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BIOREGIONAL ASSESSMENTS

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

Impact and risk analysis for the Galilee subregion

Product 3-4 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

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The Bioregional Assessment Programme is a transparent and accessible programme of baseline assessments that increase the available science for decision making associated with coal seam gas and large coal mines. A bioregional assessment is a scientific analysis of the ecology, hydrology, geology and hydrogeology of a bioregion with explicit assessment of the potential impacts of coal seam gas and large coal mining development on water resources. This Programme draws on the best available scientific information and knowledge from many sources, including government, industry and regional communities, to produce bioregional assessments that are independent, scientifically robust, and relevant and meaningful at a regional scale.

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Cover photograph

Artesian Spring Wetland at Doongmabulla Nature Refuge, Queensland, 2013

Credit: Jeremy Drimer, University of Queensland

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Executive summary

The impact and risk analysis for the Galilee subregion is a regional overview of potential impacts on, and risks to, water resources and water-dependent ecological, economic and sociocultural assets from coal resource development. Hydrological and ecosystem changes due to coal resource development are quantified where possible and impacts that are *very unlikely* (less than 5% chance) are ruled out.

The Galilee subregion in central Queensland encompasses the headwaters of six major river basins with almost all proposed coal resource developments situated in the headwaters of the Burdekin river basin. In most rivers, water flow is strongly seasonal and, from year to year, flows can vary greatly from almost no flow to major floods.

Results from regional-scale hydrological modelling indicates that the future development of seven large coal mines in the central-eastern Galilee Basin is *very likely* (greater than 95% chance) to lead to cumulative hydrological changes in regional groundwater and surface water flow systems. These changes, focused in the Belyando river basin, will affect a larger area and total length of stream network than previously predicted from any individual mine-scale impact assessments. More detailed local-scale information is required to enhance existing knowledge of the level of risk and potential impacts.

Coal resources

The impact and risk analysis considered two potential coal resource development futures in the Galilee subregion:

- *baseline coal resource development (baseline)*: a future that includes all coal mines and coal seam gas (CSG) fields that were commercially producing as of December 2012
  - in the Galilee subregion there are no existing coal resource developments and so the baseline is the same as a ‘no development’ scenario
- *coal resource development pathway (CRDP)*: a future that includes all coal mines and CSG fields that are in the baseline as well as the additional coal resource development (those that were expected to begin commercial production after December 2012)
  - in the Galilee subregion there are 17 additional coal resource developments. Seven developments near the central-eastern margin of the subregion had sufficient publicly available information to be assessed in numerical modelling: the 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
  - the remaining 10 coal resource developments in the CRDP are assessed qualitatively in this impact and risk analysis. They comprise the seven non-modelled coal mine projects, from north to south, Clyde Park, Hughenden, Pentland, West Pentland, Milray, Alpha West and Blackall, and the three CSG projects, Glenaras, Gunn and Blue Energy.

The difference in results between the CRDP and baseline is the change that is primarily reported in a bioregional assessment (BA). This change is due to the additional coal resource development. This change is quantified for the seven coal mines included in the hydrological modelling.

Zone of potential hydrological change

The zone of potential hydrological change covers an area of 14,030 km^2 (around 2% of the entire Galilee assessment extent). The zone is the union of the groundwater zone of potential hydrological change and the surface water zone of potential hydrological change:

- The *groundwater zone of potential hydrological change* is defined as the area with at least a 5% chance of exceeding 0.2 m of drawdown in the near-surface aquifer (i.e. Quaternary alluvium and Cenozoic sediments).
- The *surface water zone of potential hydrological change* includes streams and associated riparian fringes where a change in any one of the eight modelled surface water hydrological response variables exceeds its specified threshold. The thresholds can be generally described as at least a 5% chance of a 1% or greater change in a flow volume, or a three day or greater change in frequency. The surface water zone encompasses much of the Belyando river basin upstream of Lake Dalrymple (Burdekin Falls Dam).

The zone was used to rule out potential impacts on ecosystems and water-dependent assets within the Galilee assessment extent. Water resources and water-dependent assets outside the zone are *very unlikely* (less than 5% chance) to be impacted by modelled coal resource developments.

Potential hydrological changes

Groundwater

Drawdown due to modelled additional coal resource development occurs in two distinct coal mining clusters near the central-eastern margin of the Galilee subregion. Results from regional groundwater modelling show drawdown due to additional coal resource development of greater than 0.2 m is *very likely* (greater than 95% chance) for an area of 2,820 km^2. It is *very unlikely* (less than 5% chance) that more than 13,364 km^2 of the near-surface aquifer (i.e. Quaternary alluvium and Cenozoic sediments) will experience drawdowns of this magnitude due to additional coal resource development. Groundwater drawdown and impacts on ecosystems or assets are not reported inside a 986 km^2 'mine exclusion zone' close to proposed open-cut and underground mines because of very steep hydraulic gradients at the mining operations.

Results for 2 m and 5 m drawdown extents in the near-surface aquifer suggest it is:

- *very likely* that an area of at least 1596 km^2 exceeds 2 m of drawdown and *very unlikely* that more than 4426 km^2 exceeds 2 m of drawdown
- *very likely* that an area of at least 1029 km^2 exceeds 5 m of drawdown and *very unlikely* that more than 2711 km^2 exceeds 5 m of drawdown.

Modelled drawdowns are also reported for the two deeper confined aquifer systems of the Clematis Group and upper Permian coal measures, both part of the hydrostratigraphic sequence of the Galilee Basin. The pattern and extent of drawdown in these deeper layers differs from that in the near-surface sediment layer, occurring westwards of the mining areas and extending much further towards the central parts of the Galilee Basin. Drawdowns in these deeper layers are important for assessing impacts on some springs and groundwater economic assets (bores).

A relatively low resolution, regional-scale hydrogeological conceptualisation underpins the drawdown predictions from the analytic element model (AEM). Although the hydrogeological conceptualisation used in the AEM is generally well suited for the type of regional, cumulative impact analysis undertaken for this BA, it can lead to overestimated drawdown predictions at some locations within the zone of potential hydrological change. For example, upland areas to the west of the mines lack the uppermost Quaternary alluvium and Cenozoic sediment layer (i.e. Triassic rock units outcrop), which is an important component of the original AEM conceptualisation and affects drawdown predictions in the underlying Clematis Group aquifer. To better understand the likely range of modelled drawdown predictions in areas where the original conceptualisation is not appropriate due to local hydrogeological conditions (e.g. at some spring locations west of the mines), an alternative conceptualisation was also evaluated using the AEM. An important difference between the two AEM conceptualisations is that drawdown from the mines does not propagate via the uppermost (Cenozoic sediment) layer using the alternative approach. For the ‘Springs’ landscape group, the results from these two AEM conceptualisations are compared to better understand the range of potential groundwater responses to the additional coal resource development.

Surface water

Within the zone, potential changes to surface water due to additional coal resource development were assessed using three hydrological response variables, chosen to represent low-flow, high-flow and annual flow characteristics of streamflow. Changes in these variables represent the dominant hydrological drivers due to coal resource development in the Belyando river basin.

In total there are 6285 km of streams within the zone of potential hydrological change, with impacts to about 25% of this stream length not included in the modelled surface water network (i.e. some potential stream impacts were not able to be quantified).

Zero-flow days

A zero-flow day in the BA for the Galilee subregion is one when streamflow is less than 1 ML/day from the simulated 90-year period (2013 to 2102) for that stream. The most substantial modelled surface water changes are for increases in zero-flow days, and these mostly affect the main channel of the Belyando River, and the Suttor River downstream of its junction with the Belyando River. An approximate 250 km stretch of this river network from downstream of the Native Companion Creek junction northwards to Lake Dalrymple (Burdekin Falls Dam), is *very likely* (greater than 95% chance) to experience substantial increases in the number of zero-flow days per year. These results indicate that increases in zero-flow days can aggregate from individual mines and result in cumulative impacts that extend beyond individual mine leases along the main Belyando River channel. Other smaller streams that may experience substantial increases in the number of zero-flow days are proximal to the South Galilee, China First, Alpha and Kevin’s Corner mines in the southern mining cluster. North Creek is the main stream likely to experience increases in zero-flow days in the Carmichael, China Stone and Hyde Park northern mining cluster.

Much of the Belyando and Suttor rivers that have a 5% chance of an additional 200 (or more) zero-flow days 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 rivers can flow for 200 (or more) days per year. As BAs report the maximum change in zero-flow days due to additional coal resource development, the reporting is biased towards wetter years when these maximum changes can occur.

When comparing these results to interannual variability there is a 50% chance that modelled changes are comparable around the northern mining cluster in the northern-most stretches of the Belyando River upstream of Lake Dalrymple. There is a less than 5% chance that modelled changes of increases in zero-flow days exceed interannual variability for much of the Belyando River around the northern mining cluster.

High-flow days

Changes to high-flow days due to the seven modelled coal mines are generally less substantial, and also tend to have a greater effect on the smaller tributary network within the zone, rather than the main river channels of the Belyando and Suttor. For example, the largest decreases in high-flow days per year occur on Tallarenha Creek, Lagoon Creek and Sandy Creek in the south, due to their proximity to the southern mining cluster. In the north, the main impacts are modelled for North Creek and Bully Creek. Unlike for zero-flow days, these high-flow changes do not accumulate downstream in the Belyando River, such that the Suttor River downstream of the Belyando junction is *very unlikely* to experience decreases in high-flow days of more than 10 days per year.

The regional-scale modelling shows that at most nodes the maximum change is relatively small compared to interannual variability, although there is a less than 5% chance that some nodes will experience changes comparable to interannual variability.

Annual flow

Decreases in annual flow volumes are very consistent across all reported percentiles. These reductions typically range from 5% to 20%, and affect the same tributary streams that are expected to experience reductions in high-flow days. There is only one model node, on Tallarenha Creek downstream of the proposed South Galilee Coal Mine, where reductions in annual flow volume may locally exceed 20%.

There is a less than 5% chance for the various surface water nodes that occur on Sandy Creek, North Creek and Bully Creek that the modelled annual flow changes may be considered comparable to or greater than interannual variability.

Water quality

Any change in hydrology could result in changes in groundwater and/or stream water quality; however, this was not modelled as part of the BA. A range of regulatory requirements are in place in Queensland that are intended to minimise potential water quality impacts from coal resource development.

Impacts on, and risks to, landscape classes

The impact and risk analysis investigates how hydrological changes due to additional coal resource development may affect ecosystems at a landscape scale. Estimates of overall ecosystem risk integrate understanding from the conceptual model of causal pathways, hydrological modelling and expert opinion. The strength of this approach is that it provides a measure of the relative risk and emphasises where attention should focus, and also where it should not.

The diverse natural and human-modified ecosystems in the Galilee assessment extent were classified into 31 landscape classes, which were aggregated into 11 landscape groups based on their likely response to hydrological change. Landscapes that are outside of the zone of potential hydrological change are *very unlikely* (less than 5% chance) to be impacted and include more than 100,000 km^2 of groundwater-dependent vegetation; 387,000 km of streams; 20,000 km^2 of wetlands; and 1,359 springs in the assessment extent. Receptor impact modelling was undertaken for five of the 11 landscape groups in the Galilee assessment extent.

'Springs' landscape group

Groundwater flow from springs supports endemic flora and fauna, the building of peat mounds and associated groundwater-dependent vegetation. There are three clusters of springs within the zone of potential hydrological change: the Doongmabulla Springs complex, Permian springs cluster and the Triassic springs cluster. Springs are not represented directly in the hydrological model, and drawdown is estimated by comparing model layer drawdown (for the source aquifer) at the known location of the springs. It is likely that drawdown estimates based on the original analytic element model (AEM) conceptualisation overestimate drawdown in some areas where the actual distribution and thickness of the uppermost aquifer layer is much more restricted than what is implemented in the original AEM. To account for such locally overestimated drawdown values, an alternative conceptualisation was developed and used to investigate drawdown in areas where the uppermost aquifer (Quaternary alluvium and Cenozoic sediment) does not exist as an extensive, sheet-like layer that is in direct (and hydraulically unimpeded) connection with the mining areas. These areas mainly occur to the west of the mines where the Triassic rock units of the Galilee Basin outcrop, and include the area of the Doongmabulla Springs complex. Potential ecosystem impacts for the springs were investigated using a qualitative mathematical model to evaluate ecological relationships within aquatic communities.

The Doongmabulla Springs complex includes 187 springs associated with the Carmichael River and its tributaries. The hydrogeological evidence suggests that the Clematis Group aquifers, rather than the deeper Permian aquifers, are the primary source aquifers for these springs. The original AEM conceptualisation predicts that drawdown due to additional coal resource development is *very likely to* exceed 0.2 m in the source aquifer of 181 of the 187 springs in this complex. However, estimates using the alternative conceptualisation indicate that no springs in the Doongmabulla Springs complex are predicted to experience median additional drawdown in excess of 0.2 m. Resultant changes due to pressure reductions for the Doongmabulla Springs complex may include changes in water flows and decrease in water availability to groundwater-dependent ecosystems (GDEs), although the long-term impact on the springs and spring wetlands and related organisms is unclear or contestable.

In the Permian springs cluster, it is *very likely* that at least 5 springs and *very unlikely* that more than 7 springs will experience drawdown in excess of 5 m in the upper Permian coal measures due to additional coal resource development. Resultant changes due to pressure reductions for the Permian springs cluster may include reduction in flows at the surface for all springs within the Mellaluka Springs complex, with large hydrological changes that will potentially result in the loss of ecological functioning of these springs.

Drawdown for the 12 springs in the Triassic springs cluster cannot be reliably estimated by the AEM, but results are likely to fall within the range predicted for the Clematis Group model layer.

None of the other 1353 Great Artesian Basin (GAB) springs identified in the Galilee assessment extent are in the zone of potential hydrological change.

‘Streams, GDE’ landscape group

Almost half of the streams in the zone of potential hydrological change are groundwater dependent (2801 km). Potential hydrological impacts include additional groundwater drawdown in excess of 5 m, increased low-flow days, increased low-flow spells and decreased overbank flows. Hydrological modelling, expert opinion and receptor impact modelling indicate that high flow environments are ‘at some risk of ecological and hydrological changes’ along up to 8% of groundwater-dependent streams (where quantifiable) in the zone of potential hydrological change (see Section 3.4.4.3). This includes parts of Native Companion, North and Sandy creeks and the Belyando and Carmichael rivers.

‘Streams, non-GDE’ landscape group

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. This includes most of the minor temporary streams (1028 km) in the zone of potential hydrological change that are potentially impacted but not represented in the surface water model. Potential hydrological changes include increased low-flow days and low-flow spells along up to 177 km of temporary streams in the zone. The impact analysis indicates that high-flow environments in some minor stream segments are ‘at some risk of ecological and hydrological changes’, mainly in downstream parts of the Belyando and Suttor rivers above Lake Dalrymple (see section 3.4.5.3).

‘Floodplain, terrestrial GDE’ landscape group

Most groundwater-dependent vegetation in the zone of potential hydrological change occurs on floodplains (2433 km^2 or about 64% of groundwater-dependent vegetation in the zone). It is *very unlikely* that more than 296 km^2 of groundwater-dependent vegetation on floodplains experiences more than 5 m of drawdown due to additional coal resource development. Over half of the groundwater-dependent vegetation 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. Expert-derived estimates of antecedent foliage cover, additional drawdown and decreased overbank floods indicate up to 3% of floodplain, terrestrial GDEs in the zone (where quantifiable) are ‘at some risk of ecological and hydrological changes’ (see Section 3.4.6.3). This includes floodplain areas along Alpha, North, Sandy and Tallarenha creeks, and the Belyando and Carmichael rivers.

‘Non-floodplain, terrestrial GDE’ landscape group

Approximately one-third of groundwater-dependent ecosystems in the zone (1189 km^2) rely on groundwater associated with clay plains, loamy and sandy plains, inland dunefields, or fine-grained and coarse-grained sedimentary rocks. It is *very unlikely* that more than 68 km^2 (or 2% of groundwater-dependent vegetation in the zone) experiences more than 5 m of drawdown due to additional coal resource development. This landscape group is located outside of alluvial river and creek flats and is therefore unaffected by changes to surface water flow regimes. Up to 5% of groundwater-dependent ecosystems outside of floodplains or wetlands in the zone are ‘at some risk of ecological and hydrological changes’, particularly near the proposed mines where additional drawdown is greatest (see Section 3.4.7.3).

Impacts on, and risks to, water-dependent assets

Ecological assets

The Galilee subregion has 3982 ecological assets in the assessment extent. The location of assets, including potential distribution of species, was determined at a single point-in-time when the asset register was established. The 3741 ecological assets outside the zone are considered to be *very unlikely* (less than a 5% chance) to be impacted due to modelled additional coal resource development in the Galilee subregion.

Of the 241 ecological assets in the zone, 148 are identified as being ‘more at risk of hydrological changes’ because all or part of the area where these assets occur is within one or more of the potentially impacted landscape groups and there is a greater than 50% chance of the modelled hydrological change exceeding the defined threshold (see Section 3.5.2.1). These assets include:

- 106 GDEs
- habitat (potential species distribution) for 12 threatened species listed under the Commonwealth’s *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)
- 2 EPBC Act-listed threatened ecological communities
- 7 regional ecosystems listed under Queensland’s *Nature Conservation Act 1992*
- 4 parks and reserves.

A concentration of ecological assets occurs in the ‘Springs’ landscape group. Although the 200 springs in this landscape group occupy less than 1% of the zone of potential hydrological change, 48 ecological assets (20% of all ecological assets in the zone) intersect with it, including 16 that are confined entirely to the zone. Doongmabulla Springs complex is the location where most of these assets occur, and they include the springs themselves, the Doongmabulla Mound Springs Nature Refuge, habitat (potential species distribution) of an EPBC Act-listed threatened ecological community, ‘The community of native species dependent on natural discharge of groundwater from the Great Artesian Basin', and habitat (potential species distribution) of two EPBC Act-listed threatened plant species (blue devil (*Eryngium fontanum*) and salt pipewort (*Eriocaulon carsonii*)).

Economic assets

There are 129 economic water-dependent assets within the Galilee assessment extent, all of which are classed as either water access rights or basic water rights (stock and domestic). Of these, 96 are associated with groundwater management areas and 33 with surface water management areas. Each asset consists of a variable number of asset 'elements', which are typically individual groundwater bores or surface water extraction points.

The hydrological changes due to the seven coal mines modelled for the BA of the Galilee subregion will potentially impact six of these economic water-dependent assets, comprising five groundwater assets and one surface water asset. The surface water asset is a basic water right under the *Water Plan (Burdekin Basin) 2007*.

Three of the groundwater economic assets potentially impacted due to additional coal resource development are associated with the Clematis Group aquifer, and are managed as part of the *Water Plan (Great Artesian Basin) 2006* (although this plan was superseded in September 2017). Of the bores that source water from the Clematis Group aquifer near Jericho, the maximum amount of drawdown is less than 1 m for all modelling results. Potential impacts for many of the bores near Alpha cannot be quantified due to limitations of the groundwater modelling approach, and thus remain a key knowledge gap.

There are about 105 bores within the zone of potential hydrological change that are interpreted to source water from the near-surface unconfined aquifer (Quaternary alluvium and other Cenozoic sediments) that were not listed as a BA economic asset (see Section 3.5.3.4). However, 35 of these are either in the 'mine exclusion zone', company owned or 'abandoned or destroyed'. Of the remaining bores analysed, it is *very likely* that seven will experience at least 0.2 m of drawdown, and *very unlikely* that more than 52 bores will be affected by this level of drawdown. Drawdowns of greater than 2 m are modelled to affect between 2 and 13 bores (at the 5th and 95th percentiles respectively).

A further 31 bores in the central-eastern Galilee subregion source water from the Clematis Group aquifer but are not in the water-dependent asset register. The maximum modelled drawdown is about 1 m and well below the 5 m threshold legislated in Queensland for 'make good' provisions for consolidated rock aquifers. There are also 34 non-company bores within the zone that tap the upper Permian coal measures, the main coal mining (and dewatering) target in the Galilee Basin. Based on results from the AEM for the Galilee subregion most of these Permian-sourced bores are predicted to experience drawdowns in excess of 20 m.

Sociocultural assets

Of the 151 sociocultural assets in the Galilee assessment extent, only four partially intersect with the zone of potential hydrological change. Three of these assets were nominated from the Register of the National Estate, including Doongmabulla Springs (natural indicative place), Lake Buchanan and catchment (natural registered place), and the Old Bowen Downs Road (historic indicative place). Consultation with several local Aboriginal groups in the Galilee subregion identified 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 Indigenous assets it was not possible to determine if they occur within the zone of potential hydrological change.

Future monitoring

Post-assessment monitoring is important to test and validate (or not) the risk predictions of the assessment. At the highest level, monitoring effort should reflect the risk predictions, and focus the effort where the changes are expected to be the largest (i.e. areas concentrated around main proposed coal resource developments). However, it is important to place some monitoring effort at locations with lower risk predictions to confirm the range of potential impacts and identify unexpected outcomes.

Future surface water monitoring should focus on streams that pass near the additional coal resource developments, where the predicted changes suggest adverse effects on subregion assets. These streams include: Native Companion, North, Sandy, Alpha and Tallarenha creeks, and the Belyando and Carmichael rivers.

Future groundwater monitoring could focus on confined parts of Clematis Group aquifer and Dunda beds, in particular, up-hydraulic gradient (west and south) of the Doongmabulla Springs complex. Monitoring of Cenozoic aquifers in key areas of the Belyando River floodplain (e.g. near Alpha) would assist in better understanding the degree of drawdown in the near-surface aquifer and the potential connectivity and flux with deeper aquifers.

Gaps and opportunities

The BA for the Galilee subregion has been undertaken using the best available information within the constraints and timing of the Bioregional Assessment Programme. The Assessment focuses on regional-scale cumulative impacts of coal resource development, and provides an important framework for future environmental impact assessments of new coal mines or CSG developments and the local geological, hydrogeological and hydrological modelling and analyses that support them. There are also opportunities to tailor the BA modelling results, for example:

- to consider alternative CRDP futures with a different selection of mining and CSG developments
- to further refine the Galilee Basin hydrogeological (GBH) model to better understand water balance and fluxes between different aquifer systems, for testing different CRDPs and for future management of water resources in the Galilee subregion.

There are also specific opportunities for further improvement to follow on from the work completed for this BA. This is of particular importance for the greenfield Galilee subregion where there is no history, data or information for baseline coal resource development (see Section 3.7.4).

The full suite of information, including information for individual assets, is provided at www.bioregionalassessments.gov.au. Users can explore detailed results for the Galilee subregion using a map-based interface in the BA Explorer, available at www.bioregionalassessments.gov.au/explorer/GAL.

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- Technical Assurance Reference Group: Chaired by Peter Baker (Principal Science Advisor, Department of the Environment and Energy), this group comprises officials from the NSW, Queensland, South Australian and Victorian governments
- Independent reviewers: National Centre for Groundwater Research and Training, Andrew Boulton (University of New England) and Glenn Walker.

Introduction

The Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) was established to provide advice to the federal Minister for the Environment on potential water-related impacts of coal seam gas (CSG) and large coal mining developments (IESC, 2015).

Bioregional assessments (BAs) are one of the key mechanisms to assist the IESC in developing this advice so that it is based on best available science and independent expert knowledge. Importantly, technical products from BAs are also expected to be made available to the public, providing the opportunity for all other interested parties, including government regulators, industry, community and the general public, to draw from a single set of accessible information. A BA is a scientific analysis, providing a baseline level of information on the ecology, hydrology, geology and hydrogeology of a bioregion with explicit assessment of the potential impacts of CSG and coal mining development on water resources.

The IESC has been involved in the development of *Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources* (the BA methodology; Barrett et al., 2013) and has endorsed it. The BA methodology specifies how BAs should be undertaken. Broadly, a BA comprises five components of activity, as illustrated in Figure 1. Each BA is different, due in part to regional differences, but also in response to the availability of data, information and fit-for-purpose models. Where differences occur, these are recorded, judgments exercised on what can be achieved, and an explicit record is made of the confidence in the scientific advice produced from the BA.

The Bioregional Assessment Programme

The Bioregional Assessment Programme is a collaboration between the Department of the Environment and Energy, the Bureau of Meteorology, CSIRO and Geoscience Australia. Other technical expertise, such as from state governments or universities, is also drawn on as required. For example, natural resource management groups and catchment management authorities identify assets that the community values by providing the list of water-dependent assets, a key input.

The Technical Programme, part of the Bioregional Assessment Programme, has undertaken BAs for the following bioregions and subregions (see http://www.bioregionalassessments.gov.au/assessments for a map and further information):

- the Galilee, Cooper, Pedirka and Arckaringa subregions, within the Lake Eyre Basin bioregion
- the Maranoa-Balonne-Condamine, Gwydir, Namoi and Central West subregions, within the Northern Inland Catchments bioregion
- the Clarence-Moreton bioregion
- the Hunter and Gloucester subregions, within the Northern Sydney Basin bioregion

- the Sydney Basin bioregion
- the Gippsland Basin bioregion.

Technical products (described in a later section) will progressively be delivered throughout the Programme.

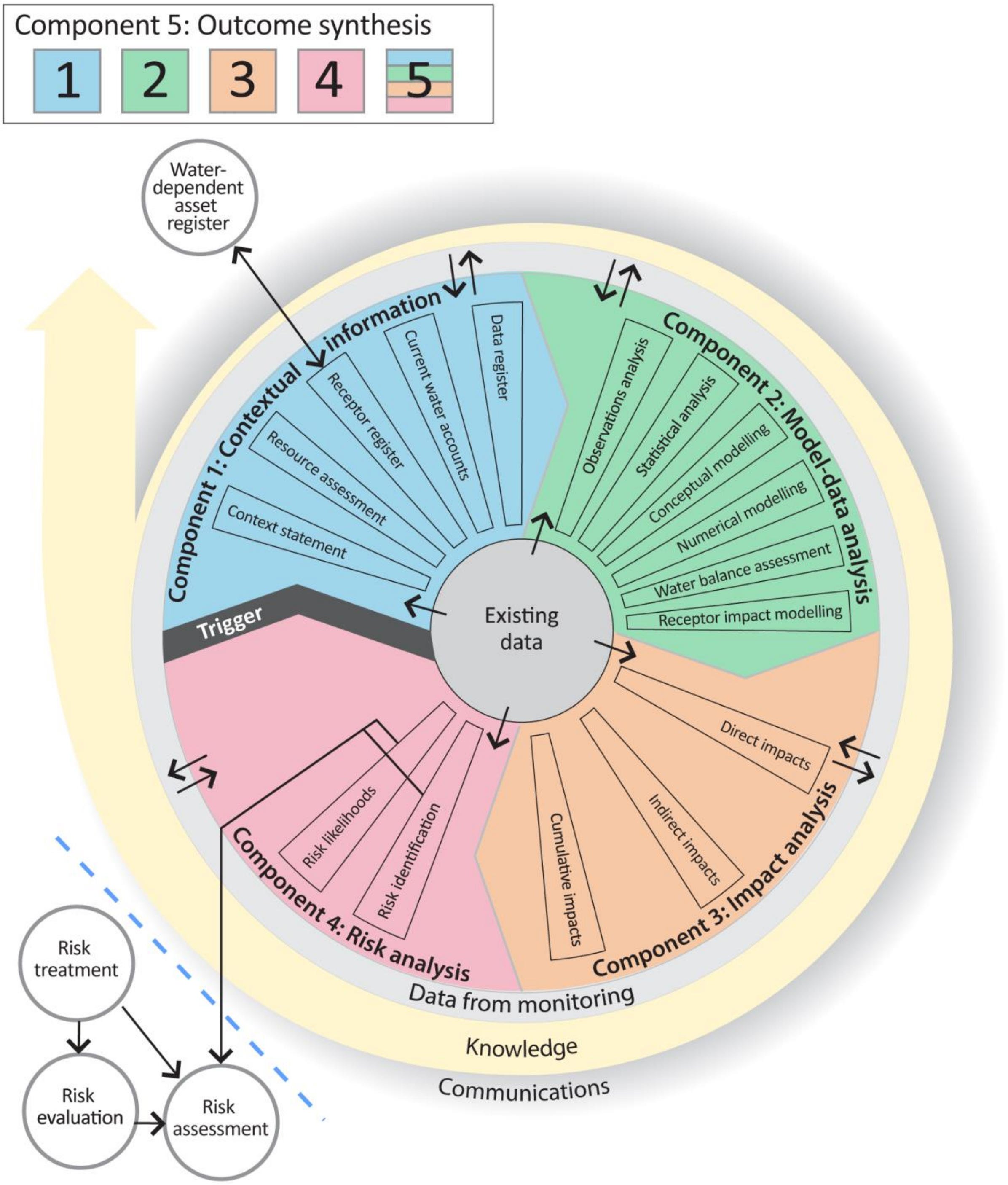

Figure 1 Schematic diagram of the bioregional assessment methodology

The methodology comprises five components, each delivering information into the bioregional assessment and building on prior components, thereby contributing to the accumulation of scientific knowledge. The small grey circles indicate activities external to the bioregional assessment. Risk identification and risk likelihoods are conducted within a bioregional assessment (as part of Component 4) and may contribute activities undertaken externally, such as risk evaluation, risk assessment and risk treatment. Source: Figure 1 in Barrett et al. (2013), © Commonwealth of Australia

Methodologies

The overall scientific and intellectual basis of the BAs is provided in the BA methodology (Barrett et al., 2013). Additional guidance is required, however, about how to apply the BA methodology to a range of subregions and bioregions. To this end, the teams undertaking the BAs have developed and documented detailed scientific submethodologies (Table 1), in the first instance, to support the consistency of their work across the BAs and, secondly, to open the approach to scrutiny, criticism and improvement through review and publication. In some instances, methodologies applied in a particular BA may differ from what is documented in the submethodologies.

