessment should focus on the discrete drawdown zones identified in the hydrological modelling. These include monitoring bores installed to target: the confined parts of the Clematis Group aquifer and Dunda beds, up-hydraulic gradient (west and south) of the Doongmabulla Springs complex; the unconfined Cenozoic aquifers in key areas of the Belyando River floodplain to assist in determining the degree of near-surface drawdown and potential connectivity with deeper aquifers; and Cenozoic aquifers associated with the Alpha town water supply.

Future surface water monitoring efforts would be best targeted along suitable reaches of Native Companion, North, Sandy, Alpha and Tallarenha creeks, and the Belyando and Carmichael rivers, where the bioregional assessment modelling results indicate the most substantial changes across the spectrum of low-flow, high-flow and annual flow regimes.

Besides future targeted monitoring points, there are a number of data-sparse areas that would benefit from consistent and regular data collection, which would improve risk quantification for this assessment. This includes surface water and ecological baseline data collection to improve the understanding of relevant environmental conditions and parameters, including those related to surface water and groundwater quality. Future monitoring efforts could also be directed towards testing some of the key hypotheses developed through the receptor impact modelling undertaken for this assessment.

The availability of ecological monitoring data for benchmarking, including identifying current conditions, and comparing and identifying changes in ecosystems and ecosystem indicators, is very limited, especially for dealing with regional-level changes. There is a lack of ecohydrological understanding around the water requirements for the many water-dependent vegetation communities and how these relate to specific hydrological response variables – a crucial requirement for assessing impacts related to hydrological changes. Consequently, future investigations and coordinated monitoring to address such knowledge shortcomings would strengthen any further assessment of cumulative impacts due to coal resource development in the Galilee Basin.

FIND MORE INFORMATION

See ‘Knowledge gaps’ sections in:

Description of water-dependent asset register, product 1.3 (Sparrow et al., 2015)

Current water accounts and water quality, product 1.5 (Evans et al., 2015)

Observations analysis, statistical analysis and interpolation, product 2.1-2.2 (Evans et al., 2018a)

Conceptual modelling, product 2.3 (Evans et al., 2018b)

Water balance assessment, product 2.5 (Karim et al., 2018b)

Surface water numerical modelling, product 2.6.1 (Karim et al., 2018a)

Groundwater numerical modelling, product 2.6.2 (Peeters et al., 2018)

Receptor impact modelling, product 2.7 (Ickowicz et al., 2018)

Impact and risk analysis, product 3-4 (Lewis et al., 2018)

See www.bioregionalassessments.gov.au for links to information about all datasets used or created, most of which can be downloaded from data.gov.au.

References and further reading

The information presented in this product for the Galilee subregion is based on the analysis and interpretation of existing data and knowledge, enhanced by new scientific studies of the geology, groundwater, surface water and ecology. All technical products developed for the Galilee subregion are listed here. Also listed are the submethodologies that describe the key approaches used to undertake the assessments.

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Glossary

The register of terms and definitions used in the Bioregional Assessment Programme is available online at http://environment.data.gov.au/def/ba/glossary. Definitions for landscape classes and landscape groups for the Galilee subregion are available online at http://environment.data.gov.au/def/ba/landscape-classification/galilee-subregion.

additional coal resource development: all coal mines and coal seam gas (CSG) fields, including expansions of baseline operations, that are expected to begin commercial production after December 2012

additional drawdown: the maximum difference in drawdown (dmax) between the coal resource development pathway (CRDP) and baseline, due to additional coal resource development

annual flow (AF): the volume of water that discharges past a specific point in a stream in a year, commonly measured in GL/year. This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102).

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

assessment extent: the geographic area associated with a subregion or bioregion in which the potential water-related impact of coal resource development on assets is assessed. The assessment extent is created by revising the preliminary assessment extent on the basis of information from Component 1: Contextual information and Component 2: Model-data analysis.

at minimal risk of ecological and hydrological changes: assessment units that overlap a landscape class are considered 'at minimal risk of ecological and hydrological changes' relative to other assessment units if modelled hydrological changes result in ecological changes that do not exceed the lower thresholds of risk. These bioregion-specific thresholds are based on expert opinion and are defined using receptor impact variables. Categorisation assists the rule-out process and in identifying where further local-scale assessment is warranted.

at some risk of ecological and hydrological changes: assessment units that overlap a landscape class are considered 'at some risk of ecological and hydrological changes' relative to other assessment units if modelled hydrological changes result in ecological changes that exceed the lower thresholds of risk but do not exceed the upper thresholds of risk. These bioregion-specific thresholds are based on expert opinion and are defined using receptor impact variables. Categorisation assists the rule-out process and in identifying where further local-scale assessment is warranted.

baseflow: the part of streamflow that comes from the sum of deep subsurface flow and delayed shallow subsurface flow

baseflow index: the ratio of baseflow to total streamflow over a long period of time (years)

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

baseline drawdown: the maximum difference in drawdown (*dmax*) under the baseline relative to no coal resource development

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

bioregional assessment: a scientific analysis of the ecology, hydrology, geology and hydrogeology of a bioregion, with explicit assessment of the potential direct, indirect and cumulative impacts of coal seam gas and coal mining development on water resources. The central purpose of bioregional assessments is to analyse the impacts and risks associated with changes to water-dependent assets that arise in response to current and future pathways of coal seam gas and coal mining development.