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

Table 1 Methodologies

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

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

Technical products

The outputs of the BAs include a suite of technical products presenting information about the ecology, hydrology, hydrogeology and geology of a bioregion and the potential impacts of CSG and coal mining developments on water resources, both above and below ground. Importantly, these technical products are available to the public, providing the opportunity for all interested parties, including community, industry and government regulators, to draw from a single set of accessible information when considering CSG and large coal mining developments in a particular area.

The information included in the technical products is specified in the BA methodology. Figure 2 shows the relationship of the technical products to BA components and submethodologies. Table 2 lists the content provided in the technical products, with cross-references to the part of the BA methodology that specifies it. The red outlines in both Figure 2 and Table 2 indicate the information included in this technical product.

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

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

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

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

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

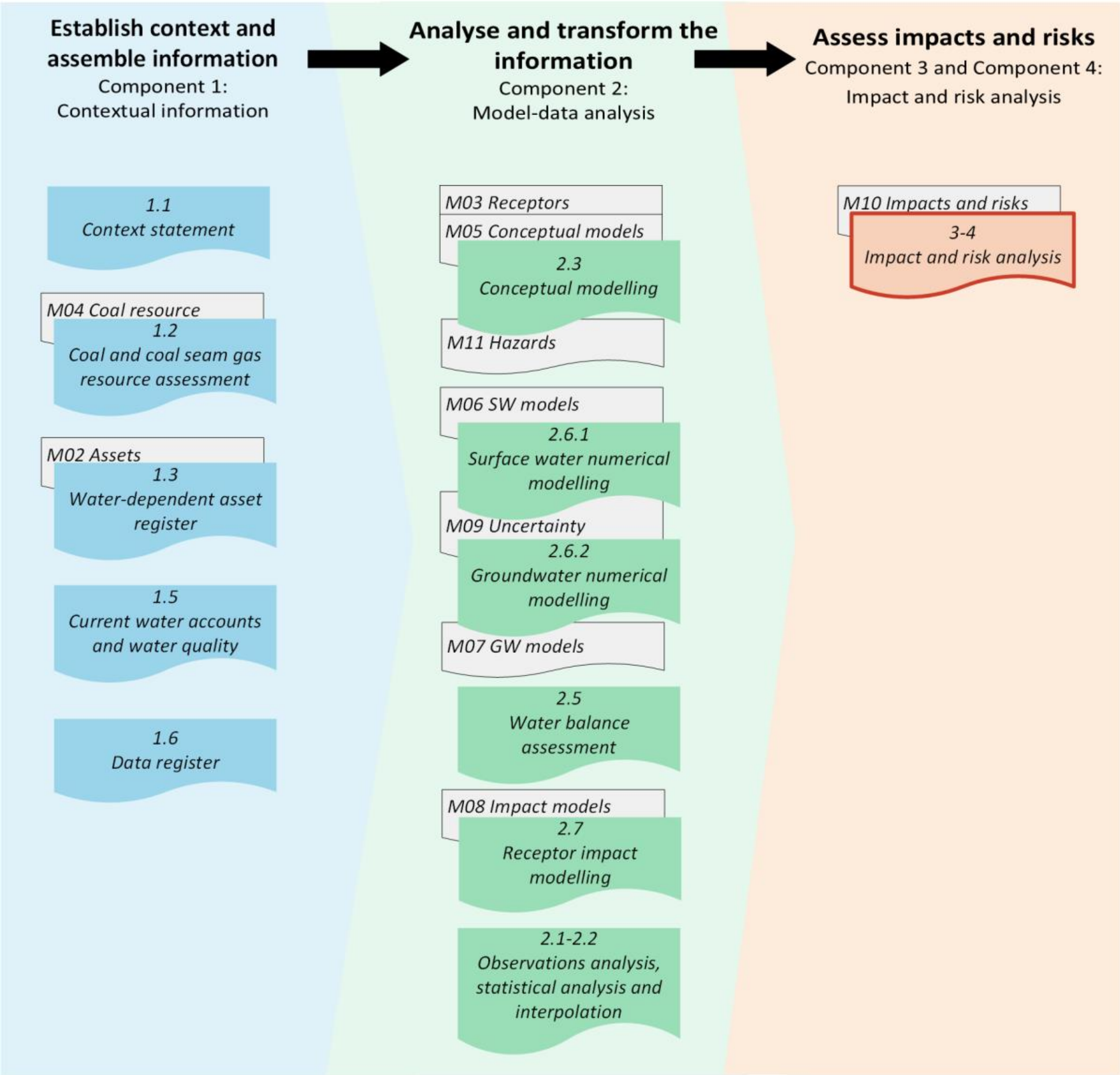

Figure 2 Technical products and submethodologies associated with each component of a bioregional assessment

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

Table 2 Technical products delivered for the Galilee subregion

For each subregion in the Lake Eyre Basin Bioregional Assessment, technical products are delivered online at http://www.bioregionalassessments.gov.au, as indicated in the 'Type' column[a]. Other products – such as datasets, metadata, data visualisation and factsheets – are provided online. There is no product 1.4. Originally this product was going to describe the receptor register and application of landscape classes as per Section 3.5 of the BA methodology, but this information is now included in product 2.3 (conceptual modelling) and used in product 2.6.1 (surface water numerical modelling) and product 2.6.2 (groundwater numerical modelling). There is no product 2.4. Originally this product was going to include two- and three-dimensional representations as per Section 4.2 of the BA methodology, but these are instead included in products such as product 2.3 (conceptual modelling), product 2.6.1 (surface water numerical modelling) and product 2.6.2 (groundwater numerical modelling).

Component	Product code	Title	Section in the BA methodology[b]	Type[a]
Component 1: Contextual information for the Galilee subregion	1.1	Context statement	2.5.1.1, 3.2	PDF, HTML
	1.2	Coal and coal seam gas resource assessment	2.5.1.2, 3.3	PDF, HTML
	1.3	Description of the water-dependent asset register	2.5.1.3, 3.4	PDF, HTML, register
	1.5	Current water accounts and water quality	2.5.1.5	PDF, HTML
	1.6	Data register	2.5.1.6	Register
Component 2: Model-data analysis for the Galilee subregion	2.1-2.2	Observations analysis, statistical analysis and interpolation	2.5.2.1, 2.5.2.2	PDF, HTML
	2.3	Conceptual modelling	2.5.2.3, 4.3	PDF, HTML
	2.5	Water balance assessment	2.5.2.4	PDF, HTML
	2.6.1	Surface water numerical modelling	4.4	PDF, HTML
	2.6.2	Groundwater numerical modelling	4.4	PDF, HTML
	2.7	Receptor impact modelling	2.5.2.6, 4.5	PDF, HTML
Component 3 and Component 4: Impact and risk analysis for the Galilee subregion	3-4	Impact and risk analysis	5.2.1, 2.5.4, 5.3	PDF, HTML
Component 5: Outcome synthesis for the Galilee subregion	5	Outcome synthesis	2.5.5	PDF, HTML

[a]The types of products are as follows:

- 'PDF' indicates a PDF document that is developed by the Lake Eyre Basin Bioregional Assessment using the structure, standards and format specified by the Programme.
- 'HTML' indicates the same content as in the PDF document, but delivered as webpages.
- 'Register' indicates controlled lists that are delivered using a variety of formats as appropriate.

[b]*Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources* (Barrett et al., 2013)

About this technical product

The following notes are relevant only for this technical product.

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

References

Barrett DJ, Couch CA, Metcalfe DJ, Lytton L, Adhikary DP and Schmidt RK (2013) Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources. A report prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development through the Department of the Environment. Department of the Environment, Australia. Viewed 14 June 2018, http://data.bioregionalassessments.gov.au/submethodology/bioregional-assessment-methodology.

IESC (2015) Information guidelines for the Independent Expert Scientific Committee advice on coal seam gas and large coal mining development proposals. Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development, Australia. Viewed 14 June 2018, http://www.iesc.environment.gov.au/publications/information-guidelines-independent-expert-scientific-committee-advice-coal-seam-gas.

3 Impact and risk analysis for the Galilee subregion

The impact and risk analysis is the key output of a bioregional assessment (BA). This product presents potential impacts of coal resource development on water resources and water-dependent assets in the Galilee subregion. Risks are analysed by assessing the magnitude and likelihood of these potential impacts.

The impact and risk analysis (Component 3 and Component 4) builds on the contextual information (Component 1) and knowledge from the model-data analysis (Component 2).

In the impact and risk analysis:

- A zone of potential hydrological change is determined using both the surface water and groundwater numerical hydrological modelling results (from product 2.6.1 (surface water numerical modelling) and product 2.6.2 (groundwater numerical modelling)).
- The zone of potential hydrological change is overlain with the extent of the landscape classes (product 2.3 (conceptual modelling)) and water-dependent assets (product 1.3 (description of water-dependent asset register)) to identify those ecosystems and assets that might be subject to hydrological change.
- Potential impacts to ecological assets are considered via:
  - qualitative mathematical models, which predict (at a high level) how components of specific ecosystems (represented by landscape classes) might respond to changes in hydrology
  - quantitative receptor impact models (where applicable), which numerically translate the changes in hydrology into predicted changes in components of ecosystems.
- Potential impacts to economic and sociocultural assets are considered via changes to water availability and accessibility.

The product then describes potential impacts for those coal resource developments that cannot be modelled and concludes with key findings, knowledge gaps, how to use the assessment and how to build on this assessment.

3.1 Overview

Summary

The proposed future development of black coal resources in central Queensland's Galilee Basin will potentially result in impacts on and risks to some water resources and water-dependent assets. Within the broader context of the bioregional assessment (BA) for the Galilee subregion, this product presents the main findings of the targeted BA impact and risk analysis. These efforts are focused mainly on an area near the central-eastern boundary of the subregion where the initial phase of coal mining is planned to occur. This multi-disciplinary investigation has been carried out to evaluate the possible regional-scale cumulative impacts on surface water and groundwater resources, and the potential risks posed to the many ecological, economic and sociocultural assets that rely on access to these water supplies.

The Galilee subregion encompasses a large swathe of outback central Queensland, covering an area slightly larger than the state of Victoria. The subregion boundary coincides with the geological Galilee Basin, although much of this basin is now buried by younger sedimentary cover. There have never previously been any commercially producing coal resource developments in the Galilee Basin. However, seven large-scale new coal mines are planned to begin operations over the next decade or so, targeting the central-eastern basin where the coal resources are relatively close to surface. Consequently, the key outcomes of this BA represent the first attempt to understand and quantify the potential combined effects of multiple coal resource developments on the extent, magnitude and timing of regional-scale hydrological impacts.

The Galilee subregion is ecologically diverse, supporting distinctive terrestrial and aquatic ecosystems including some species and communities that are of national and regional significance (e.g. it hosts seven ecological communities listed under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)). Six major surface water catchments cover the Galilee subregion, and around two-thirds of the total drainage area flows inland towards Lake Eyre as part of either the Cooper Creek – Bulloo river basin or the Diamantina river basin. The subregion's semi-arid to arid climate means that most streams are intermittent or ephemeral, with the timing and magnitude of streamflow commonly varying between the main river basins. Groundwater-fed springs provide important habitat and water supplies for many species, with most springs in the subregion sourced from aquifers of the Great Artesian Basin. There is a high degree of species endemism within many spring complexes of the Galilee subregion.

The area is sparsely populated, with fewer than 20,000 inhabitants mainly living in country towns such as Charleville, Blackall and Barcaldine. Most of the land within the subregion is used for dryland agriculture, mainly livestock grazing on native vegetation across large pastoral land holdings. There are several areas reserved for nature conservation, including the Diamantina and White Mountains national parks, and the Bimblebox Nature Refuge.

Aside from pastoralism there are no other large-scale industrial activities in the subregion, although minor gas production occurs from the Gilmore Gas Field about 100 km south-west of Blackall, targeting a conventional hydrocarbon reservoir in the deeper geological Adavale Basin (underlying the Galilee Basin).

The impact and risk analysis for the BA for the Galilee subregion focuses mainly on the seven most advanced coal mining proposals identified in the coal resource development pathway (CRDP). From south to north, these are: South Galilee, China First, Alpha, Kevin's Corner, Carmichael, China Stone and Hyde Park. The CRDP in the Galilee subregion also includes seven other less advanced coal mining projects and three pilot/exploration stage coal seam gas (CSG) developments. However, none of these projects could be evaluated through modelling in this BA due to lack of required data and information. Qualitative analysis of potential impacts of the non-modelled coal resource developments is provided in Section 3.6.

The cumulative hydrological changes due to the seven modelled coal mines were previously reported in companion products for the Galilee subregion on surface water and groundwater numerical modelling, which focused on quantifying changes in water quantity and availability. The probabilistic approach adopted for the BA modelling has enabled development of a *zone of potential hydrological change* in this product, outside of which water resources and water-dependent assets in the Galilee assessment extent are *very unlikely* (less than 5% chance) to be impacted (i.e. they are 'ruled out' of the analysis). Consequently, this assessment is focused on the zone of potential hydrological change, and is structured around the three broad system components that are in scope for the BA, namely the impacts on, and risks to, the hydrological systems, ecosystems (characterised in BAs using the landscape classification approach), and the relevant ecological, economic and sociocultural assets.

3.1.1 Galilee subregion

The Galilee subregion covers about 248,000 km^2 of central Queensland (Figure 3) and, for BA purposes, forms part of the larger Lake Eyre Basin bioregion. The Galilee subregion is defined by the mapped extent of the geological Galilee Basin, a large coal-bearing basin containing rocks of Late Carboniferous to mid Triassic age (i.e. deposited from about 323 to 238 million years ago). The basin's stratigraphic units comprise a mixed assemblage of clastic sedimentary rocks with thick successions of predominantly sandstone, mudstone and coal. The maximum thickness of the Galilee Basin strata is about 2800 m, with the thickest sequences occurring in structurally controlled depositional centres such as the Lovelle Depression and Koburra Trough (Figure 3).

Most of the Galilee Basin is now buried below younger sedimentary rocks associated either with the Jurassic to Cretaceous Eromanga Basin, the Cenozoic Lake Eyre Basin, or alluvial sediments deposited in modern rivers and lakes. The depth to the uppermost coal-bearing sequences in the Galilee Basin is commonly 500 to 1500 m (below surface) in most of the western, central and southern basin. These depths largely preclude such areas of the subregion from any future coal mining activity (although they may be prospective for future coal seam gas (CSG) development). However, near the basin's eastern margin an approximately 600 km long and up to 80 km wide corridor of older rocks of the Galilee Basin occurs either at or near surface. Although commercial coal extraction has not yet taken place (as of mid-2018), it is within this part of the Galilee subregion where most attention has focused on the potential for mining the basin's world-class resources of high volatile, low rank (thermal) black coal. The CRDP for the Galilee subregion, which was used to focus this BA, is described in Section 3.1.2.

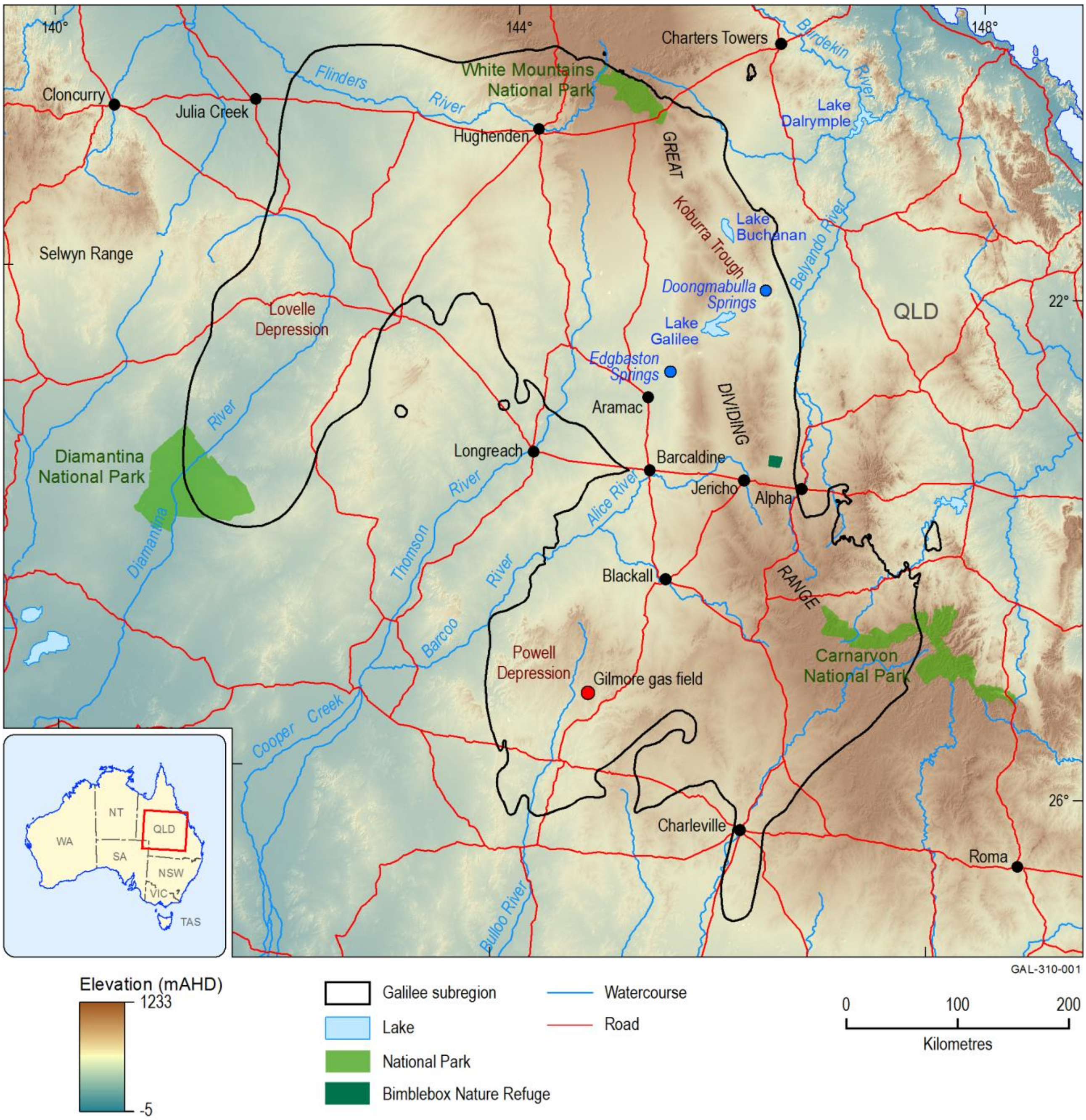

Figure 3 The Galilee subregion in central Queensland

The background data shown on this map depict variations in topography as defined using a smoothed digital elevation model (DEM) which has a resolution of 1 arc second. The topography is shown in metres relative to the Australian Height Datum (mAHD). The most elevated parts of the subregion are variously shaded brown, and these correspond with the area of the Great Dividing Range. Not all national parks in the subregion are depicted.
Data: Bioregional Assessment Programme (Dataset 1, Dataset 3); Geoscience Australia (Dataset 2); Bureau of Meteorology (Dataset 4)

Figure 4 Flat terrain and semi-arid vegetation in the central-eastern Galilee Basin

Credit: John Thompson, Queensland Government

Landscapes in the western and central parts of the Galilee subregion consist mainly of flat-lying to gently undulating terrain, typically covered by dry grassy plains of Mitchell grass (*Astrebla*) and various species of tussocks. Further eastwards, these plains give way to the more elevated uplands of the Great Dividing Range, the crest of which transects the subregion near its eastern boundary. The upland areas have sparse to moderate cover of remnant native vegetation, typically eucalypt woodland with grassy understorey. Topographic elevation across the Galilee subregion varies from lows of about 150 m (relative to the Australian Height Datum, mAHD), in the north-west near the floodplains of the Diamantina River, up to nearly 1000 mAHD in the Carnarvon National Park in the south-east. Typical landscapes of the Galilee subregion are shown in Figure 4 and Figure 5.

Most of the subregion has a semi-arid to arid climate, with variable annual rainfall commonly 300 to 600 mm/year, and very high rates of evapotranspiration (2200 to 2900 mm/year). Rainfall patterns typically diminish westwards across the subregion (i.e. inland away from the coastline), with the highest annual rainfall totals recorded in the more elevated terrain around the Great Dividing Range in the north-east and south-east of the subregion. The winter months are typically the coldest and driest. In contrast, summer is when most rainfall occurs, and daytime summer temperatures commonly exceed 35° C, with overnight minima above 20° C.

Figure 5 Typical terrain of the central-eastern Galilee Basin, on Doongmabulla Station

Credit: Jeremy Drimer, Queensland Herbarium

The Galilee subregion includes the headwaters of six major surface water catchments (Figure 6). Nearly two-thirds of the subregion's surface water drainages flow inland towards Lake Eyre, either as part of the Cooper Creek – Bulloo river basin or the Diamantina river basin. The main streams within these river basins include the Diamantina, Thomson, Alice and Barcoo rivers, which mostly flow out of the subregion towards the south-west. The other main river basins in the Galilee subregion are the Flinders (which covers about 14% of the subregion's area), Warrego (12%), Burdekin (8%) and Fitzroy (3%). Streamflow discharge and duration vary significantly within and between most of these river basins. Many streams in the subregion are ephemeral, with a strong seasonal (summer) influence on times of peak flow. In addition to the main river systems, there are two prominent semi-saline playa lakes in the eastern highlands of the Galilee subregion, lakes Buchanan (117 km^2) and Galilee (257 km^2). These lakes occur within closed, internally draining catchments. They are listed formally in *A directory of important wetlands in Australia* (Environment Australia, 2001) and are critical habitat sites for many waterbirds, including some species listed under the EPBC Act.

Groundwater systems are an important source of water for ecological, economic and sociocultural water-dependent assets within the Galilee subregion. This reflects the semi-arid to arid climate, the sporadic and generally low annual rainfall, and the intermittent flow within most surface water systems. The main groundwater systems across most of the subregion are the aquifers of the

Great Artesian Basin (GAB), primarily hosted within the Eromanga Basin and thus overlying (i.e. not in direct contact with) the Permian rock layers targeted for coal mine development. These groundwater resources include the renowned GAB aquifers of the Cadna-owie Formation, the Hooray Sandstone and the Hutton Sandstone (Ransley et al., 2015). In areas of the Galilee subregion where the Eromanga Basin does not occur, several aquifers of the Galilee Basin are locally important resources for groundwater supply, including the Triassic Clematis Group and Warang Sandstone. In some areas, local groundwater flow systems are also hosted in Cenozoic alluvial sediments, including paleovalleys (i.e. ancient rivers), although these aquifers are typically much thinner and more areally restricted than the deeper regional groundwater flow systems of the Eromanga and Galilee basins.

The Galilee subregion is ecologically diverse, supporting a large number of ecosystems. This variety reflects the subregion’s large surface area, variable geology and soil types, and climatic (e.g. temperature and rainfall) gradients with strong seasonal influences. There are characteristic terrestrial and aquatic species and communities across the subregion, including examples that are recognised as being of both national and regional significance. For example, there are seven ecological communities listed under the EPBC Act, including ‘The community of native species dependent on natural discharge of groundwater from the Great Artesian Basin’. A detailed summary of the subregion’s ecological assets and its main ecosystems is presented, respectively, in companion product 1.3 (Sparrow et al., 2015) and companion product 2.3 (Evans et al., 2018) for the Galilee subregion.

Groundwater-fed springs are important ecological systems in the Galilee subregion. Numerous spring complexes are known, including several that are nationally important and protected by various Queensland and Australian Government legislation. Most of these springs are sourced from discharge of regional groundwater systems of the GAB, such as the Barcaldine springs supergroup (Fensham et al., 2016), which has over 50 spring complexes scattered across a north-trending zone to the east of Barcaldine, and west and south-west of the playa lakes, Buchanan and Galilee. There are also several spring systems within the central-eastern part of the Galilee subregion, including the EPBC Act-listed Doongmabulla Springs complex on the Carmichael River, and the nearby Mellaluka Springs complex. There is a high level of species endemism in many of the spring complexes within the Galilee subregion, with biota adapted to relatively narrow environmental conditions (i.e. they have low resilience and resistance to environmental change).

The Galilee subregion is sparsely populated, and less than 20,000 people are estimated to reside across its vast expanse. Most residents (about 75%) live in small- to medium-size country towns, with Charleville (population about 3500) the largest populated place, situated near the southern boundary of the subregion. Other regional population centres in the Galilee subregion include Barcaldine and Blackall in the central area, and Hughenden in the north. Several small towns occur near to the main proposed area of coal mining development in the central-eastern Galilee, such as Alpha and Jericho (Figure 3).

According to the Australian Land Use and Management Classification scheme (ABARES, 2016), over 90% of the subregion is used for dryland farming practices, predominantly livestock (sheep and cattle) grazing on natural vegetation. Many large pastoral holdings exist within the Galilee subregion, on both freehold and leasehold lands. Access to reliable and good quality groundwater resources is particularly important to sustain the region's pastoral activities, given the intermittent flow of most surface water systems and the generally low annual rainfall. Minor land uses include nature conservation (e.g. the Diamantina, White Mountains and Carnarvon national parks, and the Bimblebox Nature Refuge) and some production forestry in the south-east. There are currently no commercially producing coal mines or CSG fields within the subregion, although there is one conventional gas field in production. This is the Gilmore Gas Field, which extracts gas from a conventional hydrocarbon reservoir within the Adavale Basin, which is geologically older and stratigraphically underlies the Galilee Basin (and thus is not within the scope of this BA).