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

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

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

conceptual model: abstraction or simplification of reality

cumulative impact: for the purposes of bioregional assessments, the total change in water resources and water-dependent assets resulting from coal seam gas and coal mining developments when all past, present and reasonably foreseeable actions that are likely to impact on water resources are considered depressurisation: in the context of coal seam gas operations, depressurisation is the process whereby the hydrostatic (water) pressure within a coal seam is reduced (through pumping) such that natural gas desorbs from within the coal matrix, enabling the gas (and associated water) to flow to surface

dewatering: the process of controlling groundwater flow within and around mining operations that occur below the watertable. In such operations, mine dewatering plans are important to provide more efficient work conditions, improve stability and safety, and enhance economic viability of operations. There are various dewatering methods, such as direct pumping of water from within a mine, installation of dewatering wells around the mine perimeter, and pit slope drains.

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

diversion: see extraction

drawdown: a lowering of the groundwater level (caused, for example, by pumping). In the bioregional assessment (BA) context this is reported as the difference in groundwater level between two potential futures considered in BAs: baseline coal resource development (baseline) and the coal resource development pathway (CRDP). The difference in drawdown between CRDP and baseline is due to the additional coal resource development (ACRD). Drawdown under the baseline is relative to drawdown with no coal resource development; likewise, drawdown under the CRDP is relative to drawdown with no coal resource development.

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.

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

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

groundwater: water occurring naturally below ground level (whether 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 rely on groundwater - typically the natural discharge of groundwater - for their existence and health

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

groundwater system: see water system

groundwater zone of potential hydrological change: outside this extent, groundwater drawdown (and hence potential impacts) is *very unlikely* (less than 5% chance). It is the area with a greater than 5% chance of exceeding 0.2 m of drawdown due to additional coal resource development in the relevant aquifers.

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)

high-flow days (FD): the number of high-flow days per year. This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102). The threshold for high-flow days is the 90th percentile from the simulated 90-year period. In some early products, this was referred to as 'flood days'.

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

hydrological response variable: a hydrological characteristic of the system that potentially changes due to coal resource development (for example, drawdown or the annual flow volume)

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

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

landscape group: for the purposes of bioregional assessments (BAs), a set of landscape classes grouped together based on common ecohydrological characteristics that are relevant for analysis purposes

likelihood: probability that something might happen

low-flow days (LFD): the number of low-flow days per year. This is typically reported as the maximum change due toadditional coal resource development over the 90-year period (from 2013 to 2102). The threshold for low-flow days is the 10th percentile from the simulated 90-year period.

low-flow days (averaged over 30 years): the number of days per year with low flow (<10 ML/day), averaged over a 30-year period. This is typically reported as the maximum change due to additional coal resource development.

maximum low-flow spell (LME): the maximum length of spells (in days per year) with low flow, averaged over a 30-year period. This is typically reported as the maximum change due to additional coal resource development.

mine exclusion zone: areas in the zone of potential hydrological change that are within or near open-cut mine pits or underground mine workings, and where (i) modelled drawdowns are highly uncertain due to the very steep hydraulic gradients at the mine pit interface; (ii) changes in the drawdown are inevitable where the mine pit intersects the regional watertable; (iii) other factors, such as physical removal of a wetland or creek, may have a larger impact on a landscape class than the predicted decrease in groundwater level; and (iv) impacts are predominantly site-scale, assumed to be adequately addressed through existing development approval processes, and hence not the primary focus of bioregional assessments. The modelled estimates of drawdown in the mine exclusion zone are considered unreliable for use in the receptor impact modelling.

model node: a point in the landscape where hydrological changes (and their uncertainty) are assessed. Hydrological changes at points other than model nodes are obtained by interpolation.

more at risk of ecological and hydrological changes: assessment units that overlap a landscape class are considered ‘more at risk of ecological and hydrological changes’ relative to other assessment units if modelled hydrological changes result in ecological changes that exceed the upper thresholds of risk. These bioregion-specific thresholds are based on expert opinion and are defined using receptor impact variables. Categorisation assists the rule-out process and in identifying where further local-scale assessment is warranted.

more at risk of hydrological changes: assessment units that overlap an asset are considered ‘more at risk of hydrological changes’ relative to other assessment units if modelled hydrological changes exceed bioregion-specific thresholds of risk. These thresholds are based on expert opinion and are defined using hydrological response variables. Categorisation assists the rule-out process and identifying where further local-scale assessment is warranted.

overbank flow: an extremely high-flow rate condition, when the water level stage just begins to spill out of the channel into the floodplain. Bank erosion is accentuated, with the effectiveness of these erosional forces being a function of bank condition, the health of riparian vegetation, particle shape, density, packing and biological activity such as algal growth

overbench flow: high-flow condition where a river channel is partially or completely filled for a period of weeks to months. All habitats within the river channel will be wet including boulders, logs and lateral benches, and the entire length of the channel is connected with relatively deep water, allowing biota to move freely along the river.