The outcomes of the BA impact and risk analysis for the Galilee subregion are presented in this product, representing the culmination of an extensive, multi-component and multi-disciplinary scientific investigation. This regional-scale assessment has particularly focused on better understanding of how the likely hydrological changes associated with proposed coal resource development can impact ecological, economic and sociocultural water-dependent assets. Based largely on compilation and synthesis of existing information, a more detailed description of the geography (physical, human and climate systems), geology, groundwater systems, surface water, surface water – groundwater interactions and ecology is in companion product 1.1 for the Galilee subregion (Evans et al., 2014). The conceptual modelling that underpins this impact and risk analysis, including a comprehensive landscape classification developed for the BA and a summary of the CRDP for the Galilee subregion, is presented in companion product 2.3 (Evans et al., 2018). The impact and risk analysis also draws heavily from other companion products developed for this BA, particularly the quantitative hydrological and receptor impact modelling products (see companion product 2.6.1 (Karim et al., 2018), companion product 2.6.2 (Peeters et al., 2018) and companion product 2.7 (Ickowicz et al., 2018) for further information).

3.1.2 Scope and context

The objective of the Bioregional Assessment Programme is to understand and predict regional-scale cumulative impacts on water resources and water-dependent assets caused by coal resource developments in Australia's major coal-bearing sedimentary basins. In particular, the assessments identify areas where water resources and water-dependent assets are *very unlikely* to be impacted (with a less than 5% chance), or are potentially impacted. Governments, industry and the community can then focus on these areas that are potentially impacted and apply further local-scale modelling when making regulatory, water management and planning decisions.

This impact and risk analysis considers only biophysical consequences, such as changes in hydrology or ecology; fully evaluating consequences requires value judgments and non-scientific information that is beyond the scope of BAs. A full risk assessment (with risk evaluation and risk treatment) was not conducted as part of BAs, although the information presented in this product could be used to provide critical input into such a broader assessment in the future.

The purpose of this section is to highlight important design choices that have steered the direction of the BA for the Galilee subregion and culminated in this impact and risk analysis. The following six themes are briefly covered:

- choice of modelled futures
- focus on water quantity and availability

- assessment of regional-scale cumulative developments
- focus on predictive uncertainty
- a landscape classification
- ruling out potential impacts.

Further details about the design choices are provided in companion submethodology M10 (as listed in Table 1) for analysing impacts and risks (Henderson et al., 2018).

3.1.2.1 Choice of modelled futures

A BA is a regional analysis that compares two potential futures of coal resource development. In BAs, the term 'coal resource development' specifically includes coal mining (both open-cut and underground) as well as CSG extraction. Other forms of coal-related development activity, such as underground coal gasification, were not within the scope of the assessment.

The two futures considered in the BA for the Galilee subregion are:

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

The difference in results between CRDP and baseline is the change that is primarily reported in a BA. This change is due to the *additional coal resource development* – all coal mines and CSG fields (including expansions of baseline operations) that are expected to begin commercial production after December 2012. Importantly, the focus of the BA is on the suite of coal resource developments defined for both the baseline and the CRDP, based on the development time frames (i.e. mining schedules) identified when these two futures were 'locked-in'. Once the complete suite of operations and time frames are defined for the BA the CRDP is not revisited or changed. Likewise, there are no separate, stand-alone modelling runs done to evaluate impacts of individual developments (i.e. the focus is always on the suite of operations at the regional-scale of the BA, rather than on any individual mine or CSG development).

As documented in companion product 1.2 for the Galilee subregion (Lewis et al., 2014) there were no coal mines or CSG fields in commercial production as of December 2012. Consequently, for the purposes of the BA for the Galilee subregion, the modelled baseline does not include any coal resource developments.

In contrast to the baseline, the CRDP for the Galilee subregion has 17 proposed new coal and CSG resource development projects (Table 3). Most of the developments in the CRDP are for new large-scale coal mines that target thermal coal resources hosted within upper Permian strata, such as the Betts Creek beds, Bandanna Formation and the Colinlea Sandstone (companion product 1.1 for the Galilee subregion (Evans et al., 2014)). These proposed coal mines mainly occur close to the northern and eastern margins of the geological Galilee Basin (Figure 6), where the coal-bearing Permian rock layers are relatively close to the surface (i.e. generally within several hundred metres), and are thus amenable to future mining development.

On the basis of information available as of December 2014, the proposed coal mining operations in the Galilee CRDP are:

- three open-cut coal mines (Alpha, Hyde Park and Blackall)
- two underground coal mines (Alpha West and Hughenden)
- five combined open-cut and underground coal mining operations (Carmichael, China First, China Stone, Kevin's Corner and South Galilee)
- four coal mines of currently uncertain type due to lack of relevant information (Clyde Park, Milray, Pentland and West Pentland –potentially these may be developed as combined open-cut and underground mining operations).

There are also three early-stage CSG projects included in the CRDP (Glenaras Gas Project, Gunn Project and Blue Energy's CSG project in Exploration Permit for Petroleum (EPP) 813). The locations of the proposed coal mines and CSG developments in the CRDP are shown in Figure 6. Further information about each project in the CRDP, including reasons for their inclusion, is in companion product 2.3 for the Galilee subregion (Evans et al., 2018).

Table 3 Coal resource development pathway for the Galilee subregion

Coal mine – modelled	Coal mine – not modelled	CSG 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	

Of the 17 coal resource developments in the CRDP, there are seven coal mines that were considered by the Assessment team to have sufficient information available (at the time when the CRDP was determined in December 2014) to be quantitatively assessed for this BA through hydrological modelling. These proposed coal mines are: Alpha, Carmichael, China First, China Stone, Hyde Park, Kevin's Corner and South Galilee. These are the most advanced mining developments in the Galilee subregion in terms of progressing through the various environmental and mining-related approvals processes that apply under relevant Queensland and Australian Government legislation. Most of these proposed mines have previously undertaken planning and development studies to determine optimal mining and production methods, and much of this information is publicly available as part of their respective environmental impact statements. Consequently, these seven proposed coal mines are the main focus of the quantitative impact and risk analysis undertaken for the Galilee subregion (as reported in this product).

The remaining seven coal mining developments and the three proposed CSG projects are also included in the Galilee CRDP, but these all lack sufficient information about the nature of any future commercial operations to specifically include them in the hydrological modelling. Instead, a qualitative analysis of potential impacts and risks from these less advanced coal resource developments is in Section 3.6.

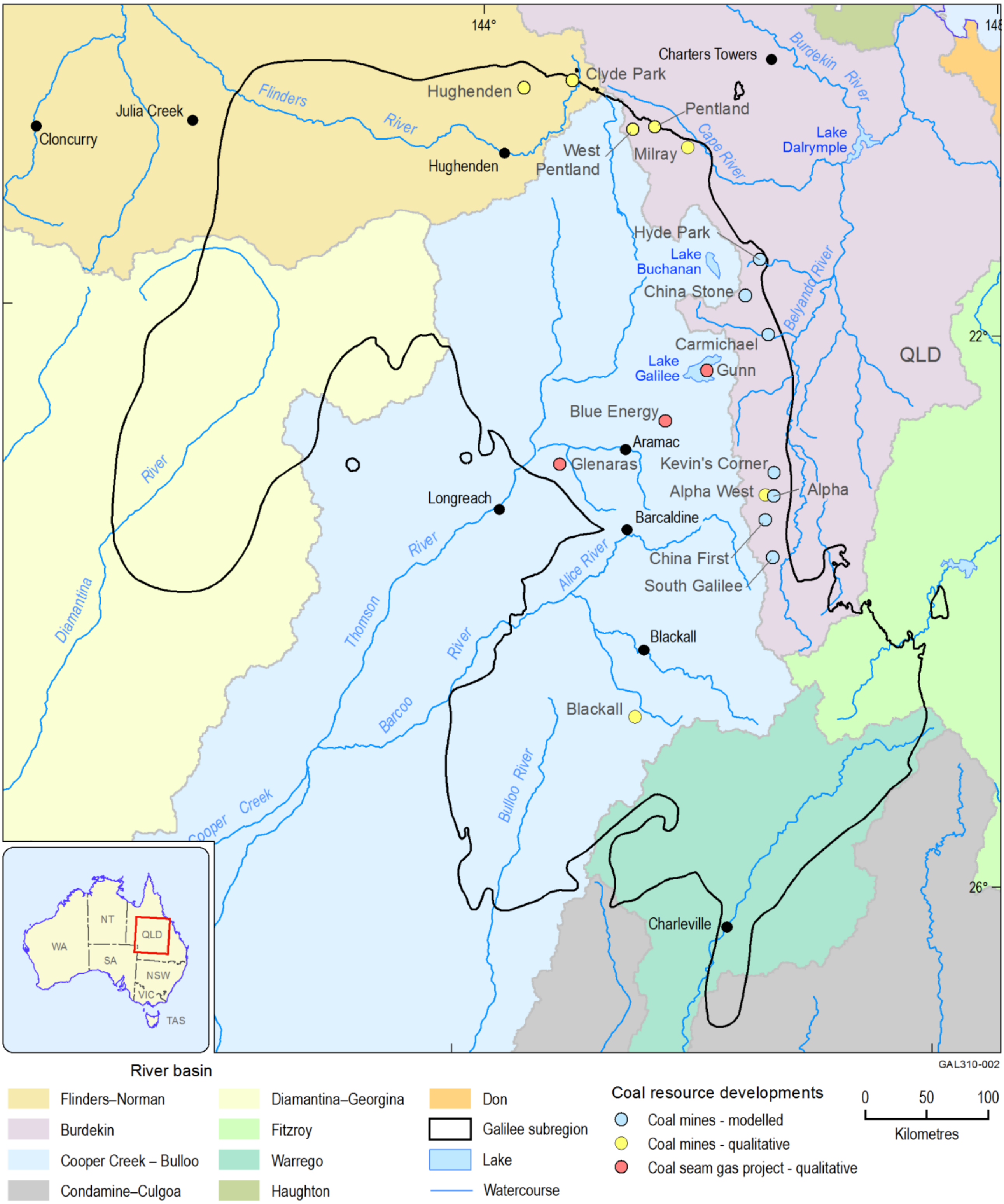

Figure 6 Coal resource developments and river basins in the Galilee subregion

Data: Bureau of Meteorology (Dataset 4, Dataset 5, Dataset 6); Geoscience Australia (Dataset 7); Geological Survey of Queensland (Dataset 8); Bioregional Assessment Programme (Dataset 9)

The CRDP is the most likely future, based on the analysis and expert judgment of the Assessment team in consultation with coal and gas industry representatives, and experts from various Queensland and Australian Government agencies. The BA approach for developing the CRDP is outlined in companion submethodology M04 (as listed in Table 1) for developing a coal resource development pathway (Lewis, 2014). The CRDP was finalised (i.e. 'locked-in') for the Galilee subregion based on information available as of December 2014 (companion product 2.3 (Evans et al., 2018), Section 2.3.4.1) to allow the hydrological numerical modelling to commence. In reality, developments in the CRDP may ultimately be implemented in different ways (e.g. changes to estimated timing of construction or production phases), or specific circumstances may change (e.g. a proponent may withdraw their development plans for some reason). This reflects the dynamic nature of resource investment decision making, related to diverse economic, political or social factors. Consequently, the Galilee CRDP needs to be viewed as an indicative future that highlights potential changes for water resources and water-dependent assets that may need to be considered further in local analyses or via approval conditions required by regulators. Equally as important, the CRDP plays a role in identifying where potential impacts to water resources and water-dependent assets are *very unlikely*.

Factors such as climate change and land use (such as agriculture) were held constant between the two futures. Although the future climate and/or land use may differ from those assumed in BAs, the effect of this choice is likely small because the focus of BAs is on reporting the difference in results between the CRDP and baseline.

The scope of the BAs is on potential impacts to water resources and water-dependent assets that are attributable to the additional coal resource development. In the case of the BA for the Galilee subregion, the absence of any baseline coal mines or CSG fields means that the CRDP only comprises additional coal resource developments. Hence, there are no baseline impacts attributable to coal resource development in the Galilee subregion. The clear focus of the BA for the Galilee subregion is directed towards understanding the potential for cumulative hydrological impacts, due to the multiple large-scale coal mines slated for future development along a north-trending fairway about 250 km long, near the eastern margin of the central Galilee Basin.

3.1.2.2 Focus on water quantity and availability

BAs focus solely on water-related impacts, and specifically those related to water quantity and availability. Potential water quality hazards were identified through the comprehensive hazard analysis undertaken as part of conceptual modelling for the Galilee subregion (companion product 2.3 (Evans et al., 2018)). However, the further analysis of these hazards, as determined by the scope of BAs, was limited to those that potentially affect salinity, and these are only addressed qualitatively (see Section 3.3.4).

BAs are mainly concerned with surface water and groundwater effects that may accumulate, either over extended time frames or as a result of multiple coal resource developments. Both of these factors are relevant for the BA for the Galilee subregion. These effects typically correspond to changes in surface water and groundwater that are sustained over long periods of time, sometimes decades or longer, and which may create the potential for flow-on effects through the wider hydrological system. As an example, consider the potential for drawdown in the watertable aquifer (due to dewatering associated with multiple coal mining operations) to subsequently affect the volume and timing of any baseflow contribution to connected streams. In this example, the prolonged effects of the hydrological changes to the watertable aquifer may also lead to long-term changes in surface water – groundwater interactions.

Many activities related to coal resource development may cause local or on-site changes to surface water or groundwater, for example, on-site compaction, settlement and contouring of open-cut pit backfill, or the spillage or disposal of various compounds (such as diesel, oils, muds, or drill cuttings). These types of hydrological changes are not considered explicitly in BAs because they are assumed to be adequately managed by site-based risk management and mitigation procedures, and are also unlikely to create potential cumulative impacts. Impacts and risks associated with water quality attributes other than salinity that are potentially affected by coal resource development are identified (see Section 2.3.5 in companion product 2.3 (Evans et al., 2018), but are not analysed further in this BA.

3.1.2.3 Assessment of regional-scale cumulative developments

BAs are designed to analyse the cumulative impacts of coal resource developments at a regional scale, and not to focus specifically on individual mines or CSG operations. The CRDP for the Galilee subregion includes a suite of proposed coal resource developments, the potential hydrological impacts of which may overlap to varying degrees in both time and space. This is particularly likely given the proximity of many proposed coal mines in the central-eastern part of the subregion, and the similarity in timing of their current development schedules. The main focus of the BAs allows for the prediction and understanding of the cumulative hydrological changes and potential impacts of those developments on surface water, groundwater and water-dependent assets. In some cases, the spatial or temporal alignment of certain coal mines may allow for some attribution of potential hydrological effects to individual operations, but that occurs only because of such alignment rather than by design.

Importantly, the regional-scale nature of the BAs means that results of the impact and risk analysis reported in this product do not replace the need for detailed site- or project-specific investigations that are currently required under existing state and national legislation. Further, the regional-scale BA results should not be used to invalidate existing site-specific modelling or impact assessments, nor pre-empt results of future investigations that may be required, for example, by various Queensland Government agencies. The hydrological and ecological system modelling undertaken for this BA are appropriate for assessing the potential impacts on and risks to water resources and water-dependent assets at the 'whole-of-basin' scale. However, the modelling done by each mining proponent for individual coal resource developments (e.g. as reported in environmental impact statements) occurs at a much finer scale and is able to more accurately capture local data and information. For example, groundwater modelling at the scale of individual coal mines will use more detailed (e.g. higher resolution) hydrogeological data and conceptualisations than is possible to use when modelling groundwater systems at the scale of the entire Galilee Basin. Consequently, modelling outcomes reported from such detailed mine-specific studies may yield differing results to those from the BAs, due to the variations in the scale of the modelling and the enhanced representation of local systems and processes in the more detailed models. However, as a wide range and combination of potential model parameter values are considered in the modelling done for this BA, it is expected that the range of predicted modelling outcomes will encompass the results from site-specific studies.

3.1.2.4 Focus on predictive uncertainty

In BAs, parameter uncertainty was considered as fully as possible when predicting hydrological outcomes (i.e. changes to surface water or groundwater) and ecological outcomes (i.e. changes to ecologically relevant receptor impact variables). For example, groundwater models were run many thousands of times using a wide range of plausible input parameters for the main hydraulic properties, such as the hydraulic conductivity and storage coefficients of all modelled hydrogeological layers (see companion product 2.6.2 for the Galilee subregion (Peeters et al., 2018). This differs from the traditional deterministic approach used more routinely for groundwater (Barnett et al., 2012) and surface water modelling and is driven by the risk analysis focus of BAs.

The density of reliable physical observation data is sparse in the Galilee subregion, meaning that the BA modelling results may not accurately represent some local conditions. However, the models do consistently represent the risk and uncertainty at all sites through probability distributions of possible hydrological changes. The area, depth, timing and assumed pumping rates of each mine largely determine the spatial variation. Additionally, the lack of detail about the physical environment at any given point in the assessment extent, as well as the absence of information about how the environment may change through time, defines the uncertainty.

Given the wide range of plausible input parameters used in the regional modelling, the hydrological changes due to additional coal resource development at any given location can be assumed to lie within the distribution of modelled changes. This assumption may not be valid near mines though, where potentially steep hydraulic gradients at the mine interface are poorly resolved in the regional groundwater model. Thus, the results from the hydrological modelling and uncertainty analysis are not reported for these mining areas, and they are also excluded from the ecological analysis for this reason; that is, the receptor impact models are not applied to landscape groups that occur within the areas defined as *mine exclusion zones* (further information about mine exclusion zones is in Section 3.3.1.3.1). Where the BA regional-scale analysis identifies an area as ‘at risk’ of large hydrological changes and there are potential impacts on ecological, economic and/or sociocultural values, local scale information may be necessary to constrain the predictive uncertainty to something more representative of local conditions, and more appropriate for informing specific management responses.

The quantitative representation of the predictive uncertainty through probability distributions allows BAs to consider the likelihood of impacts with a specified magnitude and underpins the impact and risk analysis. Sources of uncertainty that could not be quantified through numerical modelling were considered qualitatively, and are reported for both groundwater modelling (companion product 2.6.2 (Peeters et al., 2018)) and surface water modelling (companion product 2.6.1 (Karim et al., 2018)).

3.1.2.5 A landscape classification

The Galilee subregion comprises diverse landscapes with a wide range of human and ecological systems, and these may be discrete, overlapping or variably integrated. Because of this complexity, a direct analysis of each and every locality, or water-dependent asset, in the landscape is not possible. Instead, conceptual abstraction and a system-level classification were used to manage the challenges of this multi-dimensional task.

A set of landscape classes were defined for the Galilee subregion that are similar in their physical, biological and hydrological characteristics. This reduced the landscape complexity of the subregion and is an appropriate tool for a regional-scale assessment. For BA purposes, a landscape class is an ecosystem with characteristics that are expected to respond similarly to changes in groundwater and/or surface water due to coal resource development. There is expected to be less heterogeneity in the hydrological response within a landscape class than between different landscape classes.

The landscape classification characterises the landscape and focuses on the key processes, functions and interactions for the individual landscape classes. The landscape classification for the Galilee subregion built on existing and well-accepted classification schemes and is described in detail in Section 2.3.3 of companion product 2.3 for the Galilee subregion (Evans et al., 2018). Landscape classes occur across the entire assessment extent of the Galilee subregion and do not overlap. The use of this landscape classification meant that the analysis of impacts and risks could be suitably focused on those landscape classes that are water dependent.

The assessment of impacts on and risks to water-dependent ecological assets relied heavily on the landscape classification. Potential impacts to individual assets were assessed via their constituent landscape classes. For each of those landscape classes, the assessment was based on the qualitative mathematical models for those landscape classes and the indicators of hydrological change or ecosystem change identified as important for that landscape class. This is more fully explained in Section 3.4 and Section 3.5.

3.1.2.6 Ruling out potential impacts

An important outcome of this BA was to identify areas of the Galilee subregion that are not likely to be impacted due to additional coal resource development. Potential impacts were ruled out where possible, both spatially and in terms of specific groundwater or surface water effects, in order to concentrate the analysis on areas where potential impacts have a higher probability of occurring. This process started with identifying a preliminary assessment extent (PAE) for the subregion that is a conservative spatial boundary, encompassing areas of potential impact based on the catalogue of potential coal resource developments within the subregion (companion product 1.2 for the Galilee subregion (Lewis et al., 2014)). The PAE for the Galilee subregion is approximately 612,000 km^2, and the methods used to develop it are reported in companion product 1.3 for the Galilee subregion (Sparrow et al., 2015). The PAE is where assessment effort was preferentially focused for this BA, and was an important boundary in collating water-dependent assets, creating landscape classes to summarise surface ecosystems, and constructing numerical surface water and groundwater models.

For the purpose of reporting the impact and risk analysis for the Galilee subregion, the PAE is referred to hereafter simply as the 'assessment extent'. The size and shape of the Galilee subregion assessment extent is the same as the PAE, but this simple change in terminology reflects the more advanced stage of the BA that is reported in this product.

Potential impacts due to additional coal resource development in the Galilee subregion were ruled out using a *zone of potential hydrological change*. This zone was defined using probabilities of exceeding thresholds in multiple hydrological response variables, based on outputs from the groundwater and surface water models. A key role of the zone of potential hydrological change is to identify landscape classes that require further investigation through qualitative mathematical modelling and receptor impact modelling. Equally as important, this logical and consistently applied process effectively ruled out landscape classes or water-dependent assets where potential impacts due to additional coal resource development are *very unlikely* to occur (i.e. less than 5% chance of change in a relevant hydrological response variable).

3.1.3 Product overview

This product presents the impact and risk analysis for the Galilee subregion and is a key output of this BA. The structure is as follows:

- Section 3.1 describes the scope of the BA for the Galilee subregion and summarises the critical philosophical and operational choices.
- Section 3.2 describes the methods for assessing impacts and risks in the Galilee subregion. It includes details of the databases, tools and geoprocessing that support the impact and risk analysis, and the approach to aggregating potential impacts to landscape classes and assets. The approach is consistent with that outlined in companion submethodology M10 (as listed in Table 1) for analysing impacts and risks (Henderson et al., 2018), and is in addition to the methods for receptor impact modelling reported in companion product 2.7 for the Galilee subregion (Ickowicz et al., 2018).
- Section 3.3 provides a more detailed examination of the spatial extent of hydrological changes within the zone of potential hydrological change, using groundwater drawdown and a subset of the hydrological response variables defined in submethodology M06 (as listed in Table 1) for surface water modelling (Viney, 2016). The surface water hydrological response variables used include changes in low flows, high flows and annual flow due to additional coal resource development. Changes in other hydrological response variables are able to be viewed online (www.bioregionalassessments.gov.au/explorer/GAL/hydrologicalchanges). While not quantitatively modelled, the potential for additional coal resource development to impact groundwater and surface water quality is also reported in this section.
- Section 3.4 considers the impacts on and risks to landscape classes in the zone of potential hydrological change due to additional coal resource development. An aggregated, system-level analysis of potential impacts is possible at the scale of the subregion's landscape classes. A 'rule-out' process using geographic information system (GIS) processing and analysis tools identified the potentially impacted landscape classes. The impacts on and risks to selected landscape classes were assessed either quantitatively using receptor impact models, or qualitatively using qualitative mathematical models (companion product 2.7

(Ickowicz et al., 2018)). Further details on potential hydrological and ecological impacts on individual landscape classes can be accessed online (see www.bioregionalassessments.gov.au/explorer/GAL/landscapes).

- Section 3.5 considers the impacts on and risks to water-dependent assets (Sparrow et al., 2015) in the zone of potential hydrological change due to additional coal resource development. It includes ecological, economic and sociocultural assets. The analysis focuses predominantly on the asset groups previously defined for the Galilee subregion, such as endangered regional ecosystems and threatened ecological communities, although potential impacts to the habitat of some threatened species is also assessed. Additionally, profiles of potential impacts for all of the individual assets are available online (see www.bioregionalassessments.gov.au/explorer/GAL/assets).
- Section 3.6 assesses the potential hydrological changes and impacts due to additional coal resource developments that were not modelled. In the Galilee subregion, the non-modelled coal mine projects include those proposed at Alpha West, Blackall, Clyde Park, Hughenden, Pentland, Milray and West Pentland. The non-modelled CSG developments in the Galilee subregion CRDP are the Glenaras Gas Project, the Gunn Project, and Blue Energy's Exploration Permit for Petroleum (EPP) 813.
- Section 3.7 concludes with key findings and knowledge gaps, including how to validate and build on this assessment in the future.

Companion product 2.7 for the Galilee subregion (Ickowicz et al., 2018) presents the overarching methodology and development of the qualitative mathematical models and receptor impact models used as the basis for the predictions of potential impacts to ecosystems that are reported in Section 3.4. The supplementary content provided in companion product 2.7, which essentially serves as an appendix to the section on impacts to landscape classes presented here (Section 3.4), should be read in conjunction with this product.

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3.2 Methods

Summary

The core objective of the bioregional assessment (BA) for the Galilee subregion was to analyse the potential impacts on and risks to water-dependent assets caused by hydrological changes that arise due to additional coal resource development. The approach closely followed the high-level reasoning set out in companion submethodology M10 for analysing impacts and risks, and the key findings of this multi-disciplinary scientific investigation in the Galilee subregion represent the main outcome of this BA process. The particular emphasis of the impact analysis was geared towards quantifying the regional extent and magnitude of the potential hydrological and ecosystem changes due to additional coal resource development. The risk analysis, while closely related to impacts, importantly also evaluated the likelihood of such changes.

The water-dependent ecosystems and assets that are potentially impacted due to the proposed coal resource developments in the Galilee subregion may experience changes in either groundwater or surface water systems (or both). These changes may arise, for example, due to variations in certain functions of the streamflow regime, such as reductions in annual flow or increases in number of low-flow days, or due to reductions in aquifer levels caused by groundwater drawdown. Consequently, the Galilee subregion impact and risk analysis relied on the conceptual understanding of causal pathways, and used these as the basis for numerical modelling to generate probabilistic estimates of hydrological changes. The causal pathways provided the logical basis for clearly linking coal mining operations and associated activities to the surrounding hydrology, and the modelling approach then explored the potential distribution of changes to water quantity and availability both above and below ground. Subsequently, qualitative mathematical models and receptor impact models were used to translate the potential hydrological changes to ecosystem-level changes for the subregion's main water-dependent landscape groups, such as streams and terrestrial groundwater-dependent ecosystems on floodplains.

The BA for the Galilee subregion adopted a precautionary 'rule-out' approach for impact and risk analysis, and the probabilistic modelling results were used to develop the zone of potential hydrological change. This zone, which is less than 3% of the land area of the Galilee assessment extent (the initial focal point for this BA), integrates both groundwater and surface water modelling results attributed to the impacts of the subregion's additional coal resource development. Potential impacts to ecosystems (landscape classes) and water-dependent assets were initially evaluated by geographic overlay analysis. Any landscape classes or assets that were completely outside of this zone were considered *very unlikely* (less than 5% chance) to be impacted by the additional coal resource development, and were hence ruled out from further analysis.

The scale and complexity of the impact and risk analysis for the BA for the Galilee subregion, with a large number of multi-dimensional input datasets from a variety of scientific

disciplines, required an innovative approach to information management and processing. A custom-built impact and risk analysis database facilitated effective BA data handling, and allowed three main types of system-level analyses for the BA, including the analysis of hydrological changes (Section 3.3), the analysis of ecosystem (landscape groups) changes (Section 3.4), and the analysis of changes to water-dependent assets (Section 3.5). In all three cases, the focus was on the quantifiable impacts and risks that may occur within the Galilee subregion's zone of potential hydrological change.

3.2.1 Impact and risk analysis

The *Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources* (the BA methodology) (Barrett et al., 2013) states:

> The central purpose of BAs is to analyse the impacts and risks associated with changes to water-dependent assets that arise in response to current and future pathways of CSG and coal mining development.

The impact and risk analysis for the Galilee subregion (Component 3 and Component 4) followed the overarching logic described in companion submethodology M10 (as listed in Table 1) for analysing impacts and risks (Henderson et al., 2018), and is summarised diagrammatically in Figure 7. It built on, and was only possible because of, the contextual information (Component 1) and knowledge from the conceptual models of causal pathways, numerical groundwater and surface water modelling, and associated data analysis (Component 2). These components are described in detail in the preceding products for the Galilee subregion, and are referenced extensively throughout this document. The impact and risk analysis represents the culmination of the Assessment team's research to improve the knowledge base around the coal resource development pathway (CRDP) in the Galilee subregion, and to understand how water resources and water-dependent assets may be affected by hydrological changes caused by the proposed developments.

The impact analysis presented here quantified the magnitude and extent of the potential hydrological and ecosystem changes due to the additional coal resource development in the Galilee subregion. As specified in the BA methodology (Barrett et al., 2012), this included:

- *direct impacts*: a change in water resources and water-dependent assets resulting from coal seam gas (CSG) and coal mining developments without intervening agents or pathways
- *indirect impacts*: a change in water resources and water-dependent assets resulting from CSG and coal mining developments with one or more intervening agents or pathways
- *cumulative impacts*: the total change in water resources and water-dependent assets resulting from CSG and coal mining developments when all past, present and reasonably foreseeable actions that are likely to impact on water resources are considered.

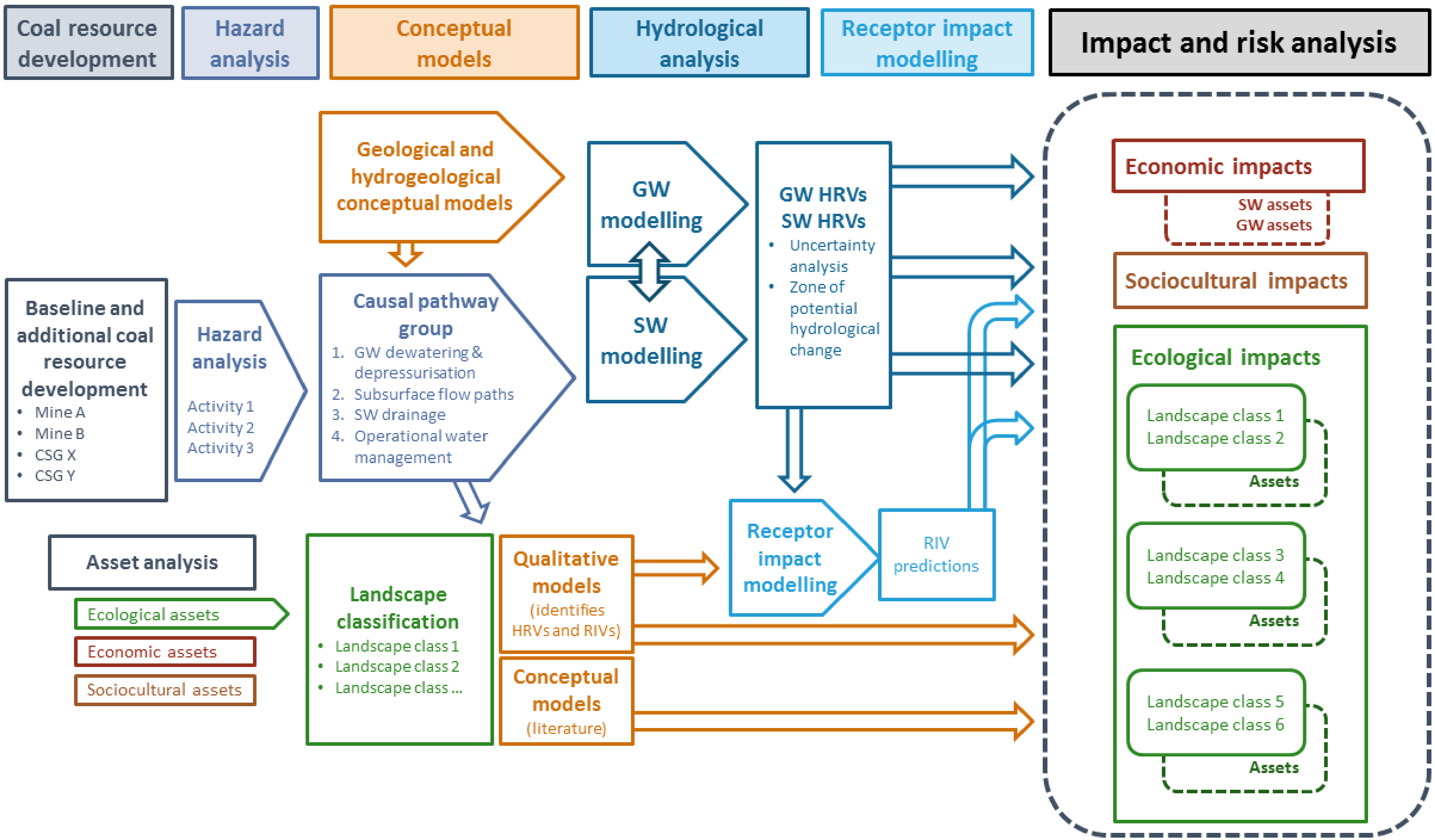

Figure 7 Generic methodology for impact and risk analysis in bioregional assessments

CSG = coal seam gas, GW = groundwater, HRV = hydrological response variable, RIV = receptor impact variable, SW = surface water. Refer to Table 1 and Figure 2 for an overview of the various technical products and submethodologies that relate to the main components of the bioregional assessment depicted in this diagram.

The risk analysis is related, but considers not only the magnitude and extent of the potential impact but also the likelihood of that impact. This is commonly framed as 'consequence multiplied by the likelihood'. The quantification of the likelihood was underpinned by an uncertainty analysis that allowed probabilistic statements about the occurrence of particular events or impacts, such as the magnitude, extent and timing of groundwater drawdown in an aquifer. Within BAs, the uncertainty analysis stochastically propagated uncertainties in the most important hydrological parameters through the models to produce distributions of potential surface water and groundwater changes. These in turn were input to receptor impact models (see companion product 2.7 for the Galilee subregion (Ickowicz et al., 2018)) to produce distributions of receptor impact variables that were chosen as indicators of potential ecosystem impacts.

The BA for the Galilee subregion has identified risks through a comprehensive hazard analysis and analysed those risks by estimating the magnitude and likelihood of specific impacts. The risk assessment, risk evaluation and risk treatment that occur as part of broader risk management (see, for example, ISO 31000:2009 Risk Management Standards) are beyond the scope of BAs because they require careful consideration of a number of non-scientific matters and value judgments; these are roles of proponents and government regulators in the first instance.

This product first describes the hydrological changes to groundwater and surface water systems in the Galilee subregion, as modelled to occur due to the coal resource development pathway (Section 3.3). Following this, the product explains the potential impacts of those hydrological changes on the main water-dependent ecosystems (as represented through landscape classes, Section 3.4) and water-dependent assets (Section 3.5), which contain various ecological, economic and sociocultural values.

BAs present the likelihood of certain impacts occurring, for example, the percent chance of exceeding 0.2 m of groundwater drawdown in a particular aquifer at a particular location. The underpinning data and information are available at www.bioregionalassessments.gov.au for others to use more broadly in their own targeted risk assessments. Future users of this BA can choose thresholds of impact that may threaten the specific values they are trying to protect and calculate the corresponding likelihood of occurrence. More details about hydrological changes and potential impacts in the Galilee subregion are available via the BA Explorer online mapping interface at www.bioregionalassessments.gov.au/explorer/GAL.

3.2.2 Causal pathways

The conceptual models of causal pathways describe the logical chain of events – either planned or unplanned – that link coal resource development and potential impacts on water resources and water-dependent assets. These conceptual models integrate existing knowledge about the main system components, processes and interactions of the Galilee subregion's geology, groundwater and surface water, as well as the surficial ecology. The most plausible and important potential impacts predicted from the CRDP are specifically considered, in both space and time. The causal pathways provide the logical and transparent foundation for the impact and risk analysis, as well as underpinning the development of the hydrological models.

As a starting point for developing causal pathways, a systematic hazard analysis using the Impact Modes and Effects Analysis method (described in companion submethodology M11 (as listed in

Table 1) for hazard analysis (Ford et al., 2016)), was undertaken for the Galilee subregion. This analysis was used to identify the activities that occur as part of CSG and coal mining development that might result in a change in the quality or quantity of surface water or groundwater. Hazards were prioritised according to the likelihood, severity and detectability of potential impacts (Bioregional Assessment Programme, Dataset 1). Importantly, all hazards identified during this process need to be addressed for the impact and risk analysis to meet the necessary quality criteria of the BA. This does not mean that all causal pathways need to be assessed in the same manner or to the same level of detail, only that they are all addressed in some way.

The many individual 'hazards' themselves were not represented directly in the hydrological models, but instead they were aggregated into four causal pathway groups. These groups reflect the main hydrological pathways via which the effects of a hazard can propagate from its origin, and such pathways were broadly represented in the BA hydrological models. The causal pathway groups are:

- 'Subsurface depressurisation and dewatering'
- 'Subsurface physical flow paths'
- 'Surface water drainage'
- 'Operational water management'.

Figure 8 generically illustrates the causal pathway groups associated with both open-cut and underground coal mining, whereas Figure 9 shows the causal pathway groups for generic CSG operations. Table 4 summarises the main causal pathways and hazards within the 'Subsurface depressurisation and dewatering' causal pathway group, Table 5 highlights similar information for the 'Subsurface physical flow paths' causal pathway group, and Table 6 for the 'Surface water drainage' causal pathway group. The main causal pathway in the 'Operational water management' causal pathway group is 'storing extracted water', and this mainly relates to storing untreated water associated with both mining and CSG operations (e.g. co-produced water extracted from coal seams during CSG production), which has the potential to leak from storage ponds and affect groundwater and surface water quality. Further details about hazards, their identified effects and their link to causal pathway groups are explained in companion product 2.3 for the Galilee subregion (Evans et al., 2018).

The hydrological models represent causal pathways through their conceptualisations and parameterisations. The outputs from the hydrological models do not align with individual causal pathways but rather integrate the effects of the possible causal pathways into the predicted hydrological response, at particular points in space and time.

The effects of some hazards were not modelled in this BA. Some cannot be quantitatively modelled due to scale or complexity, and these were addressed qualitatively using the current conceptual understanding and knowledge base for the Galilee subregion. Changes in water quality due to coal resource development were considered only through potential effects on the salinity of either groundwater or surface water (Section 3.3.4). Some identified hazards were deemed to be local in scale and addressed adequately by existing site-based management procedures (such as leaching of various compounds from on-site coal stockpiles or waste rock dumps), whereas some were considered knowledge gaps (e.g. because the long-term means of disposal for co-produced water extracted during CSG production is currently unknown for CSG projects in the Galilee subregion). Other hazards were considered of such low likelihood and/or consequence for contributing to broader cumulative impacts at the regional scale that they were not included (e.g. littering and minor fuel spills associated with ground support staff at mining operations are potential hazards to groundwater and surface water, but are considered to be of low priority for contributing to regional-scale cumulative impacts, and are generally well managed on site).

While the causal pathway groups are generic, the physical characteristics of a subregion, such as its geological, geophysical and topographic architecture, and related surface water and groundwater networks, will influence the regional hydrological connectivity. The Assessment team's conceptual understanding of the dominant geological and topographic influences on surface water and groundwater connectivity in the Galilee subregion are described in companion product 2.3 (Evans et al., 2018). Importantly, these conceptualisations have provided the knowledge base that underpins many aspects of the impact and risk analysis presented here.

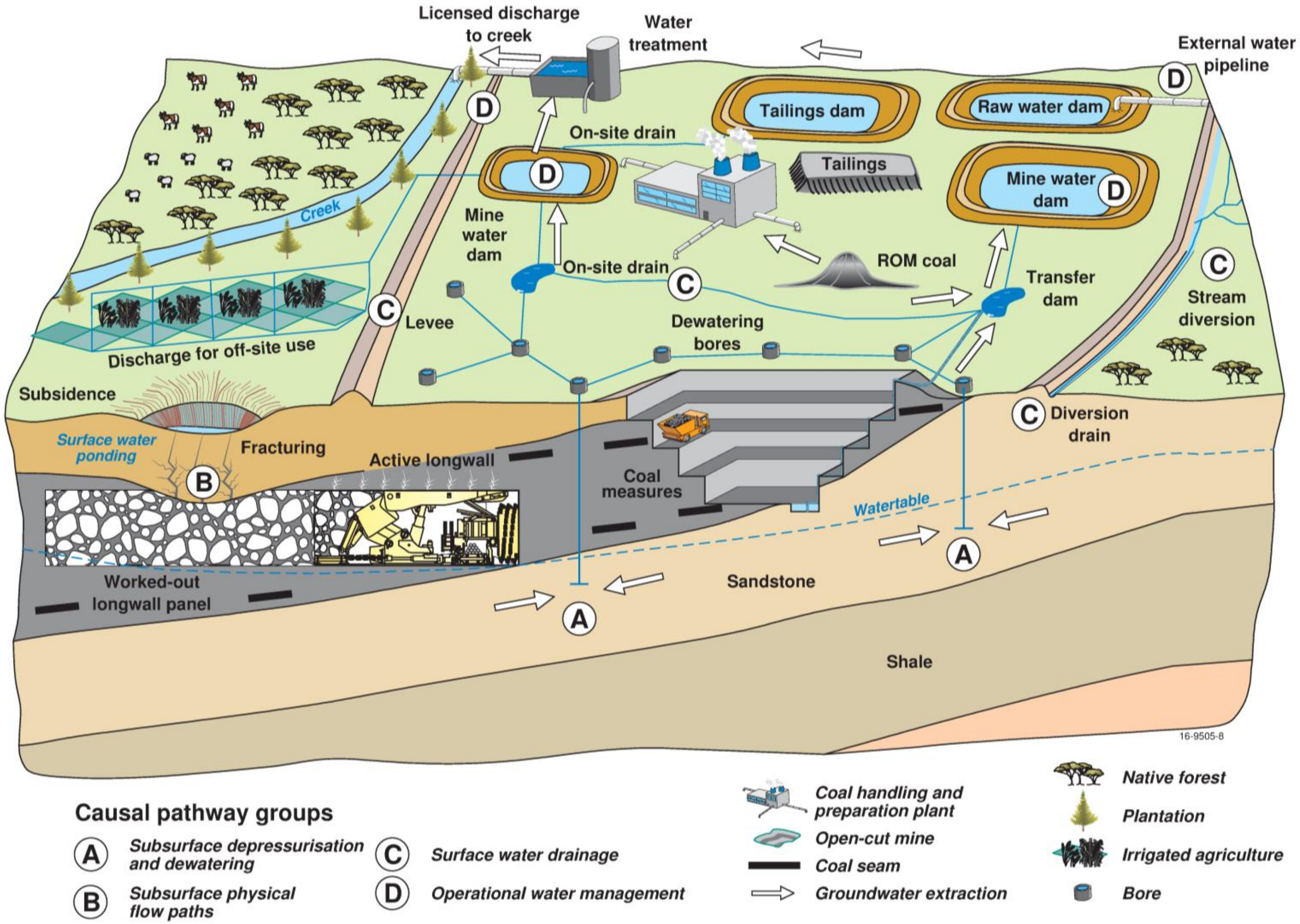

Figure 8 Conceptual diagram of the generic causal pathway groups defined in bioregional assessments that are associated with open-cut and underground coal mines

This is a schematic diagram that is not drawn to scale. This generic diagram does not specifically relate to any proposed coal mines in the Galilee Basin, 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. A summary of causal pathways is in the accompanying text, with a more detailed description in companion product 2.3 (Evans et al., 2018). The arrows shown below ground in this diagram refer to groundwater extraction, whereas the arrows above ground illustrate various aspects of mine water management, which may include transferring extracted groundwater around the mine site.

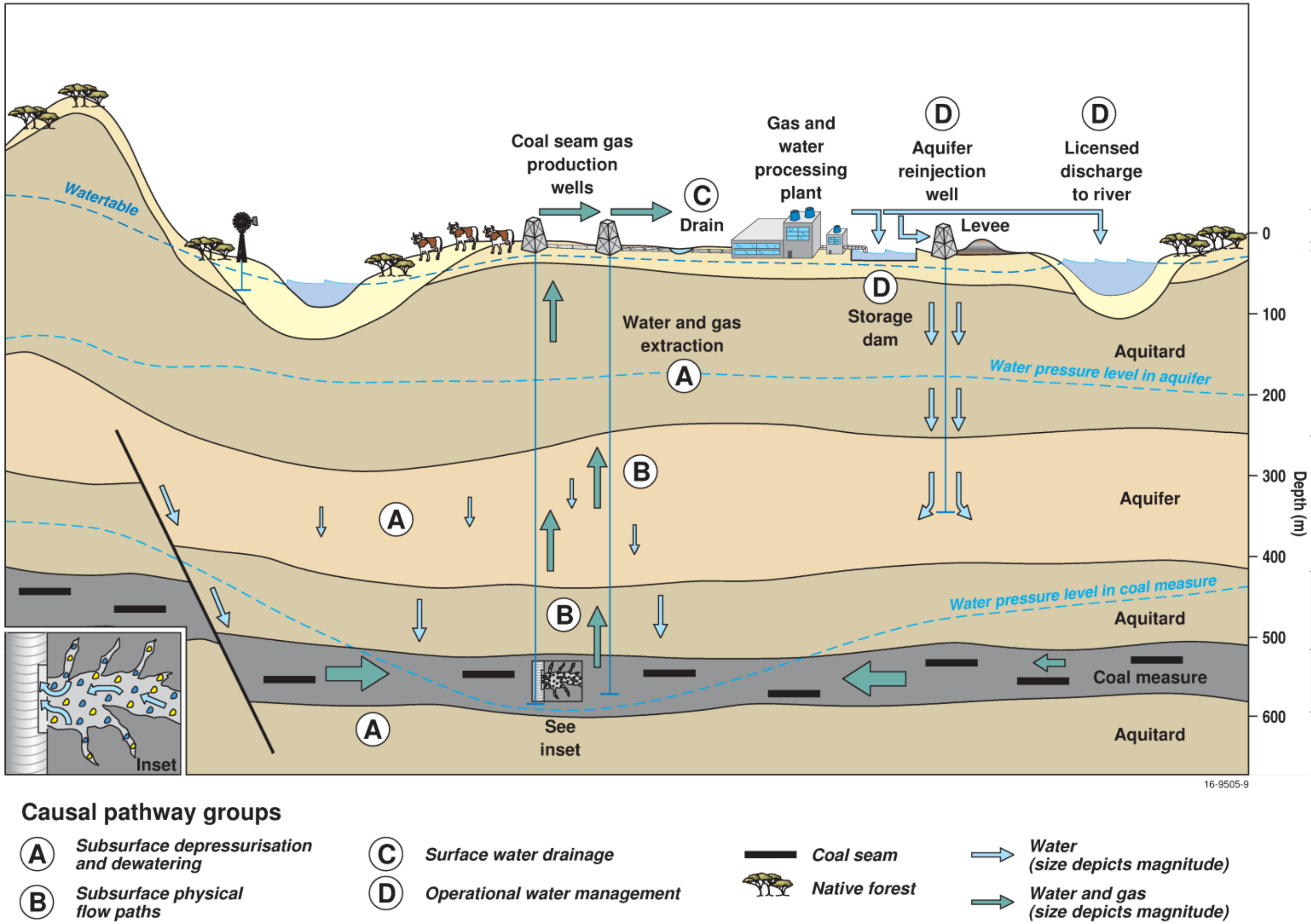

Figure 9 Conceptual diagram of the generic causal pathway groups defined in bioregional assessments that are associated with coal seam gas extraction

This schematic diagram is not drawn to scale. The inset schematic shows a zoomed view of hydraulic fracturing of a coal seam, where a mixture predominantly composed of water (blue) and sand (yellow), with minor amounts of chemical additives, is injected at high pressure into the well to produce small cracks in the coal (lighter grey zone). This process (which is an example of causal pathway group B) enhances the permeability of the coal seam, enabling larger volumes of gas and water to be subsequently pumped from the well. The diagram does not specifically relate to any proposed coal seam gas developments in the Galilee subregion, nor does it represent any specific geographic features, geological units or land uses in the subregion.

Table 4 Main causal pathways in the 'Subsurface depressurisation and dewatering' causal pathway group in the Galilee subregion

Causal pathway	Activities causing hazards	Impact mode of hazards	Potential hydrological effects
Groundwater pumping enabling open-cut coal mining	• Pit wall stabilisation – dewatering, treatment, reuse and disposal	• Deliberate aquifer dewatering (groundwater pumping) to stabilise open-cut pit and enable safe and efficient coal extraction	• Groundwater level • Groundwater flow • Groundwater pressure • Groundwater quantity/volume
Groundwater pumping enabling underground coal mining	• Longwall coal extraction (underground) • Development of underground mine panels	• Deliberate aquifer dewatering (groundwater pumping) for underground mine development and coal production	• Groundwater level • Groundwater flow • Groundwater pressure • Groundwater quantity/volume
Groundwater pumping enabling coal seam gas extraction	• Extraction of water and gas from coal seam gas production wells	• Hydrostatic depressurisation of target coal seams	• Groundwater pressure • Groundwater flow
Unplanned groundwater changes in non-target aquifers	• Extraction of water and gas from coal seam gas production wells • Dewatering open-cut and underground coal mines	• Hydrostatic depressurisation (coal seam gas operations) or dewatering (coal mines) of non-target aquifers (may occur due to propagation of depressurisation or dewatering effects via faults or other geological structures, or due to partial or complete absence of intervening aquitards)	• Groundwater pressure • Groundwater flow

Full descriptions of the causal pathways and causal pathway groups are available in companion submethodology M05 (as listed in Table 1) for developing a conceptual model of causal pathways (Henderson et al., 2016). Hazards that potentially change groundwater or surface water flow may alter characteristics such as the direction, timing and magnitude of flow within or between aquifers, or within streams.
The impact mode of the hazards associated with the coal seam gas causal pathways listed in this table involves reducing the pressure of groundwater in the coal seam to enable gas to desorb from the coal matrix, so that the gas (and associated water) can be extracted by pumping. The reduction in water pressure within the coal seam (i.e. hydrostatic depressurisation) differs from aquifer dewatering associated with mining, as the coal seams are generally not completely pumped dry.

Table 5 Main causal pathways in the 'Subsurface physical flow paths' causal pathway group in the Galilee subregion

Causal pathway	Activities causing hazards	Impact mode of hazards	Potential hydrological effects
Subsurface fracturing above underground longwall panels	• Coal extraction from longwall panels	• Creation of new subsurface fractures, and modification of existing fracture networks	• Groundwater pressure • Groundwater flow • Groundwater quality • Groundwater quantity/volume • Surface water flow
Hydraulic fracturing	• Deliberate hydraulic fracturing of target coal seams to enhance coal seam gas production	• Connecting coal seams and aquifers via new fracture networks • Changing physical and chemical properties of coal seam target layers • Contaminating groundwater in non-target aquifer	• Groundwater composition and quality, in coal seam target layers or non-target aquifers • Modified aquifer properties
Failure of well integrity	• Cementing and casing of coal seam gas wells • Constructing groundwater monitoring bores • Abandoning wells or bores • Pressure concrete durability	• Incomplete or physically compromised cement or casing in well, leading to direct linkage of aquifers or leakage of gas and/or water • Leakage and mixing of groundwater between different aquifers, or to the surface • Loss of well seal integrity	• Groundwater composition and quality

Full descriptions of the causal pathways and causal pathway groups are available in companion submethodology M05 (as listed in Table 1) for developing a conceptual model of causal pathways (Henderson et al., 2016). Hazards that potentially change groundwater or surface water flow may alter characteristics such as the direction, timing and magnitude of flow within or between aquifers, or within streams.

Table 6 Main causal pathways in the 'Surface water drainage' causal pathway group in the Galilee subregion

Causal pathway	Activities causing hazards	Impact mode of hazards	Potential hydrological effects
Altering surface water systems	• Surface water filling open-cut pits after mine closure • Blasting, excavation and storage of overburden and waste rock • On-site dam construction for mine water or tailings dams • Construction of surface infrastructure for coal seam gas operations	• Creation of artificial lake at surface, and potential new point source of groundwater recharge • Disruption of natural surface water drainage system • Enhanced soil erosion processes following heavy rainfall • Changing characteristics of surface water runoff	• Surface water quality • Groundwater quality • Groundwater quantity/volume • Surface water flow • Surface water volume/quantity • Groundwater flow
Intercepting surface water runoff	• Rainwater runoff diversions on mining sites	• Disruption of natural surface water drainage system	• Surface water flow • Surface water volume/quantity • Surface water quality • Groundwater quantity/volume
Subsidence of land surface	• Coal extraction from longwall panels (underground mining)	• Land surface subsides due to removal of coal and collapse of overlying strata.	• Surface water flow • Surface water quality • Groundwater flow • Groundwater level • Groundwater recharge rate and timing

Full descriptions of the causal pathways and causal pathway groups are available in companion submethodology M05 (as listed in Table 1) for developing a conceptual model of causal pathways (Henderson et al., 2016). Hazards that potentially change groundwater or surface water flow may alter characteristics such as the direction, timing and magnitude of flow within or between aquifers, or within streams. Surface infrastructure for coal seam gas operations can include roadways and easements, gas-gathering pipeline networks, gas and water processing plants, ponds for storage of treated water and brines, pipelines and well head sites.

3.2.3 Hydrological analysis

The hydrological investigation that supports the impact and risk analysis builds upon the surface water and groundwater modelling reported respectively in companion product 2.6.1 (Karim et al., 2018) and companion product 2.6.2 (Peeters et al., 2018) for the Galilee subregion. The modelling was designed to quantify potential changes in hydrology, such as changes in the magnitude and timing of streamflow or groundwater drawdown in an aquifer, caused by activities undertaken at multiple coal resource developments. This modelling approach enabled an assessment of the cumulative impacts of coal resource development at the regional scale of the Galilee assessment extent. The hydrological analysis has been used to define the *zone of potential hydrological change* for the Galilee subregion, outside of which potential impacts from the additional coal resource development are *very unlikely* (less than 5% chance of occurring). See Section 3.3.1 for more details, including the probability and exceedance threshold criteria used to determine the spatial extent of the zone of potential hydrological change.

3.2.3.1 Groundwater

The regional groundwater modelling for the BA for the Galilee subregion was undertaken using an analytic element model (AEM) implemented in TTim (Bakker, 2015). This was designed to simulate the change in drawdown at specific locations in the vicinity of the seven coal mines modelled in the CRDP, as well as the change in surface water – groundwater flux (Figure 10). The AEM was used to estimate spatially explicit probabilities of hydrological changes due to the proposed coal mining operations of the CRDP. Although BAs for other regions focus on potential hydrological changes for two futures (the baseline and the CRDP), there is no coal mining or CSG production in the Galilee subregion baseline as it is a greenfield basin for coal resource development. Hence, for the purposes of this assessment, the CRDP is defined by the seven coal mines comprising the additional coal resource development, and there is no separate reporting of baseline modelling results (Section 3.1.2.1).