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.

receptor impact model: a function that translates hydrological changes into the distribution or range of potential ecosystem outcomes that may arise from those changes. Within bioregional assessments, hydrological changes are described by hydrological response variables, ecosystem outcomes are described by receptor impact variables, and a receptor impact model determines the relationship between a particular receptor impact variable and one or more hydrological response variables. Receptor impact models are relevant to specific landscape classes, and play a crucial role in quantifying potential impacts for ecological water-dependent assets that are within the landscape class. In the broader scientific literature receptor impact models are often known as ‘ecological response functions’.

receptor impact variable: a characteristic of the system that, according to the conceptual modelling, potentially changes due to changes in hydrological response variables (for example, condition of the breeding habitat for a given species, or biomass of river red gums)

recharge: see groundwater recharge

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

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.

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

subsidence: localised lowering of the land surface. It occurs when underground voids or cavities collapse, or when soil or geological formations (including coal seams, sandstone and other sedimentary strata) compact due to reduction in moisture content and pressure within the ground.

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

surface water zone of potential hydrological change: outside this extent, changes in surface water hydrological response variables due to additional coal resource development (and hence potential impacts) are *very unlikely* (less than 5% chance). The area contains those river reaches where a change in any one of eight surface water hydrological response variables exceeds the specified thresholds. For the four flux-based hydrological response variables (annual flow (AF), daily flow rate at the 99th percentile (P99), interquartile range (IQR) and daily flow rate at the 1st percentile (P01)), the threshold is a 5% chance of a 1% change in the variable. That is, if 5% or more of model runs show a maximum change in results under coal resource development pathway (CRDP) of 1% relative to baseline. For four of the frequency-based hydrological response variables (high-flow days (FD), low-flow days (LFD), length of longest low-flow spell (LLFS) and zero-flow days (ZFD)), the threshold is a 5% chance of a change of 3 days per year. For the final frequency-based hydrological response variable (low-flow spells (LFS)), the threshold is a 5% chance of a change of 2 spells per year.

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

very likely: greater than 95% chance

very unlikely: less than 5% chance

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

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

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

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

zero-flow days (ZFD): the number of zero-flow days per year. This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102).

zero-flow days (averaged over 30 years) (ZQD): the number of zero-flow days per year, averaged over a 30-year period. This is typically reported as the maximum change due to additional coal resource development.

zone of potential hydrological change: outside this extent, hydrological changes (and hence potential impacts) are *very unlikely* (less than 5% chance). Each bioregional assessment defines the zone of potential hydrological change using probabilities of exceeding thresholds for relevant hydrological response variables. The zone of potential hydrological change is the union of the groundwater zone of potential hydrological change (the area with a greater than 5% chance of exceeding 0.2 m of drawdown due to additional coal resource development in the relevant aquifers) and the surface water zone of potential hydrological change (the area with a greater than 5% chance of exceeding changes in relevant surface water hydrological response variables due to additional coal resource development).

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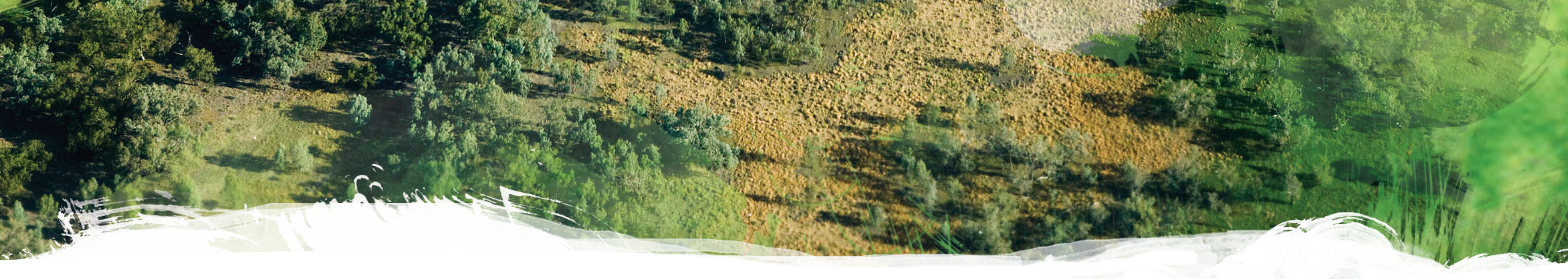

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