As explained in companion product 2.6.2 for the Galilee subregion (Peeters et al., 2018), the main focus of the groundwater modelling is the hydrostratigraphic sequence of the Galilee Basin. This is conceptualised as an alternating sequence of aquifers and aquitards, which outcrop near the basin's eastern boundary and dip gently westwards (Figure 11). The main regional Galilee Basin aquifer modelled here is the Clematis Group, although the deeper upper Permian coal measures (i.e. the main target for mining) are also classified as a partial aquifer (for modelling purposes the coal measures are aggregated into a single layer). The main aquitards simulated in the AEM are the Rewan Group, a thick aquitard separating the upper Permian coal measures and the Clematis Group, and the basal aquitard of the lowermost unit, the Joe Joe Group. Additionally, thin Cenozoic sediment layers are also incorporated into the model, as these unconformably overlie much of the Galilee Basin strata. The Cenozoic layers are conceptualised as an uppermost aquifer (Figure 11), which represents the highly permeable alluvial and colluvial sediments commonly associated with surface water systems such as the Belyando River and its tributaries. The underlying sediment layer is conceptualised as a lower permeability zone that represents a clay-rich weathering profile (which formed during the Cenozoic). In total, the AEM has seven hydrostratigraphic layers, which are of infinite extent, constant thickness and uniform hydraulic properties across the entire modelling domain.

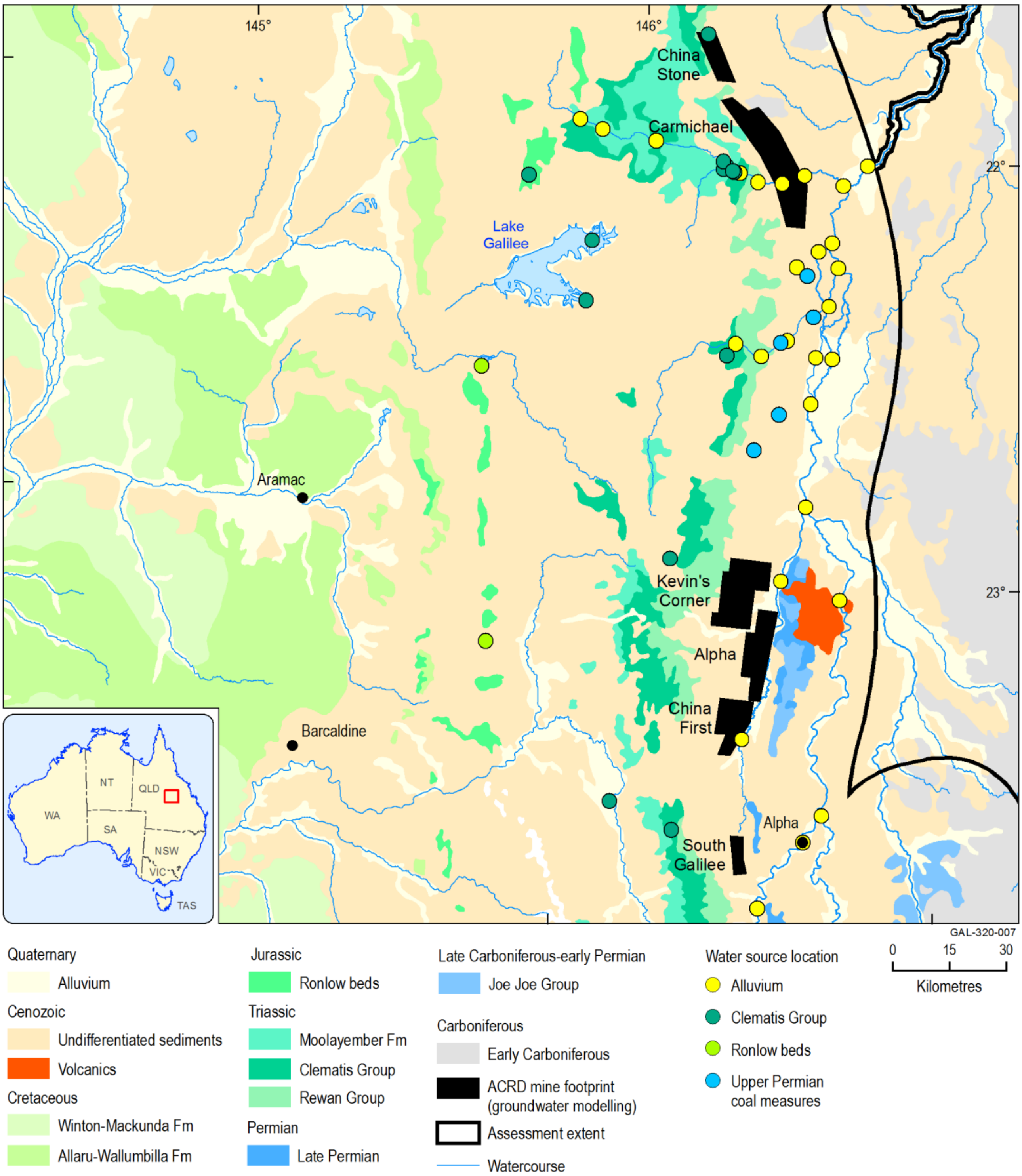

Figure 10 Locations of groundwater model nodes in the Galilee subregion, overlain on the regional surface geology mapped by the Geological Survey of Queensland

The geological units that belong to the stratigraphic sequence of the Galilee Basin occur sporadically at surface (outcrop) in a narrow north-trending zone adjacent to the proposed coal mines, and range from the basal (stratigraphic) Joe Joe Group to the upper unit of the Moolayember Formation. The Jurassic and Cretaceous units occur further west of the mines, and belong to the overlying (and geologically younger) Eromanga Basin. Most of the mapped area depicted here is covered by undifferentiated Cenozoic sediments, with Quaternary alluvium common along the rivers and streams. As explained in companion product 2.6.2 (Peeters et al., 2018), drawdown at the two nodes assigned to the Ronlow beds is not simulated directly in the analytic element model for the Galilee subregion, but is instead evaluated by proxy through drawdown in model layer 1 (alluvium and sediments).
ACRD = additional coal resource development, Fm = Formation
Data: Geological Survey of Queensland (Dataset 2); Bioregional Assessment Programme (Dataset 3, Dataset 4)

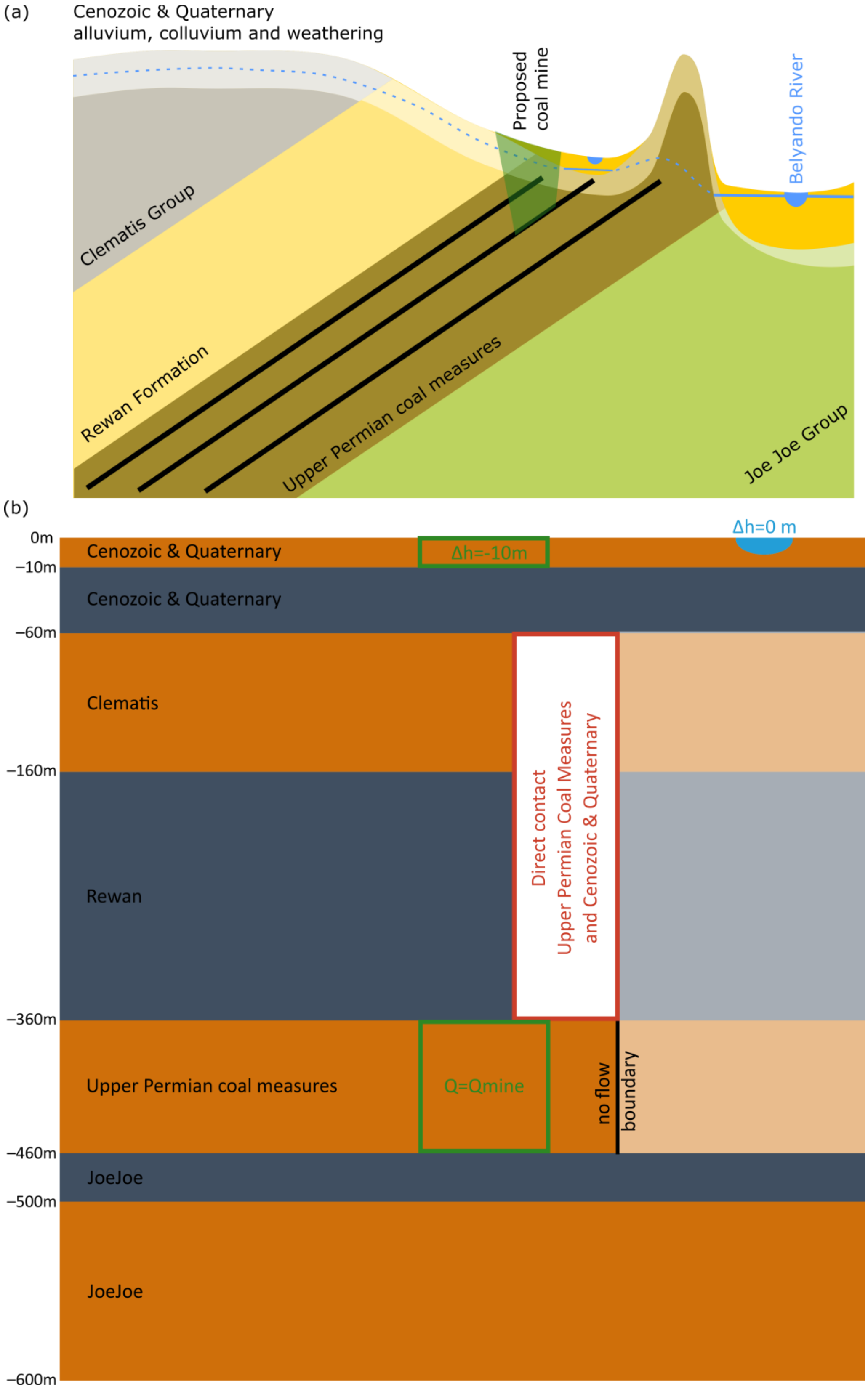

Figure 11 (a) hydrogeological conceptual cross-section, (b) corresponding cross-section of the analytic element groundwater model for the Galilee subregion

The limitations of the analytic element model mean that it is necessary to simplify the conceptual understanding of the hydrogeology in the central-eastern Galilee Basin depicted in (a) to the modelling conceptualisation shown in (b). In (b) aquifers are in dark orange, aquitards in dark grey. Green colours indicate stresses related to coal mining. Blue indicates surface water – groundwater interaction. Q is the mine dewatering pumping rate (Qmine). Δh is the change in groundwater level, which is set to –10 m in model layer 1 (Quaternary alluvium and Cenozoic sediments layer).

The hydrogeological units (layers) of the overlying Eromanga Basin sequence are not included in the AEM for the BA for the Galilee subregion. These layers are not present in the immediate vicinity of the modelled coal mines. Furthermore, they are stratigraphically separated from the Clematis Group by the low permeability aquitard of the Moolayember Formation, which is up to several hundred metres thick in this area. Consequently, any hydrological change in the Eromanga Basin layers would be much smaller than the change simulated in the Clematis Group. The decision not to specifically model the Eromanga Basin layers for this BA is justified by the Assessment team on the basis of sufficiently small hydrological changes predicted for the Clematis Group, and the known thickness and extent of the Moolayember Formation forming a substantial low permeability barrier to any potential drawdown propagation.

Groundwater modelling results reported in companion product 2.6.2 for the Galilee subregion (Peeters et al., 2018) focus on the three main aquifers simulated in the AEM, namely the:

- upper Cenozoic and Quaternary sediment layer
- Galilee Basin's main regional aquifer of the Clematis Group
- upper Permian coal measures, which is the target geological unit for the coal mines.

For the purpose of the impact and risk analysis, most of the focus from the groundwater modelling is on the results from the uppermost Cenozoic sediment layer. This is because this is the hydrostratigraphic unit that mainly hosts the regional watertable within the area of proposed mining development. From a groundwater perspective, most of the groundwater-dependent landscape classes and ecological assets source their water requirements from the watertable, and hence hydrological changes simulated for this aquifer are of most concern for analysing impacts and risks for this BA.

Importantly though, there are some areas within the groundwater zone of potential hydrological change where the Cenozoic sediment layer does not exist. Rather, much older Triassic or Permian rocks outcrop at surface, and are here the likely host layers for the regional watertable (given the absence of Cenozoic sediments). In these areas, the main hydrogeological conceptualisation used in the Galilee subregion's AEM may be considered invalid, and modelled drawdown results are very likely to be overestimated at the regional scale. In the areas of the modelling domain where Cenozoic sediments are absent, an alternative hydrogeological conceptualisation was presented in companion product 2.6.2 for the Galilee subregion (Peeters et al., 2018). The AEM outputs produced from this alternative conceptual model are expected to provide a more robust and accurate estimate of groundwater drawdown in areas where the regional watertable is not hosted in Cenozoic sediments (further discussed in Section 3.3). However, for the purposes of defining the zone of potential hydrological change (used as the basis for most of the Galilee impact and risk analysis), the more conservative conceptualisation (i.e. original version) which is applicable to the largest area of the model domain has been used.

There are also some economic assets (such as water access rights) and ecological assets (such as groundwater discharge springs) that may rely on access to groundwater from deeper confined aquifers in the Galilee subregion, such as the Clematis Group. For assessing potential impacts to these types of assets, the groundwater drawdown simulated for the relevant deeper confined aquifer layer must be used. Impacts to some important springs in the Galilee subregion, as well as economic groundwater assets, are discussed further in Section 3.4 and Section 3.5 (respectively).

The simulation of coal mining in the Galilee subregion assumes that the near-surface Quaternary alluvium and Cenozoic sediment cover (i.e. the uppermost aquifer modelled in the AEM) is completely removed during mining operations and that the mines act as a drain for the local Cenozoic aquifer system throughout the simulation period. This means that in the near-surface aquifer there is no post-mining recovery of drawdown simulated in the AEM. Consequently, should the Cenozoic cover sediments be partially restored as part of mine rehabilitation works before 2102, the time of maximum drawdown will be earlier than simulated. However, should the Cenozoic cover not be restored or only restored after 2102, a new dynamic equilibrium will be established between local aquifer recharge and mine void discharge. The extent of this dynamic drawdown equilibrium will likely be smaller than the extent simulated in this BA as the compensation of drawdown by recharge is not included in the AEM. However, the actual physical extent of the near-surface aquifer is a more substantial constraint on the extent of drawdown in it than the way the mine rehabilitation is implemented in the model. As explained in Section 2.6.2.9 of companion product 2.6.2 (Peeters et al., 2018) for the Galilee subregion, simulating the uppermost aquifer as a continuous groundwater system across the entire modelled domain adopts a very precautionary approach. This is because the actual extent of the upper aquifer as it exists in the central-eastern Galilee subregion covers a much smaller area than what is simulated in the model domain of the AEM. Consequently, the potential extent of drawdown derived from the regional modelling is likely to be overestimated.

Groundwater modelling results were generated at specified nodes across the modelling domain (Figure 10). Hydrological response variables representing the maximum drawdown and the year of maximum drawdown under the CRDP were defined for summarising the model results. Drawdown from the groundwater model nodes was spatially interpolated to obtain valid posterior distributions at all assessment units across the modelling domain. A Delaunay Triangulation was generated in the R package ‘tripack’ (Renka et al., 2015). For each assessment unit in the subregion (Section 3.2.4.1), the quantiles of maximum drawdown at the nodes of the triangle enclosing the assessment unit were linearly interpolated to the new location. A forward-backward cubed-root transform was applied during the interpolation to improve performance over potentially non-linear surfaces.

Section 3.3.1.1 describes how the groundwater modelling results have been used to define the groundwater zone of potential hydrological change, which focuses the remaining impact and risk analysis on areas where potential groundwater impacts may occur, and dismisses areas where impacts related to drawdown are *very unlikely* (less than 5% chance of occurring).

3.2.3.2 Surface water

Surface water modelling for the Galilee subregion was undertaken using the Australian Water Resources Assessment landscape model (AWRA-L). Details of the application of this model to the Galilee subregion are reported in companion product 2.6.1 (Karim et al., 2018). No river modelling was carried out because the rivers in the subregion are unregulated and their streamflow characteristics can be simulated solely by using a rainfall-runoff model (see companion submethodology M06 (as listed in Table 1) for surface water modelling (Viney, 2016)). This means that streamflow can be predicted by accumulating output from the spatially explicit streamflow model AWRA-L. The proposed coal mining development in the Galilee subregion will affect regional surface water hydrology directly through disruption of surface water drainage systems and some aspects of operational water management, and indirectly through changes in surface water – groundwater fluxes in response to mine dewatering. Consequently, the surface water modelling was designed to specifically assess these types of causal pathways.

Surface water model results for eight hydrological response variables were reported at 61 model nodes across the Galilee subregion and some adjacent river basins (Figure 12). These hydrological response variables were selected to characterise impacts of coal resource development, and were considered representative of flow characteristics that are important for assessing impacts to ecological and economic assets. Most of the model nodes are on streams in the Belyando river basin, which is a headwater catchment of the larger Burdekin river basin (Figure 12). In order to carry out the impact and risk analysis, results from these model nodes needed to be interpolated to specific stream reaches (i.e. stream links upstream or downstream of the model nodes). Interpolating these changes from nodes to links is an important step in analysing the changes in surface water across the entire assessment extent.

The process for interpolating hydrological response variable data from model nodes to stream links is shown schematically in Figure 13 and Figure 14. In addition, Table 7 provides information on some of the codes used in these schematic diagrams. The schematics include a number of stream links with no model nodes (dashed lines). Although it was not possible to generate model results for these stream reaches, they were important links for extrapolating results across the wider Galilee stream network. For example, the junctions of non-modelled streams with the modelled stream network may correspond to significant changes in streamflow and hence represent limits to interpolation from the nearest upstream or downstream model node.

As a starting principle, interpolations were not initially undertaken for stream links that contain inflows proximal to the coal mines. For example, the Carmichael River above node 14, the reach upstream of node 18 on Bully Creek, and the reach from a point upstream of node 5 to downstream of node 6 on Lagoon Creek – Sandy Creek are all proximal to one or more large open-cut mine pits and mine surface infrastructure. However, during the hydrological impact analysis (as outlined in Section 3.3), the Assessment team undertook more detailed evaluation of the results for the three hydrological response variables that are the focus of Section 3.3.3 (i.e. zero-flow days, high-flow days and annual flow volume). This involved further careful assessment of every interpolated reach in the stream network, and their adjoining node data both upstream and downstream. This work particularly focused on those reaches mentioned above where extrapolation was initially not done due to proximity to the coal mines. Working systematically through the data for the three hydrological response variables of interest, expert hydrological judgement was used to update the initial extrapolation schematic for some reaches that had previously not had node data assigned. This process resulted in an improved node-to-reach mapping that substantially increased the length of stream network for which the node data could be reliably interpolated. The results of the interpolations are presented in the series of maps showing changes in zero-flow days, high-flow days and annual flow volumes in Section 3.3.3.

Section 3.3.1.2 describes how the surface water modelling results were used to define the surface water zone of potential hydrological change.

The main focus of the hydrological modelling in BAs was on the maximum predicted change between the baseline and the CRDP for the surface water and groundwater hydrological response variables. As described in companion product 2.6.1 (Karim et al., 2018) and companion product 2.6.2 (Peeters et al., 2018) for the Galilee subregion, these maximum hydrological changes are primarily modelled to occur during and post-mining to the end of the 90-year simulation period (2102). However, the BA modelling approach did not examine hydrological changes after 2102, nor factor the medium- to long-term effectiveness of mine rehabilitation efforts. Additionally, post-mine closure legacy issues were not incorporated in the modelling including the potential impacts of any remaining open-cut mine pits on groundwater flow systems.

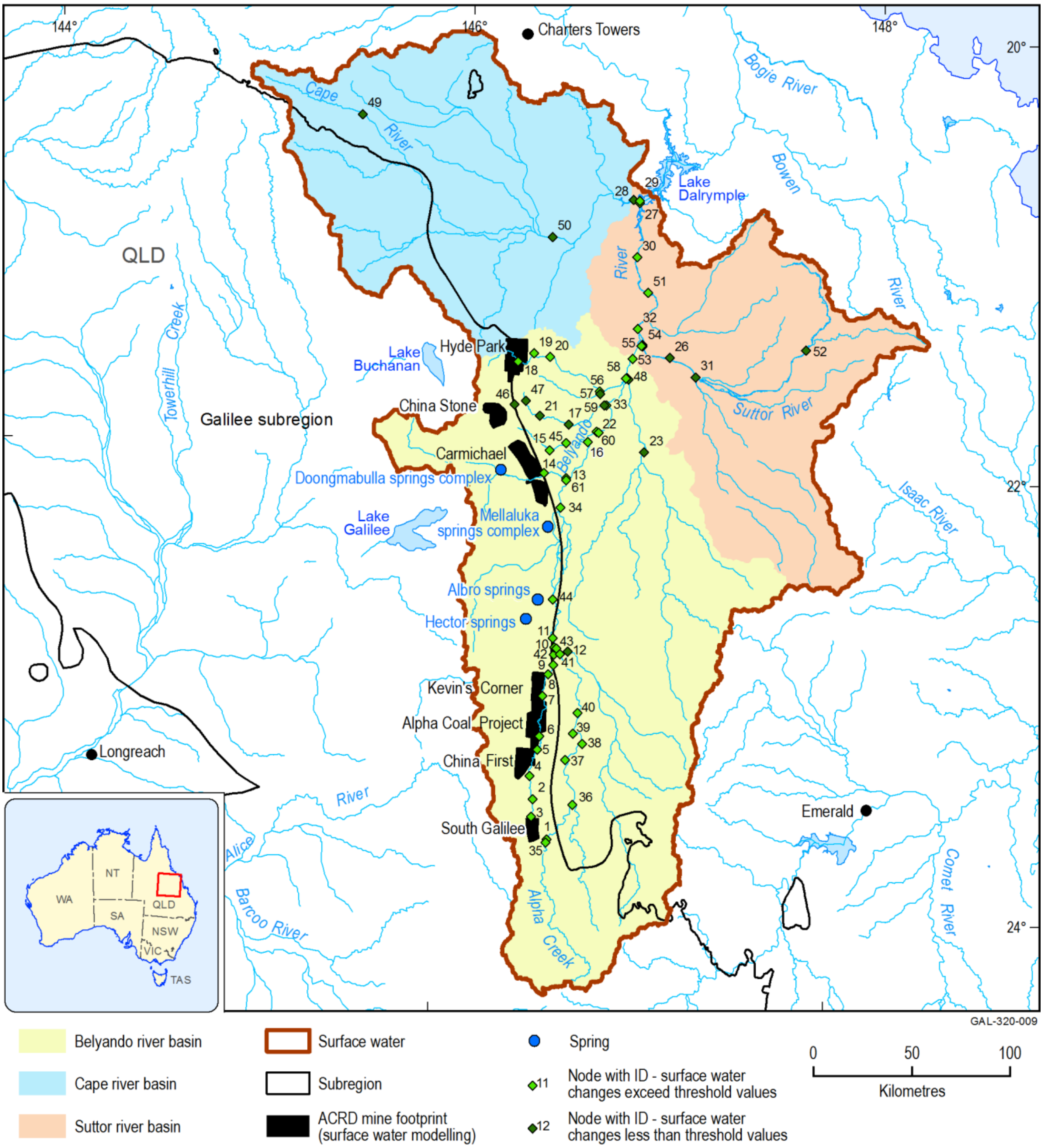

Figure 12 Surface water model nodes in the Galilee subregion

Probabilistic model outputs for eight hydrological response variables were estimated at the surface water nodes shown here, and reported in companion product 2.6.1 for the Galilee subregion (Karim et al., 2018). Four of these eight hydrological response variables characterise low streamflow, namely zero-flow days, low-flow days, low-flow spells, and length of the longest low-flow spell. Another two hydrological response variables characterise high streamflow (daily flow rate at the 99th percentile and high-flow days), and the remaining two characterise flow volume and variability (annual flow and interquartile range).
ACRD = additional coal resource development
Data: Bioregional Assessment Programme (Dataset 4, Dataset 5, Dataset 6, Dataset 7)

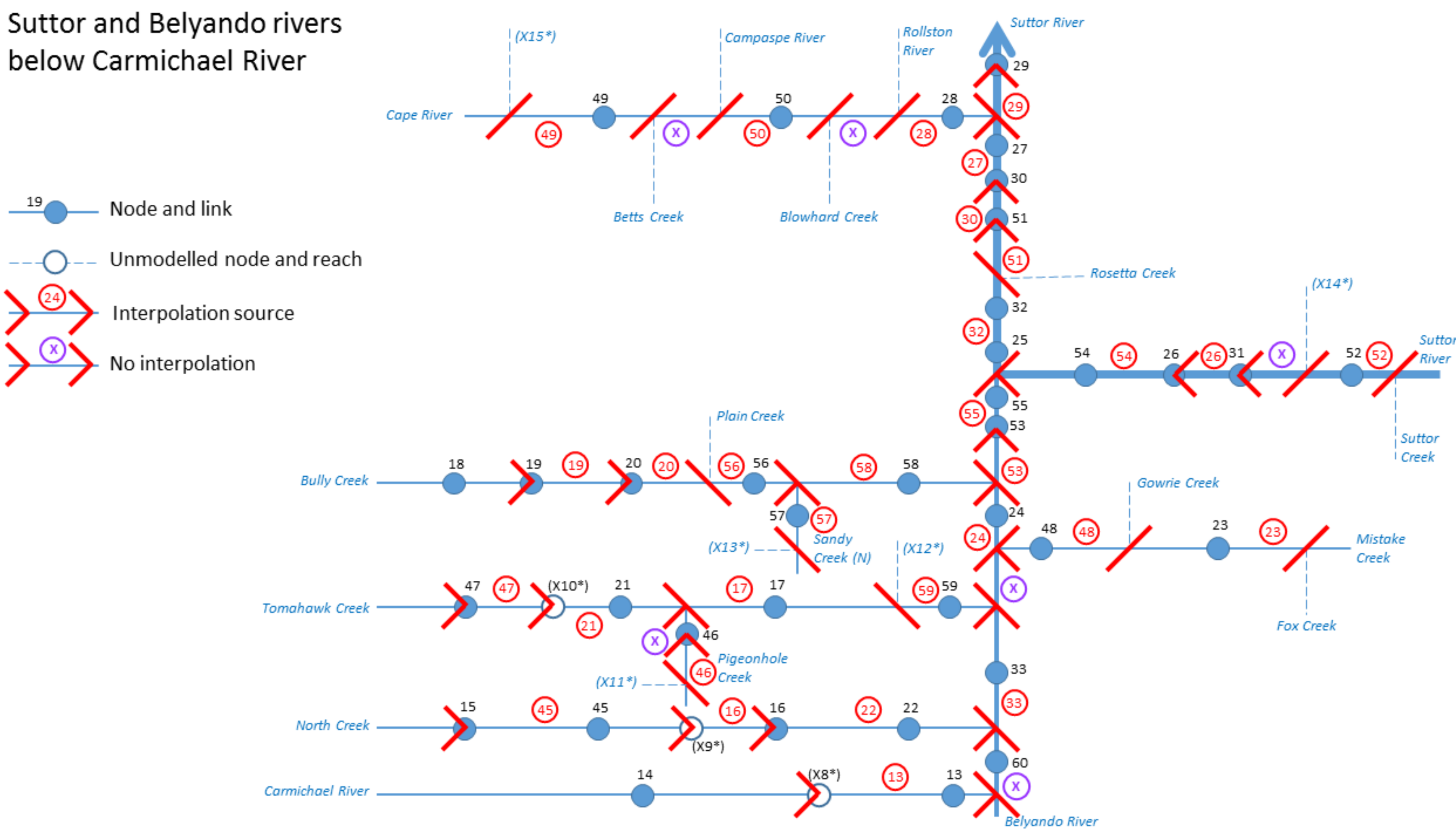

Figure 13 Scheme for interpolating surface water hydrological response variables from model nodes to stream links for the Suttor River and the Belyando River, below the Carmichael River junction

The red arrows that occur at some nodes denote the direction of surface water flow along the stream network, and also bound the interpolation source for discrete links in the stream network to specific model nodes (e.g. the segment of North Creek between the red arrow at node 15 and the red arrow at location X9* is assigned the model outputs generated at node 45). In contrast, the straight red lines only occur on stream links between model nodes (commonly where a smaller non-modelled tributary joins the modelled stream network), although they also bound the interpolation source for the link to a specific node. Further information about the locations on this diagram denoted by an ‘X*’ is in Table 7. Model node 29 at the top of this node – link schematic occurs at the start of Lake Dalrymple.

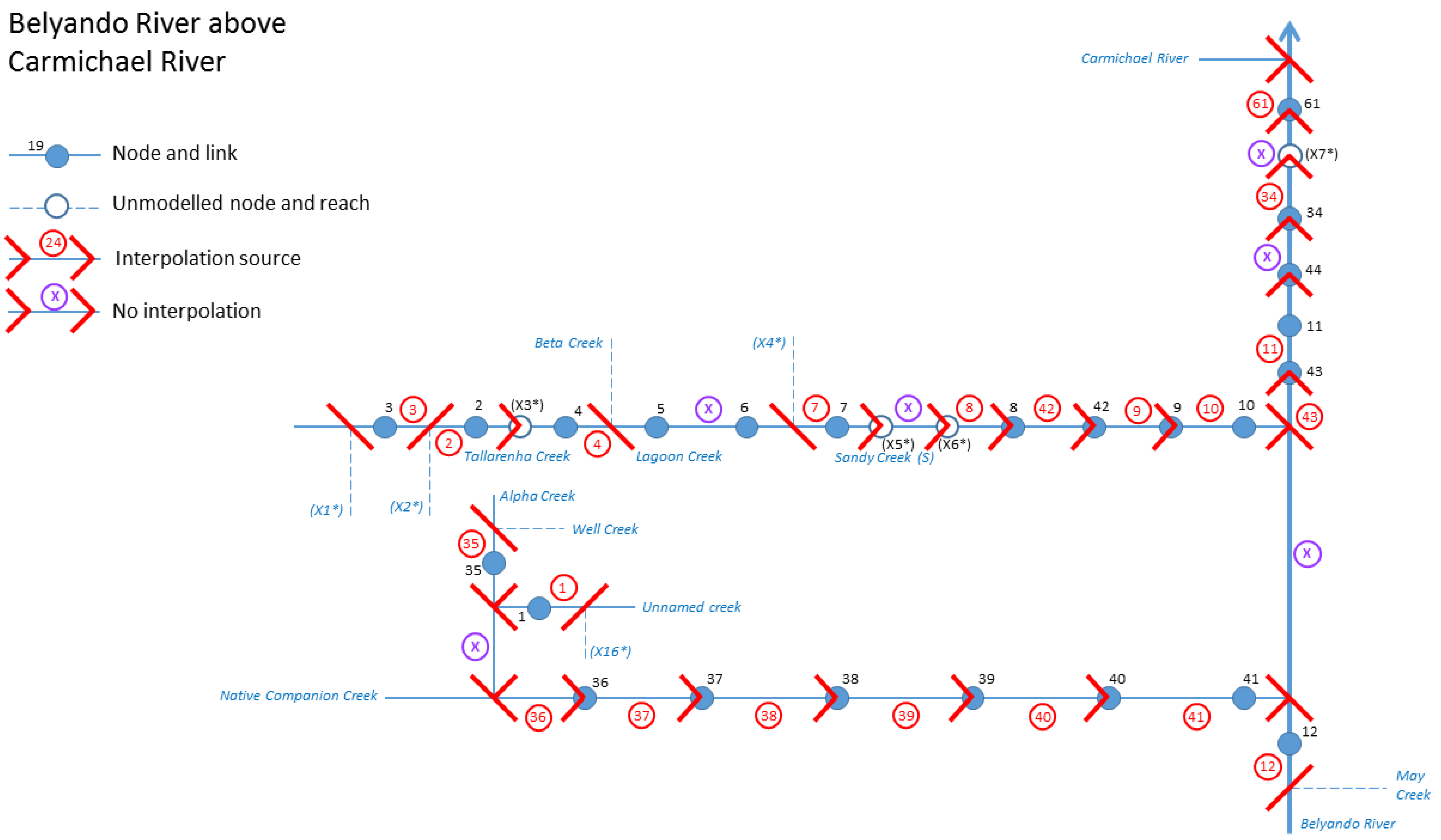

Figure 14 Scheme for interpolating surface water hydrological response variables from model nodes to stream links for the Belyando River above Carmichael River junction

The red arrows that occur at some nodes denote the direction of surface water flow along the stream network, and also bound the interpolation source for discrete links in the stream network to specific model nodes (e.g. the segment of Native Companion Creek between the red arrow at node 36 and the red arrow at node 37 is assigned the model outputs generated at node 37). In contrast, the straight red lines only occur on stream links between model nodes (commonly where a smaller non-modelled tributary joins the modelled stream network), although they also bound the interpolation source for the link to a specific node. Further information about the locations on this diagram denoted by an 'X*' is in Table 7.

Table 7 Explanation of codes used in Galilee surface water model node to stream link interpolation schematics

Symbol used on schematics	Type	Longitude	Latitude	Description
X1	Stream	146.4707	–23.6411	Small unnamed stream joining Tallarenha Creek from the east
X2	Stream	146.4835	–23.6092	Small unnamed stream joining Tallarenha Creek from the east
X3	Location	146.4656	–23.5379	Location on Tallarenha Creek below model node 2 at road crossing
X4	Stream	146.4995	–23.0921	Small unnamed stream joining Sandy Creek from west
X5	Location	146.4988	–23.0651	Location on Sandy Creek below model node 7
X6	Location	146.5152	–22.9941	Location on Sandy Creek above model node 8
X7	Location	146.5368	–22.1521	Location on Belyando River
X8	Location	146.5282	–22.0812	Location on Carmichael River where lower end of Cabbage Tree Creek anabranch re-joins river
X9	Location	146.6046	–21.9407	Location on North Creek where Belyando River anabranch joins
X10	Location	146.3512	–21.7721	Location on Tomahawk Creek
X11	Stream	146.2638	–21.7202	Unnamed stream joining Pigeonhole Creek from the west
X12	Stream	146.6721	–21.7990	Unnamed stream joining Tomahawk Creek from the west
X13	Stream	146.6571	–21.7174	Unnamed stream joining Sandy Creek (north) from the west
X14	Stream	147.6085	–21.6029	Unnamed stream joining Suttor River from the east
X15	Stream	145.3641	–20.4423	Unnamed stream joining Cape River from the west
X16	Stream	146.5232	–23.7434	Unnamed stream joining unnamed creek containing model node 1, from the west

This table explains the codes used for various small streams and point locations on the surface water interpolation schematics, shown in Figure 13 and Figure 14. The symbols X1 to X7 (inclusive), as well as X16, are shown in Figure 14. The symbols X8 to X15 (inclusive) are depicted in Figure 13.

3.2.3.3 Applying remotely sensed data

Several components of the impact and risk analysis have applied remotely sensed data (e.g. satellite imagery from Landsat) and derivative products such as tasselled cap wetness (Section 3.2.3.3.1) and the normalised difference vegetation index to aid in the assessment (Section 3.2.3.3.2). In particular, these tools have helped to evaluate the potential groundwater contribution (baseflow) to the minor stream network (non-modelled streams) in the zone of potential hydrological change, as well as assisting in the interpretation of the hydrological processes that support several distinct areas of the ‘Springs’ landscape group within the zone of potential hydrological change. The general remote sensing workflow used in this assessment involved:

- geographic overlay analysis, which involved overlaying the remote sensing datasets (using GIS tools and applications) with other types of geographic data, such as the stream network and digital elevation model data, within the zone of potential hydrological change
- assessment of distinctive spatial and temporal trends in the tasselled cap wetness and normalised difference vegetation index datasets within the zone, for example, correlating stream segments (or spring areas) with vegetation greenness and detectable surface water signatures (particularly in drought periods)
- qualitative evaluation of the non-modelled stream network within the zone to assess the level of groundwater dependency. As explained further in Section 3.3.1.2.2, this analysis was used to classify which parts of the non-modelled stream network in the groundwater zone of potential hydrological change may be potentially impacted due to additional coal resource development (although the magnitude of impact cannot be quantified as these groundwater-dependent streams were not modelled).

The specific application of these remotely sensed datasets and tools to improve understanding of the nature of surface water – groundwater interaction is detailed in Section 3.3.1.2.2. Further information about the 'Springs' landscape group is in Section 3.4.3, with specific spring-related ecological assets discussed in Section 3.5.2.

The remotely sensed data analysis used for this BA was undertaken in collaboration with researchers from the Digital Earth Australia team (Geoscience Australia, 2017). Digital Earth Australia (DEA) is an analysis platform for satellite imagery and other earth observation data that are based on the Australian Geoscience Data Cube (Lewis et al., 2017). DEA holds an archive of 30 years of corrected and processed earth observation data, and provides tools to interact with the data through the Australian National Computational Infrastructure (NCI) high performance computing environments. Published DEA products based on remotely sensed data include Water Observations from Space (WOfS) and the Inter-Tidal Extents Model (ITEM), a map of Australia's intertidal zone (Mueller et al., 2016; Sagar et al., 2017).

3.2.3.3.1 Tasselled cap wetness

The tasselled cap wetness in the landscape summary output is produced using DEA. Landsat surface reflectance data at 25 m resolution with information in the red, green, blue, near infra-red and short-wave infra-red spectral bands are retrieved from the DEA archive using a spatial query for the area of interest. Clouds and areas of terrain shadow are masked from the surface reflectance data. A tasselled cap transformation is performed on each of the surface reflectance bands to produce a per-pixel 'wetness' value. This method is based on the tasselled cap transformation of Crist (1985), but only uses the component of transformed surface reflectance in the 'wetness' direction to identify the presence of water and wet vegetation.

Areas of water and wet vegetation are highlighted where pixels exceed a specified wetness threshold. Pixels exceeding the wetness threshold are counted through the temporal image archive. The wetness in the landscape summary is then presented as the percentage of scenes where the pixel has contained water or wet vegetation through time. Selecting a spatial transect of interest (e.g. a line that follows a river, or crosses a wetland or spring) allows for retrieval of the wetness threshold data for each image pixel along the transect line. Stacking the pixel information with respect to time (given the 30-year temporal coverage of DEA) can be used to create a Hovmöller plot, which allows for analysis of wetness (or other relevant variables, such as rainfall) along the transect line (or at particular points) through time. Examples of Hovmöller plots for selected transects in the zone of potential hydrological change are presented and assessed in Section 3.5.2.

3.2.3.3.2 Normalised difference vegetation index

The normalised difference vegetation index (NDVI) was initially developed in the late 1970s (Tucker, 1979). The NDVI provides a consistent metric of vegetation greenness for terrestrial vegetation (i.e. vegetation where there is no water present beneath the canopy within the pixel). Hovmöller plots of vegetation greenness provide a valuable way of characterising how persistent vegetation is, and whether it has an evergreen habit, or is responding to annual or multi-decadal patterns of rainfall. The Hovmöller plots presented in Section 3.5.2 also provide information about spatial and temporal variations in NDVI for selected areas within the zone of potential hydrological change in the Galilee subregion.

3.2.3.4 Representing predictive uncertainty

The models used in the BA for the Galilee subregion were run many hundreds or thousands of times and 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 15). This approach allowed an assessment of the likelihood of exceeding a given magnitude of change, and has underpinned the analysis of the risk posed to landscape classes and water-dependent assets due to coal resource development.

An important point to note here is that the probabilities reported in the BAs are conditional probabilities, that is, they are conditional on the various assumptions and limitations that have underpinned the development of the probabilistic models. The concept of conditional probabilities is critical to the uncertainty propagation methodology used in BAs (see companion submethodology M09 (Peeters et al., 2016)), as demonstrated through the emphasis on the qualitative uncertainty analysis reported in several products for the Galilee subregion, including companion product 2.6.1 (Karim et al., 2018) and companion product 2.6.2 (Peeters et al., 2018). Within these hydrological modelling products there are detailed descriptions and analyses of the key assumptions and limitations incorporated in the surface water and groundwater modelling approaches.

Groundwater models require information about physical properties such as the thickness of geological layers, and the hydraulic conductivity and specific storage of aquifers. As the exact values of these properties at every point and subsurface depth across the modelling domain are not known, the Assessment team used a credible range of values, which are based on various sources of data (commonly point-scale) combined with expert hydrogeological knowledge. The groundwater model was run thousands of times using a different set of plausible values for these physical properties each time. Historical observations, such as groundwater levels and changes in water movement and volume, were used to constrain and validate the model runs. Further details about the input parameter ranges used for the Galilee subregion groundwater modelling is in Table 13 of companion product 2.6.2 (Peeters et al., 2018).

The complete set of model runs produced a range or distribution of predictions (Figure 15) that are consistent with available observations and the conceptual understanding of the modelled system. The range conveys the confidence in model results, with a wide range indicating that the expected outcome is less certain, whereas a narrow range provides stronger evidence for decision making due to an increased level of confidence in the results. The distributions created from these model runs are expressed as probabilities that drawdown or a change in streamflow will exceed relevant thresholds, as there is no single 'best' estimate of change.

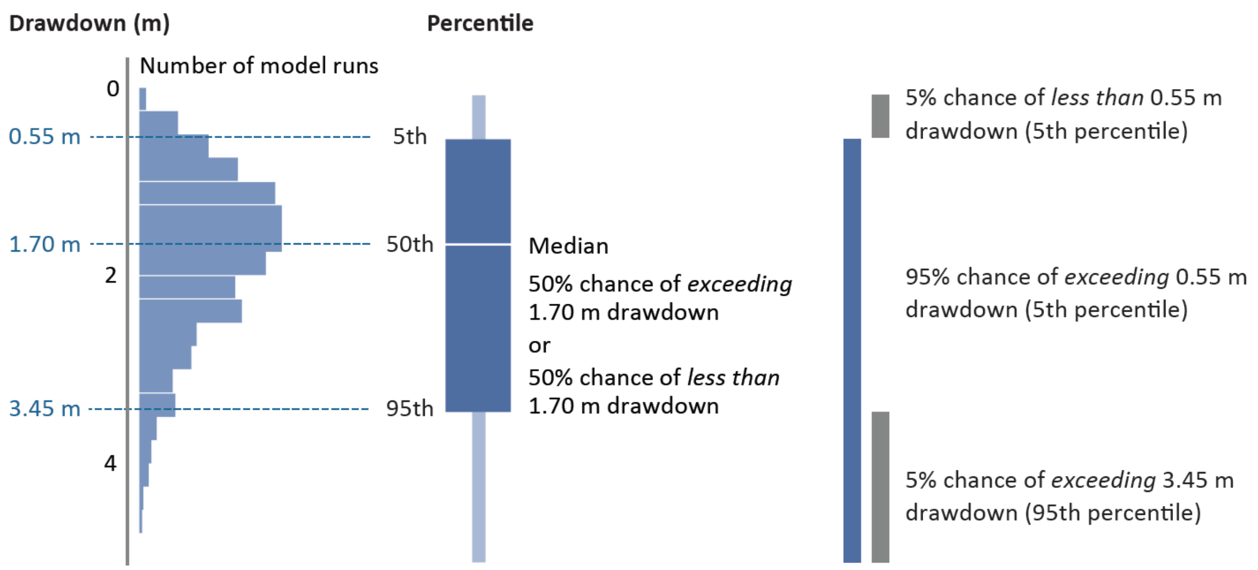

Figure 15 Illustrative example of probabilistic drawdown results using percentiles and percent chance and the probability terminology used in bioregional assessments

The chart on the left shows the distribution of results for drawdown, obtained from an ensemble of thousands of model runs that use many sets of parameters. These generic results are for illustrative purposes only and are not actual results from the Galilee subregion.

In this assessment, the estimates of the various hydrological response variables, such as drawdown or annual flow, are commonly presented as the 95th, 50th or 5th percentile results. These generally correspond to a 5%, 50% or 95% chance of exceeding specified thresholds. Figure 16 illustrates how the probabilistic approach applied in this BA is used to spatially segregate the subregion and its landscape classes, including criteria used to define the zone of potential hydrological change.

Throughout this product, the term *'very likely'* is used to describe areas where there is a greater than 95% chance of something occurring, and *'very unlikely'* is used where there is a less than 5% chance.

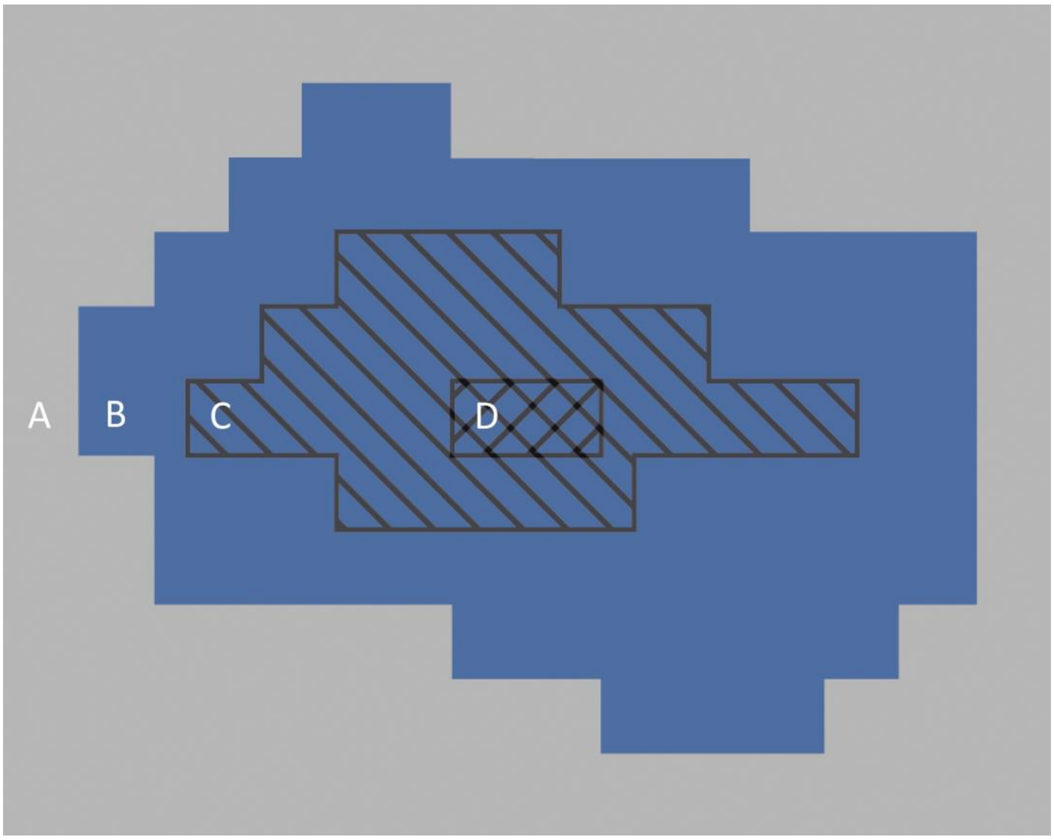

Figure 16 Schematic example of key areas in the landscape defined by probabilistic results

The assessment extent was divided into smaller square assessment units (see Section 3.2.4.1) and the probability distribution (Figure 15) was calculated for each. In this product, results are reported with respect to the following areas:
A. outside the zone of potential hydrological change, where hydrological changes (and hence potential impacts) are *very unlikely* (defined by maps showing the 95th percentile)
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 95th percentile). Further work is required to determine whether the hydrological changes in the zone translate into impacts for water-dependent assets and landscapes
C. 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 50th percentile)
D. 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 5th percentile).

3.2.4 Assessing potential impacts for landscape classes and assets

The BA approach for assessing potential impacts for landscape classes (ecosystems) and water-dependent assets is discussed in companion submethodology M10 (as listed in Table 1) for analysing impacts and risks (Henderson et al., 2018). The zone of potential hydrological change focuses the attention of the analysis on areas where there may be changes in surface water and/or groundwater that are attributable to additional coal resource development.

The principal focus of the BA's impact analysis is on water-dependent assets that are nominated by the community, or are recognised as being significant at state- or national-level (e.g. listed as a matter of national environmental significance under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999*). These assets may have a variety of values, including ecological, sociocultural and economic values. The water-dependent asset register (companion product 1.3 for the Galilee subregion (Sparrow et al., 2015); Bioregional Assessment Programme, Dataset 8) provides a simple and authoritative listing of the assets within the assessment extent. The register is a compilation of assets identified in databases compiled by several natural resource management groups in the Galilee subregion, as well as Australian and Queensland government databases. Additional assets were also supplied during several Galilee subregion BA assets workshops with various experts and organisations with local knowledge, held in September 2014 (in Longreach and Richmond), and October 2014 (in Brisbane). The identified assets compiled from all sources were assessed by the Assessment team for fitness for BA purpose, location within the assessment extent and water dependency. Assets that satisfied the requirements were considered in the impact and risk analysis reported in this product.

Landscape classification is fundamental to the impact and risk analysis and was used to discretise the heterogeneous landscape across the Galilee assessment extent into a manageable number of landscape classes for the impact and risk analysis. For BA purposes, a landscape class is an ecosystem with characteristics that are expected to respond similarly to changes in groundwater and/or surface water due to coal resource development. Landscape classes were used to reduce the complexity of assessing potential impacts on a large number of water-dependent assets by focusing on the hydrological drivers and interactions relevant for regional-scale assessment. Although some degree of inherent heterogeneity invariably exists, individual landscape classes are nevertheless considered by the Assessment team to share a greater level of biophysical attributes (in comparison to different landscape classes), and hence are regarded as appropriate for the regional-scale focus of the BA for the Galilee subregion.

The landscape classes provide a meaningful scale for understanding potential ecosystem impacts and communicating them through their more aggregated system-level view. The landscape classification for the Galilee subregion is described in Section 2.3.3 of companion product 2.3 (Evans et al., 2018) and the methodology that underpins it is described in companion submethodology M05 (as listed in Table 1) for developing a conceptual model of causal pathways (Henderson et al., 2016).

Potential hydrological changes were assessed by overlaying the extent of a landscape class or asset on the zone of potential hydrological change due to additional coal resource development. For the landscape classes or assets that lie wholly outside the zone, hydrological changes (and hence any potential ecosystem or asset-level impacts) are *very unlikely*, and are thus ruled out in terms of further analysis. Section 3.4.2 identifies landscape classes in the Galilee subregion that can be ruled out from potential impacts on this basis.

Where an asset or landscape class wholly or partially intersects the zone of potential hydrological change, there is the potential for impact. This does not necessarily mean there will be an impact, but rather, based on the magnitude of the hydrological change, the possibility of an impact cannot be ruled out and further investigation is required. The nature of the water dependency of the landscape class can also be important at this stage of the analysis. For example, if the water dependence of a landscape class relates to overbank flows to support seedling establishment, but the significant hydrological changes in the nearby stream relate only to low-flow variables (i.e. flows that are contained within the streambanks), then it may be possible to rule the landscape class out of further consideration because it is unlikely to be impacted.

Four receptor impact models were built, representing three landscape groups in the Galilee subregion (Table 8). These were used to quantify the potential impact of the predicted hydrological changes on a selected receptor impact variable within the receptor impact model (companion product 2.7 for the Galilee subregion (Ickowicz et al., 2018)). Meaningful hydrological response variables and receptor impact variables (Table 8) were elicited from experts (listed in Table 3 in companion product 2.7 for the Galilee subregion (Ickowicz et al., 2018)) during qualitative and receptor impact model workshops and subsequent correspondence. A full description of receptor impact modelling is described in companion submethodology M08 (as listed in Table 1) (Hosack et al., 2018), with its application to the Galilee subregion in companion product 2.7 (Ickowicz et al., 2018). This includes Table 4 in Section 2.7.1.2.6 of companion product 2.7 which summarises some of the assumptions made for the receptor impact modelling, the implications of those assumptions for the results, and how those implications are acknowledged through the BA workflow and ultimately within this product. Examples of the main assumptions include the simplification of complex ecological systems, the segregation of the system into discrete classes that are assumed to respond similarly to hydrological changes, and the assumption that areas of landscapes classes remain constant over time (see Table 4 in companion product 2.7 for the Galilee subregion (Ickowicz et al., 2018) for the complete list of assumptions). The specific implications or flow-on effects of these assumptions are further explained in the respective sections for individual landscape classes in companion product 2.7 (Ickowicz et al., 2018). It is also important to note that the outputs from receptor impact modelling (which translate potential hydrological change into potential change in ecosystem indicators) are only one line of evidence used in this impact and risk analysis, and these outputs need to be considered in the context of the assumptions made and the availability and quality of local data.

Table 8 Landscape groups, receptor impact variables and relevant hydrological response variables for receptor impact modelling for the Galilee subregion

Landscape group	Receptor impact variable	Receptor impact variable description and sampling area	Hydrological response variables
Streams, GDE and Streams, non-GDE (combined)	***Offadens* sp. (Baetidae)** (aquatic)	Density of aquatic nymphs of *Offadens* sp. (Baetidae) (a type of mayfly), sampled in riffles, 3 months after the wet season. Sampling is focused on a 2.0 x 0.5 m area of stream.	LQD LME
Streams, GDE	**Percent foliage cover** (terrestrial)	Target species include *Eucalyptus camaldulensis* and *Melaleuca* spp. The sample unit is a 100 m length transect along the stream reach extending from the stream channel to the top of the bank. The width is at least 10 m increasing to 15 m in areas where more than a single row of river red gum is present during the reference period. This sample frame is invariant for predictions in future periods.	EventsR2.0 LQD dmaxRef
Floodplain terrestrial groundwater-dependent ecosystems	**Percent foliage cover** (terrestrial)	Target species include *Eucalyptus coolabah*, *E. brownii*, *E. populnea* and *Acacia cambagei*. Species excluded are *E. tereticornis* and *E. camaldulensis*. The sample unit is 1 ha.	EventsR2.0 dmaxRef
Non-floodplain, terrestrial groundwater-dependent ecosystems	**Percent foliage cover non-floodplain** (terrestrial)	Annual average percent foliage cover of non-floodplain tree species in a notional 50 x 50 m quadrant.	dmaxRef tmaxRef

LQD = the number of days per year with low flow (<10 ML/day), averaged over a 30-year period, LME = the maximum length of spells (in days per year) with low flow, averaged over a 30-year period, dmaxRef = maximum difference in drawdown under the baseline future or under the coal resource development pathway future relative to the reference period (1983 to 2012), tmaxRef = the year that the maximum difference in drawdown occurs, across all years. tmaxRef is negative if before the end of the relevant period or positive if after the end of the relevant period. The short-term period is 2013 to 2042 and the long-term period is 2073 to 2102, EventsR2.0 = the mean annual number of events with a peak daily flow exceeding the threshold (the peak daily flow in flood events with a return period of 2.0 years as defined from modelled baseline flow in the reference period (1983 to 2012)). This metric is designed to be approximately representative of the number of overbank flow events in future 30-year periods. Each hydrological response variable is typically reported as the maximum change due to additional coal resource development.

Potential impacts as determined from this BA are reported in Section 3.4 for landscape classes and Section 3.5 for assets. Given the large number of assets, the focus of Section 3.5 is on identifying those assets that are considered to be 'more at risk of hydrological change'. These are the assets that overlap with areas in the zone of potential hydrological change that have at least a 50% chance of a hydrological change larger than the threshold hydrological response variable values used to define the zone. Local information is necessary to improve upon the regional-scale risk predictions made by this BA at any given site.

In addition to the analysis presented in this product, impact profiles for landscape classes and assets are available at www.bioregionalassessments.gov.au. Each profile summarises the hydrological changes and potential impacts that pertain to that landscape class or asset, for example, an increase in groundwater drawdown in the 'Floodplain terrestrial groundwater-dependent ecosystems' landscape group in the zone of potential hydrological change. Users of the BA products can aggregate and consider potential impacts for their own scale of interest.

The BA product suite can also be used to explore the results for landscape groups and assets using the map-based BA Explorer interface at www.bioregionalassessments.gov.au/explorer/GAL/.

3.2.4.1 Information management and processing

A large number of multi-dimensional and multi-scaled datasets were used in the impact and risk analysis for the Galilee subregion, including hydrological model outputs, and ecological, economic and sociocultural asset data from a range of sources. To manage these datasets and produce meaningful results, a consistent spatial framework was needed that permitted rapid spatial and temporal analyses of impacts, without compromising the resolution of the results.

The datasets for this BA were organised into an *impact and risk analysis database* (Bioregional Assessment Programme, Dataset 9) to enable efficient and effective data management. The purpose of the database is to produce result datasets that integrate the available modelling and other evidence across the Galilee assessment extent. The database is required to support three types of analyses:

1. Analysis of hydrological changes
2. Impact profiles for landscape classes
3. Impact profiles for assets.

The results of these analyses are summarised in each of the following three main sections of this product (i.e. Sections 3.3, 3.4 and 3.5), with more detailed information available at www.bioregionalassessments.gov.au. The impact and risk analysis database is also available at data.gov.au (Bioregional Assessment Programme, Dataset 9).

3.2.4.1.1 Displaying analysis results

As previously mentioned, the main geographic focus of the impact and risk analysis for the Galilee subregion is on the area termed the *zone of potential hydrological change* (see Section 3.3.1 for details regarding the development of this zone). This area is near the central-eastern boundary of the Galilee assessment extent, around the seven coal mines evaluated by the numerical hydrological modelling. The area of the Galilee zone of potential hydrological change is about 14,000 km^2, which represents less than 3% of the total area of the Galilee assessment extent (about 612,000 km^2). One important consequence of narrowing the spatial extent of this BA is that most of the maps presented in this product have been redesigned to zoom into the main area of interest, thereby excluding large parts of the Galilee assessment extent (Figure 17).

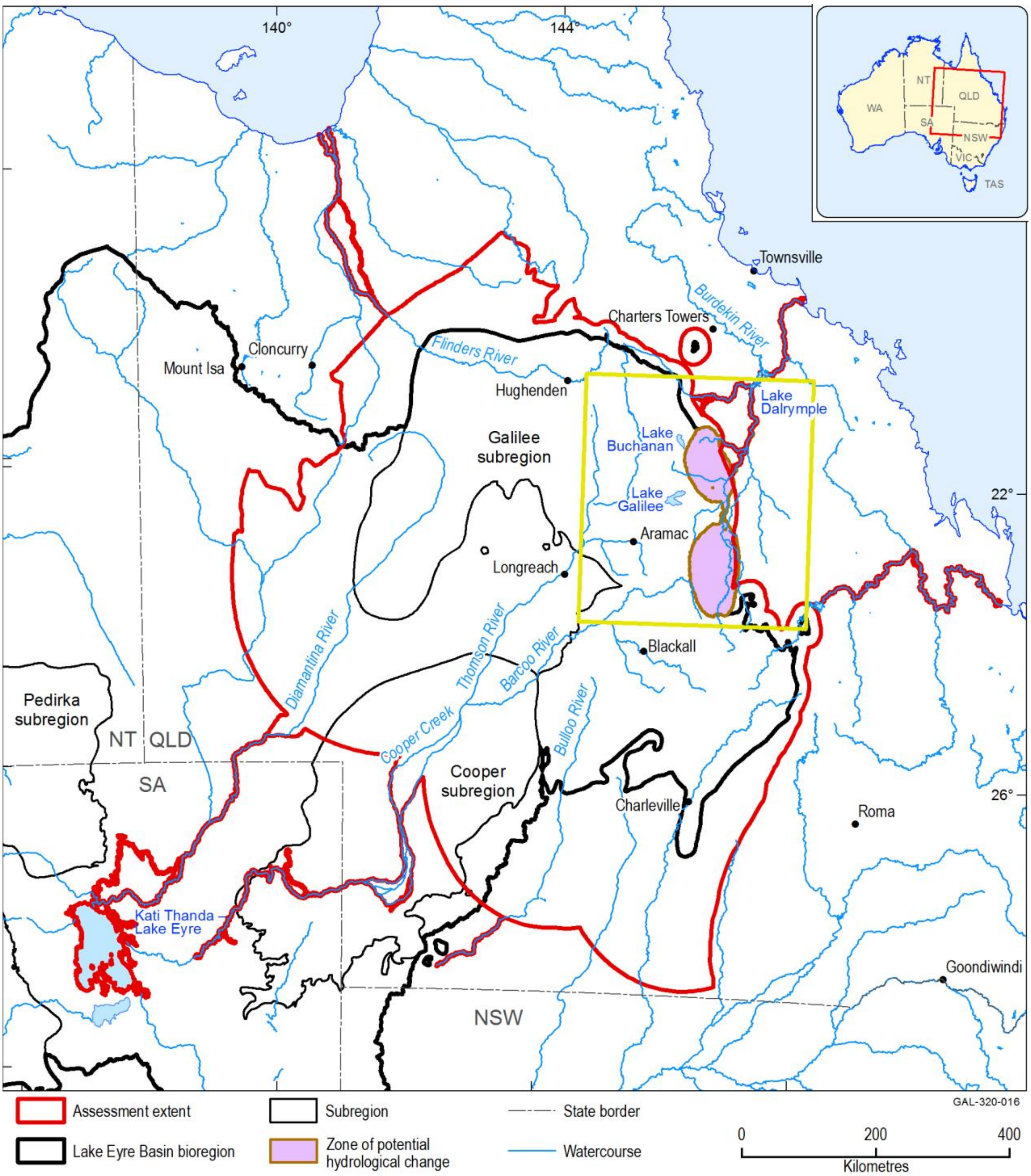

Figure 17 Comparison of map extent (yellow box) commonly used in reporting results of the Galilee impact and risk analysis with the much larger Galilee assessment extent

The Galilee zone of potential hydrological change is less than 3% of the area of the assessment extent, which represents the entire area investigated for this bioregional assessment. Consequently, most results presented on maps in the impact and risk analysis product are zoomed to this main area of interest, and exclude much of the broader Galilee assessment extent.
Data: Bioregional Assessment Programme (Dataset 9)

In addition to displaying results on various maps, this product uses two other main data and information presentation methods. The Assessment team considers these are the most appropriate means to communicate the impact and risk analysis results:

1. Data tables
2. Cumulative exceedance plots.

3.2.4.1.1.1 Data tables

The vast amount of data produced by the impact and risk analysis database are summarised in this product in tabular form (see Section 3.3 and Section 3.4 for specific examples). The probabilistic outputs for selected hydrological response variables (output from either the groundwater or surface water models) are categorised against specified thresholds and reported for the 5th, 50th and 95th percentile results from relevant modelling runs. The thresholds are used consistently across all impact and risk products in the Bioregional Assessment Programme, and have been chosen with regard for existing impact thresholds under either Queensland or NSW legislation (such as groundwater drawdown thresholds of 0.2 m, 2 m and 5 m specified in Queensland's *Water Act 2000*), or for clarity in reporting data ranges across the surface water impacts.

3.2.4.1.1.2 Cumulative exceedance plots

Cumulative exceedance diagrams are another method of presenting the impact and risk analysis results in this product. Specific hydrological examples are provided in Section 3.3. Similar to the data tables, these results are also shown for the 5th, 50th and 95th percentiles to illustrate the range of predictions. The cumulative exceedance plots are particularly useful in summarising changes in various hydrological response variables for different areas or stream lengths. For example, these plots can provide a clear summary of the total area within the zone of potential hydrological change that may be subject to a certain amount of drawdown due to additional coal resource development (across the range of the probability distribution). Likewise, the total length of stream network potentially subjected to increases or decreases in the number of days of low flow or high flow (respectively) is clearly summarised using cumulative exceedance plots, as reported in Section 3.3.3.

3.2.4.1.2 Data processing

The datasets used in the impact and risk analysis database (Bioregional Assessment Programme, Dataset 9) include the water-dependent assets, landscape classes, numerical modelling results (groundwater, surface water and receptor impact modelling), coal resource development 'footprints' and other relevant geographic information, such as the boundaries of the subregion, assessment extent and zone of potential hydrological change. All data in the impact and risk analysis database (and the results derived from it) meet the overarching BA requirements for data transparency and accessibility.

The data were structured to overcome the slow geoprocessing operations typical of complex queries of very large spatial datasets, such as those required for this BA. This structuring was achieved by:

- loading as many attributes as possible into relational tables, including some spatial information such as area and length data
- simplifying and partitioning the remaining spatial data using assessment units while, importantly, retaining spatial geometries below the resolution of the assessment units.

An assessment unit is a geographic area represented by a square polygon with a unique identifier. Assessment units are non-overlapping and completely cover the Galilee zone of potential hydrological change. The spatial resolution of the assessment units is closely related to that of the BA groundwater modelling and is 1 km x 1 km for the Galilee subregion (Figure 18). Assessment units were used to partition asset and landscape class spatial data for the impact analysis. The partitioned data can be combined and recombined into any aggregation supported by the conceptual modelling, causal pathways and model data.

The interpolated modelled groundwater drawdowns (see Section 3.2.3.1) are at the same resolution as the assessment units and contain a single value per assessment unit. However, the surface water modelling generated results at points (model nodes). These are then extrapolated to specific reaches of the surface water network (see Section 3.2.3.2), and are mapped to assessment units. For assessment units with only a single stream reach, the assessment unit stores the information associated with this stream segment. However, where the assessment unit contains multiple stream reaches (e.g. at the confluence of two streams), it was necessary to prioritise which stream reach was used to inform the value of the assessment unit for representing the surface water modelling results. This process applied expert hydrological judgement and reasoning, and followed a general set of rules for prioritising stream reaches, including:

- whether the modelled reaches show a hydrological change (i.e. a reach with a potential hydrological change takes priority over a reach predicted to have no significant change)
- whether the stream reach is represented in the model (i.e. modelled reaches take priority)
- the stream order of each reach (i.e. a higher order stream, such as a main channel, takes priority over a lower order stream, such as a tributary)
- reach length (i.e. where two streams in an assessment unit are of equally high stream order, priority is given to the longer of the two).

To manage issues of geospatial quality in source datasets and also technology integration, the impact and risk analysis database performed a series of geospatial operations on the source data geometry. These operations are PostGIS geometry validation, 1 m or less snap-to-grid, and (in some cases) 1 cm polygon buffering. The effect of these operations on area and length calculations is considered small. In general, the larger an individual geospatial feature, the smaller the relative impact and vice versa. For features with area greater than 10 km^2 and length greater than 10 km, variation from source data calculations ranges between 0.0% and 0.5%. This variation may approach 40% for smaller geospatial features (e.g. features that may be up to several square metres in area). The geospatial operations necessary for the impact and risk analysis account for all differences in length and area that may be found when comparing data stored and used within a GIS environment, with that used in the impact and risk analysis database.

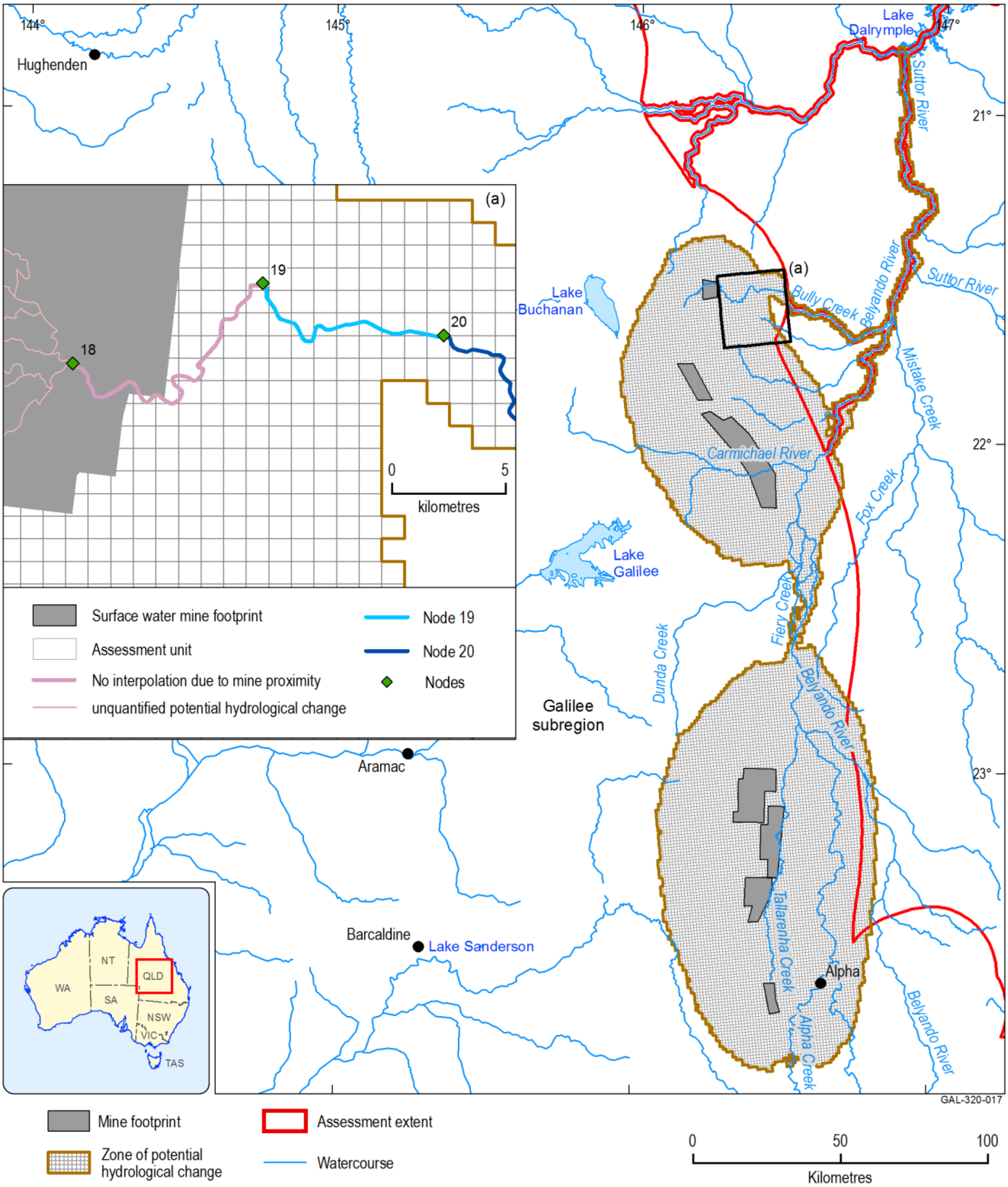

Figure 18 Assessment units across the zone of potential hydrological change for the Galilee subregion

The inset box (a) provides an example of the interpolation approach used to allocate hydrological response variable data from surface water model nodes to adjacent surface water reaches. In this example, near the proposed Hyde Park Coal Mine, there are three surface water model nodes shown on the main stream (Bully Creek) that flows through the mining project. Surface water model interpolation upstream of node 19 was not possible due to proximity to the proposed mine site. Hence, these stream reaches are classed as 'unquantified potential hydrological change' for the purposes of the bioregional assessment for the Galilee subregion. Likewise, the network of smaller non-modelled streams that will be intersected by the mine pits and site infrastructure are also classed as streams with 'unquantified potential hydrological change'. The other stream reaches shown on Bully Creek are coloured according to the model node used for the interpolation. This inset also depicts the regular 1 km x 1 km grid of assessment units for the zone.

Data: Bioregional Assessment Programme (Dataset 4, Dataset 9)

3.2.5 Categorising risk to ecosystems and assets

3.2.5.1 Ecosystems

Within BAs the relative level of risk to ecosystems and ecological assets within the zone of potential hydrological change is categorised to assist the rule-out process and help identify where further local-scale assessment may be required. In the context of water-dependent ecosystems (as represented by landscape groups), three levels of relative risk due to additional coal resource development are here defined, based on the combined outputs of relevant hydrological modelling and receptor impact modelling (see product 2.7 for the Galilee subregion (Ickowicz et al., 2018) for more information on the receptor impact models). The three risk categories in BAs relevant to landscape groups are:

- 'more at risk of ecological and hydrological changes'
- 'at some risk of ecological and hydrological changes'
- 'at minimal risk of ecological and hydrological changes'.

Assessment units that overlap with a landscape group for which receptor impact modelling has been undertaken may be categorised under one of these three classes if the modelled hydrological changes (i.e. as represented by the relevant groundwater and/or surface water hydrological response variables) result in ecological changes that lie within defined risk thresholds. These thresholds have been chosen by the Assessment teams based on multiple lines of evidence and are defined using relevant receptor impact variables. For example, the defined risk thresholds selected for the 'High-flow macroinvertebrate' receptor impact model applied to the 'Streams, non-GDE' landscape group are:

- The lower risk threshold is defined as a decrease of greater than 10 mayfly nymphs per m^2
- The upper risk threshold is defined as a decrease of greater than 20 mayfly nymphs per m^2.

Thus, any assessment units that exceed the lower risk threshold (but not the upper risk threshold) for a landscape group are defined as being 'at some risk of ecological and hydrological changes'. If the upper risk threshold is exceeded, then these assessment units are defined as being 'more at risk of ecological and hydrological changes'. Importantly, these risk definitions highlight areas relative to the rest of that landscape group, and thus flag locations where any future local-scale assessment is best prioritised. To aid this interpretation, composite risk maps are provided in Section 3.4 for each of the landscape groups assessed through receptor impact modelling in the BA of the Galilee subregion. The overall risk categories depicted on these maps represent the highest level of relative risk estimated for each assessment unit. The specific application of this risk categorisation approach for the four landscape groups for which receptor impact models were built for the Galilee subregion is outlined in Section 3.4 (the four landscape groups are: 'Streams, GDE', 'Streams, non-GDE', 'Floodplain, terrestrial GDE' and 'Non-floodplain, terrestrial GDE').

3.2.5.2 Ecological water-dependent assets

Categorising risk for assets follows a similar general approach as for ecosystems, but does not incorporate ecological modelling results as receptor impact models were developed only for some of the landscape groups in the BA of the Galilee subregion. Although it is technically possible to develop receptor impact models for individual ecological assets, the total number of such assets within the zone (241 ecological water-dependent assets occur in the zone of potential hydrological change for the Galilee subregion, as explained in Section 3.5.2) precluded the development of individual asset-scale receptor impact models due to the operational constraints of the BA. As a result, composite risk maps as presented for the landscape groups (Section 3.4) were not developed for assets.

Consequently, there is only a single risk category used to highlight those assets that are considered 'more at risk of hydrological changes'. Assessment units that overlap with the spatial distribution of an asset are considered 'more at risk' based on the degree of hydrological changes that exceed the thresholds of risk defined by the Assessment team (based on their expert opinion and using multiple lines of available evidence). For example, assets that intersect with the 'Streams, GDE', 'Floodplain, terrestrial GDE' and 'Non-floodplain, terrestrial GDE' landscape groups were deemed 'more at risk' if the assessment unit in which they occur has an increase in drawdown exceeding 2 m. Drawdown is used for these landscape groups as it is a hydrological response variable that is identified as important through the qualitative mathematical modelling (see Ickowicz et al. (2018) for further information about the qualitative mathematical modelling results for these landscape groups). For other landscape groups, other hydrological response variables are used. The identification of assets considered 'more at risk of hydrological changes' in the Galilee subregion's zone of potential hydrological change is outlined in Section 3.5.2.5.

The risk categorisation approach and associated terminology used for assets is shown in Figure 19. Although a more detailed investigation of risk to each asset in the zone was not possible for this BA, Section 3.5.2.7 provides a case study for an individual ecological asset (the 'potential distribution of Black Ironbox'). This example illustrates how multiple lines of evidence, including the outputs of ecosystem-scale receptor impact models for relevant landscape groups, can be integrated with existing knowledge to develop a more refined assessment of potential impacts on, and risks to, individual assets.

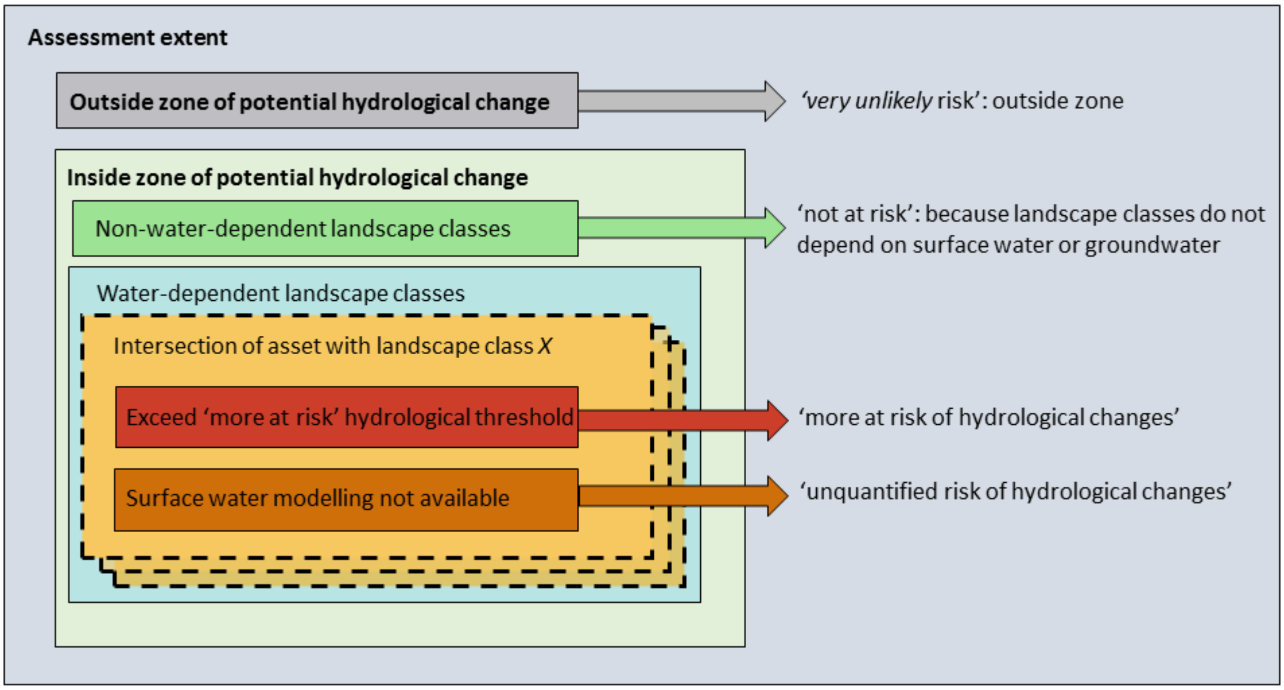

Figure 19 Risk categorisation terminology for ecological water-dependent assets

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3.3 Potential hydrological changes

Summary

The future development of seven large-scale thermal coal mines near the central-eastern margin of the Galilee Basin has the potential to affect the groundwater and surface water systems of this area. For bioregional assessment (BA) purposes, these seven proposed coal mines define the modelled component of the coal resource development pathway (CRDP) for the Galilee subregion. The potential hydrological changes due to these additional coal resource developments (i.e. the modelled CRDP) are the main focus of this section, as there are no baseline coal mines or coal seam gas (CSG) fields in the Galilee subregion. Potential impacts of the non-modelled CRDP, which comprises seven other potential coal mining projects and three CSG developments, are qualitatively assessed in Section 3.6 (and not further discussed in this section).

Probabilistic hydrological modelling has been used to define the zone of potential hydrological change for the Galilee subregion, which covers a total area of 14,030 km^2. Within this zone changes in hydrology due to additional coal resource development exceed defined thresholds for either groundwater or surface water (or both). The groundwater zone of potential hydrological change is defined as the area with at least a 5% chance of drawdown exceeding 0.2 m in the near-surface (unconfined) aquifer system (Quaternary alluvium and Cenozoic sediments). The groundwater zone comprises two separate elongate areas (north and south), with the northern part centred around the cluster of coal mines at Hyde Park, China Stone and Carmichael, and the southern part centred on South Galilee, China First, Alpha and Kevin's Corner. These separate parts of the zone indicate that drawdown from individual mines may overlap in both space and time, thereby leading to cumulative hydrological changes. The southern cumulative drawdown zone is the larger of the two areas and covers about 7898 km^2, whereas the northern area is approximately 5466 km^2. Overall, the combined area of the groundwater zone of potential hydrological change is 13,364 km^2, which includes the 986 km^2 area of the mine exclusion zone (where modelled drawdowns are considered unreliable due to the regional-scale nature of the BA modelling approach).

The groundwater modelling undertaken for the BA of the Galilee subregion is well suited to assessing regional-scale, cumulative impacts of the proposed coal resource developments, for example, as a means of defining the zone of potential hydrological change to then rule out impacts to any water resources and water-dependent assets outside of this area. However, the underpinning hydrogeological conceptualisation and modelling approach is recognised as being unsuitable for providing reliable drawdown results at some specific locations, such as springs, especially where the uppermost Quaternary alluvium and Cenozoic sediment aquifer does not exist. In these places, drawdown in the near-surface aquifer, and the underlying

Clematis Group aquifer, will likely be overestimated. Applying an alternative modelling conceptualisation that better represents the likely hydraulic pathways that link areas of mining development to specified points in the landscape generates more plausible drawdown results in areas lacking Cenozoic sediments, such as those outcrop areas where the Triassic geological units of the Galilee Basin occur (e.g. the Rewan Group and Moolayember Formation). The variability of modelling results from the application of alternative hydrogeological conceptualisations highlights the importance of applying local knowledge to improve the regional-scale modelling outcomes of this BA at specific locations.

The surface water zone of potential hydrological change is largely restricted to the Belyando river basin, a headwater catchment of the larger Burdekin river basin. The surface water zone corresponds to the area along the modelled stream network where the change in at least one of eight surface water hydrological response variables exceeds a defined threshold due to additional coal resource development. The thresholds can be generally described as at least a 5% chance of a 1% (or 3 days) or greater change in a flow volume or yearly event frequency (e.g. increase in number of zero-flow days per year). The surface water zone also includes non-modelled streams in the groundwater zone that are likely to receive baseflow (i.e. available evidence supports some level of groundwater contribution), and any non-modelled streams that are directly affected by mining and mine-site infrastructure. In total, there are 6285 km of streams in the zone of potential hydrological change, with impacts to about 25% of this stream length not quantified (i.e. not included in the modelled surface water network).

The potential impacts to surface water hydrology due to additional coal resource development are evaluated across the spectrum of the low-flow (using zero-flow days), high-flow and annual flow regime. The most substantial modelled surface water changes are for increases in zero-flow days, which mostly affect the main channel of the Belyando River, and the Suttor River downstream of its junction with the Belyando. In particular, the approximately 250 km stretch of this river network from downstream of the Native Companion Creek junction northwards to Lake Dalrymple (Burdekin Falls Dam) is *very likely* (greater than 95% chance) to experience substantial increases in the number of zero-flow days per year. At the 95th percentile of all model simulations, increases in zero-flow days along this river stretch exceed 200 days/year for all model nodes and interpolated stream links. These results indicate that increases in zero-flow days can aggregate from individual mines and thus result in cumulative impacts that extend beyond the mine areas along the main Belyando River channel. Other smaller streams that may experience substantial increases in the number of zero-flow days due to additional coal resource development include Tallarenha Creek, Lagoon Creek, Sandy Creek, Alpha Creek and Native Companion Creek, all of which are proximal to the cluster of four mines in the south of the zone. North Creek is the main surface water drainage likely to experience increases in zero-flow days in the area of the northern mining cluster.

In contrast to the effects on zero-flow days, changes to high-flow days and annual flow volumes due to the seven modelled coal mines are generally less substantial, and also tend to have a greater effect on the smaller tributary network within the zone (i.e. in smaller catchments that are closer to the mines) rather than the main river channel. For example, the largest decreases in high-flow days per year occur on Tallarenha Creek, Lagoon Creek and Sandy Creek in the south, due to their proximity to the southern mining cluster. In the north, the main impacts are modelled for North Creek and Bully Creek. However, unlike for zero-flow days, these high-flow changes do not accumulate downstream in the Belyando River, such that the Suttor River downstream of the Belyando junction is *very unlikely* (less than 5% chance) to experience decreases in high-flow days of more than 10 days per year. About 269 km of the modelled stream network is *very likely* (greater than 95% chance) to experience reductions in annual flow volume of 5% to 20%. These decreases in annual flow affect the same streams that are expected to experience reductions in high-flow days. There is only one surface water model node, on Tallarenha Creek downstream of the proposed South Galilee Coal Mine, where reductions in annual flow volume may exceed 20%.

Any change in hydrology could result in changes to stream water quality; however, this was not modelled as part of the BA. A range of regulatory requirements are in place in Queensland that are intended to minimise potential salinity impacts from coal resource development. Groundwater is typically more saline than surface water runoff, which suggests that any reductions in baseflow are more likely to lead to decreases in stream salinity. However, the actual effects depend very much on local conditions, and increases in stream salinity cannot be ruled out.

Users can visualise more detailed results for hydrological changes in the Galilee subregion using a map-based interface on the BA Explorer, available at www.bioregionalassessments.gov.au/explorer/GAL/hydrologicalchanges.

In the BA for the Galilee subregion, potential hydrological changes due to additional coal resource development are summarised using hydrological response variables based on results from the surface water and groundwater modelling. These modelling results are reported, respectively, in companion product 2.6.1 (Karim et al., 2018b) and companion product 2.6.2 (Peeters et al., 2018) for the Galilee subregion. The hydrological response variables have been specifically defined to represent the maximum difference between the CRDP and baseline futures for groundwater drawdown and a range of streamflow characteristics. They have also been used to define the zone of potential hydrological change – the main focus of this impact and risk analysis (Section 3.3.1). As previously discussed, the baseline for the Galilee subregion does not have any coal resource development, as there were no commercially producing coal mines or coal seam gas (CSG) fields in the subregion as of December 2012. Consequently, the CRDP is here defined simply by the seven coal mines (Table 3) that comprise the additional coal resource development modelled in this BA.

Potential changes to groundwater and surface water systems within the zone of potential hydrological change are presented in Section 3.3.2 and Section 3.3.3, respectively. Areas within the zone are identified as being ‘more at risk’ of experiencing hydrological changes, and hence potentially adverse impacts, based on variations in the magnitude of modelled hydrological change, coupled with the probability of such change occurring. Conversely, the areas of the Galilee assessment extent that occur outside of this zone are effectively ruled out from further consideration in this BA (i.e. the impact and risk analysis is not undertaken in these areas). Importantly though, the regional-scale analysis of the BA for the Galilee subregion means that, to further refine the assessment of risk and determine appropriate management responses for particular assets or ecosystems within the zone, local-scale data and information may be further required to develop locally specific and development-scale impact predictions. Additionally, while changes in water quality were not part of the hydrological modelling undertaken for this BA, the potential for changes in water quality due to additional coal resource development in the Galilee subregion is considered qualitatively in Section 3.3.4.

Additional hydrological response variables have been defined for input into the landscape class qualitative models and receptor impact models developed for the Galilee subregion as part of this BA. These modelling approaches focus specifically on predicting ecosystem-level responses to modelled hydrological changes, and are discussed in detail in companion product 2.7 for the Galilee subregion (Ickowicz et al., 2018). They represent key water dependencies in these systems and are based on average differences over 30-year (2013 to 2042) and 90-year (2013 to 2102) periods. The application of the receptor impact models to landscape classes, using the hydrological response variables that were considered to best reflect key dependencies between ecosystems and hydrological systems, are presented as part of the impact and risk analysis in Section 3.4.

3.3.1 Defining the zone of potential hydrological change

The zone of potential hydrological change is the area within the assessment extent where changes in hydrology due to additional coal resource development exceed defined thresholds for both groundwater and surface water. The impact and risk analysis presented in Section 3.4 and Section 3.5 focuses mainly on landscape classes and ecological assets that intersect with this zone. Any landscape class or asset wholly outside of the zone of potential hydrological change is generally considered *very unlikely* (less than 5% chance) to be impacted due to additional coal resource development. However, an important exception to this rule is for cases where impact and risk analysis is undertaken for assets that are interpreted to source groundwater from deeper confined aquifer systems (i.e. deeper aquifers below the level of the upper Quaternary alluvium and Cenozoic sediment aquifer in the Galilee subregion, such as the Clematis Group aquifer). Examples of such assets include discharge springs and their local ecosystems, and groundwater bores that tap deeper groundwater sources (as further discussed in Section 3.4.3 and in the economic assets analysis in Section 3.5.3). In these cases, a similar type of analysis is done as for the zone of potential hydrological change, with the focus being on the probabilistic groundwater drawdown results obtained for the deeper source aquifers instead of the upper Quaternary alluvium and Cenozoic sediment aquifer (companion product 2.6.2 for the Galilee subregion (Peeters et al., 2018)). Of course, such analysis is predicated on the source aquifer for the relevant springs or bores being accurately known and, in cases where ambiguity may exist as to the source, the analysis presented here has relied on the best available data and information available. This has been supplemented in some cases by additional review and analysis to guide the Assessment team's conceptual understanding.

The zone of potential hydrological change for the BA of the Galilee subregion is defined as the union of the groundwater zone of potential hydrological change (Section 3.3.1.1) and the surface water zone of potential hydrological change (Section 3.3.1.2). It is presented in Section 3.3.1.3.

3.3.1.1 Groundwater

The groundwater zone of potential hydrological change is defined as the area with a greater than 5% chance of exceeding 0.2 m drawdown in the uppermost aquifer, due to additional coal resource development (Figure 20). As previously discussed, the relevant aquifer in the Galilee subregion used to define the zone is the near-surface (unconfined) Quaternary alluvium and Cenozoic sediment layer (Section 3.2.3). The 5% chance is determined based on the uncertainty analysis described in Section 2.6.2.8 of companion product 2.6.2 for the Galilee subregion (Peeters et al., 2018). It means that, for each assessment unit in the groundwater zone, at least 5% of groundwater model runs exceeded this specified level of drawdown. Groundwater impacts of coal mines and CSG projects are regulated under Queensland and Australian Government legislation, and various state regulatory and management frameworks also apply. The 0.2 m drawdown threshold adopted in BAs is consistent with the most precautionary minimal impact threshold under Queensland's *Water Act 2000.*

The groundwater component of the zone of potential hydrological change consists of two separate areas near the central-eastern margin of the Galilee subregion (Figure 20). The two drawdown zones extend to the east beyond the boundary of the Galilee Basin, as the upper alluvial/sediment aquifer is geologically younger than the rocks of the Galilee Basin and is not constrained (conceptually) to only occur within the basin extents. To the west, the area of each drawdown zone does not overlap with the eastern boundary of the geologically younger Eromanga Basin sequence that overlies much of the Galilee Basin beyond this line. The Eromanga Basin contains most of the main productive aquifers of the Great Artesian Basin (GAB) (Ransley et al., 2015).

An important point to note here is that some eastern parts of the zone of potential hydrological change extend beyond the boundary of the Galilee assessment extent (Figure 20). This boundary was used to define the area in which landscape classes were developed for this BA, as well as defining the area in which the water-dependent assets were identified for the BA asset register. Consequently, this means that it is not possible to assess impacts and risks to both landscape classes and water-dependent assets in the part of the zone that occurs beyond the boundary of the assessment extent. Although this is a recognised limitation of the current BA, the area of the zone beyond the assessment extent equates to only about 6% of the total area of the zone of potential hydrological change. Additionally, most of this area is predicted to have a relatively low chance of a small level of drawdown, ranging from a 5% to 10 % chance of 0.2 m of drawdown in the upper Quaternary alluvium and Cenozoic sediment aquifer. Within this area there is no drawdown impact predicted to affect the aquifers of either the Clematis Group or upper Permian Coal Measures, as both of these geological units do not exist in the eastern part of the zone.

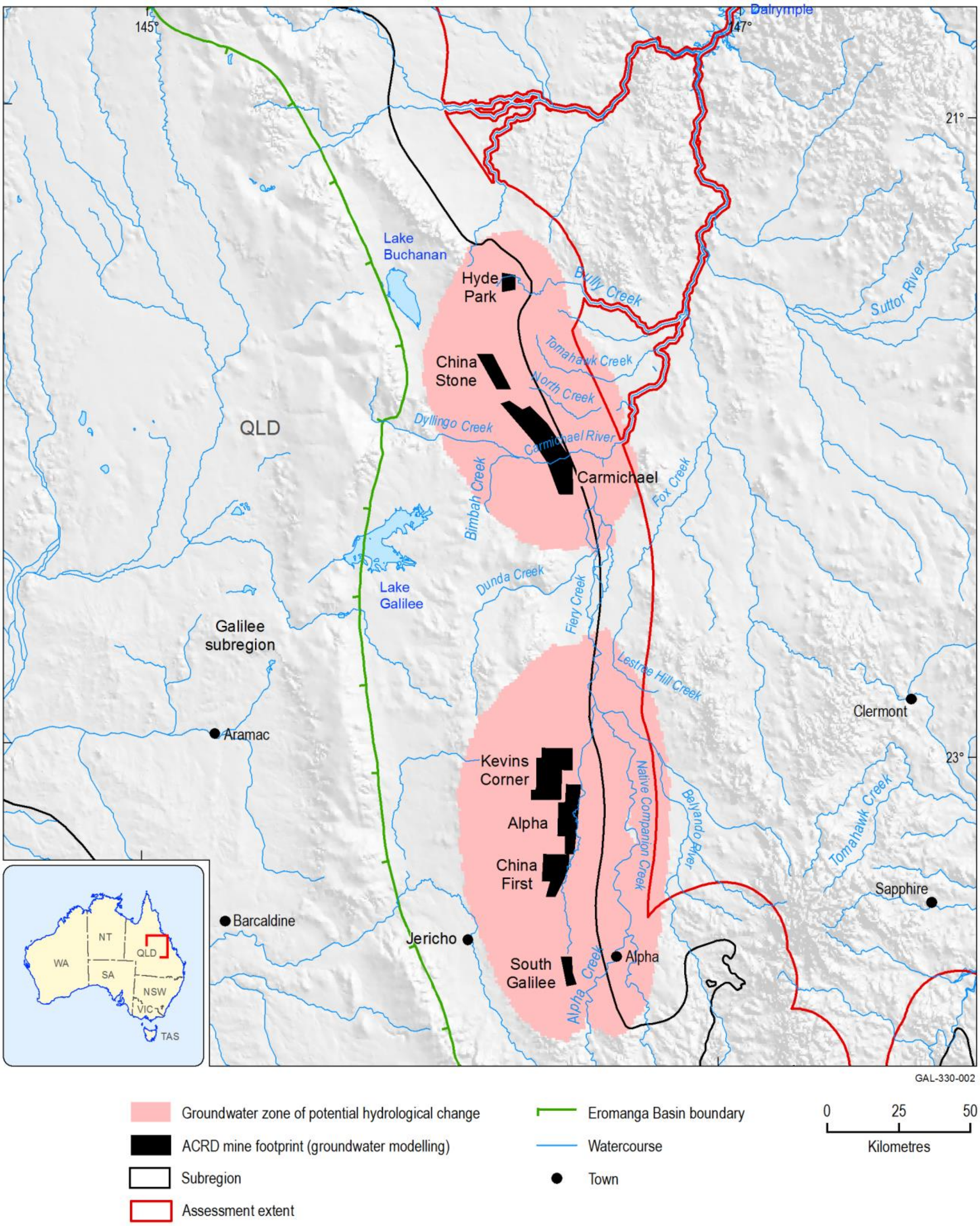

Figure 20 Groundwater component of the zone of potential hydrological change for the Galilee subregion

The two areas depicted here are defined based on at least a 5% chance of groundwater drawdown exceeding 0.2 m in the Quaternary alluvium and Cenozoic sediment aquifer due to additional coal resource development. Coal mine development footprints as used in the groundwater modelling for the Galilee subregion are shown.
ACRD = additional coal resource development
Data: Bioregional Assessment Programme (Dataset 1, Dataset 2), Geoscience Australia (Dataset 3)

The separate groundwater drawdown zones defined here for the BA of the Galilee subregion cover an area in which cumulative groundwater impacts in the upper aquifer may occur due to multiple coal mining operations. These zones clearly indicate that, at the 95th percentile of groundwater model results, drawdown from individual mines may overlap spatially and temporally, thereby potentially leading to cumulative hydrological impacts. Such impacts as modelled at the upper probabilistic range for this BA exceed the extent of drawdown in aquifers previously reported for the individual mine developments (e.g. in the environmental impact statements (EIS) for each proposed mine – see Section 2.6.2.2 in companion product 2.6.2 for further information about the groundwater models previously developed for each proposed mine). However, when the BA modelling is considered across the entire range of results (i.e. from the 5th to the 95th percentile), the predicted groundwater impacts of individual mines all fall within this probabilistic range.

The southern cumulative drawdown zone is the larger of the two polygons that comprise the groundwater zone and covers approximately 7898 km^2, including the proposed coal mining operations at South Galilee, China First, Alpha and Kevin's Corner. The northern part of the zone encompasses about 5466 km^2 and includes the Carmichael, China Stone and Hyde Park coal mines. Overall, the combined area of the groundwater zone of potential hydrological change is 13,364 km^2, which includes the 986 km^2 area covered by the mine exclusion zone (Section 3.3.1.3).

Many ecosystems and ecological assets, as well as some economic assets, are interpreted to source their water requirements from the shallow (near-surface) groundwater system. Hence, the zone of potential hydrological change provides an entirely appropriate construct in the BA for ruling out impacts to such ecosystems and assets (i.e. if they occur beyond the extent of the zone then they are considered *very unlikely* to be impacted due to additional coal resource development). In the Galilee subregion, the near-surface aquifer is represented by the Quaternary alluvium and Cenozoic sediment layer, which is one of three layers modelled in the analytic element model (AEM) for the Galilee subregion where drawdown predictions are made.

However, the zone of potential hydrological change is not suitable for assessing impacts to ecological or economic assets that may rely on access to deeper water sources. In the Galilee AEM, there are two deeper groundwater systems modelled –1) the aquifers of the Clematis Group and 2) the upper Permian coal measures (companion product 2.6.2 (Peeters et al., 2018)). For any assets that are interpreted to source their water requirements from these two deeper aquifers, a similar 0.2 m threshold of drawdown at the 95th percentile is applied to identify assets that can be ruled out from potential impact, or if there may be potential for groundwater changes to cause adverse impacts. This process of defining a deeper analysis zone to assess potential impacts to some water-dependent assets is further discussed in Section 3.4.3 (for springs) and Section 3.5.3 (for economic assets).

3.3.1.2 Surface water

The thresholds to define surface water changes for the impact and risk analysis for the BA of the Galilee subregion are presented in Table 9. These thresholds apply to the suite of hydrological response variables reported in companion product 2.6.1 for the Galilee subregion (Karim et al., 2018b), and were used to define the surface water component of the zone of potential hydrological change. Together, the hydrological response variables (see Table 9) represent potential changes across the surface water flow regime, ranging from low flows (i.e. zero-flow days (ZFD), low-flow days (LFD), low-flow spells (LFS) and length of the longest low-flow spell (LLFS)) to high flows (daily flow at the 99th percentile (P99) and high-flow days (FD)), and include two other variables to represent changes in annual flow volume (AF) and interquartile range (IQR) (see companion submethodology M06 (as listed in Table 1) for surface water modelling (Viney, 2016) for further details). As previously explained, none of the streams experience any baseline hydrological changes due to coal resource development in the Galilee subregion.

Table 9 Surface water hydrological response variables and the thresholds used in defining the surface water component of the zone of potential hydrological change

Hydrological response variable	Units	Description	Threshold
AF	GL/year	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).	≥5% chance of ≥1% change in AF
P99	ML/day	Daily flow rate at the 99th percentile (ML/day). This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102).	≥5% chance of ≥1% change in P99
IQR	ML/day	Interquartile range in daily flow (ML/day); that is, the difference between the daily flow rate at the 75th percentile and at the 25th percentile. T This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102).	≥5% chance of ≥1% change in IQR
FD	days/year	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’.	≥5% chance of a change in FD ≥3 days in any year
ZFD	days/year	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).	≥5% chance of a change in ZFD ≥3 days in any year
LFD	days/year	Number of low-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 low-flow days is the 10th percentile from the simulated 90-year period.	≥5% chance of a change in LFD ≥3 days in any year
LFS	number/year	Number of low-flow spells 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). A spell is defined as a period of contiguous days of flow below the 10th percentile threshold.	≥5% chance of a change in LFS ≥2 spells in any year
LLFS	days/year	Length (days) of the longest low-flow spell each year. This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102).	≥5% chance of a change in LLFS ≥3 days in any year

A location on the modelled stream network is deemed to be in the zone of potential hydrological change if the change in at least one of the eight hydrological response variables in Table 9 exceeds its specified threshold. Probability estimates are derived from the predictions of 347 modelling replicates (companion product 2.6.1 for the Galilee subregion (Karim et al., 2018b)), each of which uses a unique set of model parameter values. A 5% threshold implies that at least 17 of the 347 replicates have modelled changes that exceed the relevant change threshold. If fewer than 17 replicates have modelled changes that exceed the threshold at a particular location, then the change in that hydrological response variable (at that location) is considered *very unlikely* to impact water-dependent landscape classes and assets. The results of surface water modelling are presented in Section 2.6.1.6 of companion product 2.6.1 for the Galilee subregion (Karim et al., 2018b). Within companion product 2.6.1 (Karim et al., 2018b) Figure 12 to Figure 19 (inclusive) identify the 16 model nodes in the surface water network (out of the 61 nodes in total) where hydrological changes do not exceed the specified threshold values for each variable listed in Table 9. The location of these 16 surface water nodes with hydrological response variable changes below threshold values is shown in Figure 12 (Section 3.2.3.2), and include nodes 12, 17, 21, 23, 26, 28, 31, 46 to 50, 52, 54, 57 and 59.

The surface water zone of potential hydrological change includes all stream reaches that represent the links between model nodes (Figure 12) where the surface water modelling has predicted hydrological changes due to additional coal resource development. The rule set used to interpolate results from surface water model nodes to adjacent stream reaches is shown schematically in Figure 13 and Figure 14 in Section 3.2.3.2. However, there are also stream reaches included in the surface water zone that were not explicitly modelled, but which may potentially be impacted due to additional coal resource development (e.g. non-modelled streams that occur near to mines). Consequently, these stream reaches could not be ruled out from potential impact and, consistent with the precautionary principle adopted for this BA, they have been included in the definition of the zone. The non-modelled stream reaches included in the surface water zone of potential hydrological change include:

- streams that intersect with areas of proposed coal mining
- some temporary streams within the groundwater zone of potential hydrological change that are considered (e.g. on the basis of independent lines of evidence such as remotely sensed data) to receive some level of baseflow contribution
- temporary streams with assumed hydrological change that could not be quantified.

3.3.1.2.1 Streams intersecting proposed coal mines

On the basis that all of the proposed coal mining operations will substantially alter the pre-development state of any watercourses on the mining lease, any part of the non-modelled stream network that intersects an area of open-cut mining, the surface area above underground longwall panels or a mine-site infrastructure area (including proposed dams) at one of the seven additional coal resource developments is flagged as being potentially impacted. During mine development, each operation will implement various management strategies to address surface water flows along such watercourses, including potential stream diversions around the mine. Consequently, these site-specific operational plans are better able to incorporate and model any local-scale impacts to watercourses or drainage lines that may arise during initial development, and as mining progresses over the course of the entire mine life. The inclusion of streams in the zone above areas of proposed longwall mining is based on the potential for land surface subsidence and/or enhanced surface fracturing to potentially affect various aspects of these watercourses, such as the timing and magnitude of flow, as well as possibly enhancing local recharge to groundwater systems. Any stream segments that partially intersect such mining areas have also been flagged as potentially impacted along any upstream and/or downstream parts of the same reach.

3.3.1.2.2 Temporary streams within the groundwater zone of potential hydrological change

The groundwater component of the zone of potential hydrological change (Figure 20) encompasses many minor, temporary streams that were not specifically included in the surface water modelling network. Some of these stream segments were classed as groundwater-dependent ecosystem (GDE) streams using the general approach taken to develop the landscape classification for the Galilee subregion (refer to Section 2.3.3 in companion product 2.3 for the Galilee subregion (Evans et al., 2018b) for further details about the landscape classification approach). This suggests that some of these streams could potentially be affected by drawdown in the near-surface aquifer (e.g. reducing the magnitude and timing of any baseflow contribution to streams). However, as the landscape classification was done using a standardised regional mapping approach at the scale of the entire assessment extent (which meant that once the various input datasets had been assessed as suitable and fit for purpose for defining the landscape classes, they were not subjected to further desktop or field-based verification), some further independent validation of potential surface water – groundwater interaction within the zone was undertaken to improve upon these initial interpretations at the smaller scale of the zone of potential hydrological change.

Several lines of evidence were used to improve the understanding of potential surface water – groundwater interaction for the minor non-modelled streams in the zone of potential hydrological change. This included analysis of the available groundwater bore records of standing water levels in the zone, which were sourced primarily from information in the Queensland groundwater bore database, and supplemented by data available from some coal mine environmental impact statement (EIS) documentation. This information is presented in Figure 39 in Section 3.4, and clearly shows that the depth to the watertable in much of the zone is greater than 20 m, implying that surface water – groundwater interaction along watercourses in these areas is *very unlikely* to occur.

Further verification was undertaken using a suite of remote sensing techniques that are currently in development as part of work being undertaken by Digital Earth Australia (Geoscience Australia, 2017). A summary of the methods applied using these remote sensing applications is provided in Section 3.2, focused mainly on evaluating temporal trends in vegetation greenness and detectable surface water using the archive of Landsat imagery. Using Digital Earth Australia outputs (Geoscience Australia, 2017), the Assessment team visually inspected a variety of derived datasets that covered the zone of potential hydrological change. Focusing on the data from several drought periods over the past 30 years allowed watercourses to be evaluated for the likelihood that groundwater contribution played an important role in maintaining vegetation health and/or available surface water during such times. Streams that maintained vegetation cover even during long periods of drought were flagged as being more likely to receive some groundwater contribution than streams that mostly lacked consistently green vegetation during these drier times.

Applying this remote sensing method helped to determine that the main non-modelled stream network in the zone that potentially receives some baseflow contribution occurs along the upper tributaries that feed the Carmichael River. In particular, Dyllingo Creek, Cattle Creek, and lower parts of Surprise Creek may all receive some (at present unquantified) volume of groundwater contribution. Springs belonging to the Doongmabulla Springs complex also occur in the vicinity of reaches of these streams. Sparse groundwater level data suggest that the watertable is relatively shallow (within a few metres of the surface) within these areas (Figure 39 in Section 3.4).

From the analysis of these independent datasets, the Assessment team interpreted that the upper parts of Carmichael River and its tributary network are likely to be the only non-modelled streams in the zone of potential hydrological change that are (at least partially) connected to shallow groundwater flow systems. Consequently, these streams were included in the surface water zone of potential hydrological change, and identified as being potentially impacted (but not quantified) due to groundwater drawdown, which could affect any baseflow contribution that supports these streams. The reaches upstream of the boundary of the groundwater zone of potential hydrological change were not included in this surface water zone.

3.3.1.2.3 Temporary streams with assumed hydrological change

Some reaches of the modelled stream network consist of multiple anabranches (commonly anastomosing reaches) between surface water model nodes. This makes it especially difficult to reliably interpolate the surface water changes from model nodes to any particular anabranch segment. However, if hydrological changes occur at the model nodes upstream and downstream of an anabranch reach it is assumed that a hydrological change will also occur between the two modelled nodes. An example from the zone of potential hydrological change is for the stream reach that occurs between model nodes 44 and 34 (Figure 12), which joins the southern and northern groundwater zones. This stretch of the Belyando River consists of multiple anastomosing channels, all of which are likely to receive surface water flows of variable magnitude, timing and duration. This makes it challenging to reliably assign modelled changes in the hydrological response variables from the adjacent nodes.

In reporting the total length of streams identified as being ‘potentially impacted but not quantified’, there is no distinction made between the three different categories as explained above. Thus, all of the surface water maps shown later in this section simply describe such streams as having ‘unquantified potential hydrological change’. Streams for which the surface water modelling identified that there was no change are not included in the surface water zone of potential hydrological change (e.g. the modelled parts of the Cape River and the Suttor River above their respective junctions with the Belyando River, where all surface water model results were below threshold values (Figure 12)).

3.3.1.2.4 Characteristics of the surface water zone of potential hydrological change

In all, about 3012 km of the total 6285 km (Bioregional Assessment Programme, Dataset 1) of streams in the zone of potential hydrological change were identified as potentially impacted. These streams were used to select the 1 km x 1 km assessment units (Bioregional Assessment Programme, Dataset 1) that intersect the stream network (Bureau of Meteorology, Dataset 4), to define the surface water zone of potential hydrological change. The surface water zone of potential hydrological change is shown in Figure 21, including the footprints of the seven proposed coal mines that were included in the BA surface water modelling.

For the purpose of producing some of the analysis results, it is necessary to prioritise a single stream segment in assessment units containing multiple stream segments. The prioritisation takes into account the stream order of each segment, stream segment lengths and the landscape classes and assets relevant to each particular hydrological response variable. Rules are applied according to the specific circumstances at each assessment unit. A summary of the various rules used in this prioritisation approach is provided in Section 3.2.4.1.2.

The surface water zone of potential hydrological change covers an area of 4115 km^2 and encompasses much of the Belyando river basin upstream of Lake Dalrymple (the Burdekin Falls Dam). There is some variability in the application of the rules used to interpolate the node data to the adjacent reaches, and this depends on the hydrological response variables (as node data for some variables allowed for more extensive interpolation from nodes to reaches). This means that the total stream lengths that cannot be quantified can vary depending on the chosen hydrological response variables, ranging from 54% for high-flow days and annual flow, and up to 65% for zero-flow days. Surface water modelling suggests that the catchments of the Cape River, and the Suttor River upstream of its junction with the Belyando River, are *very unlikely* to be impacted by the seven coal mines that comprise the modelled component of the additional coal resource development.

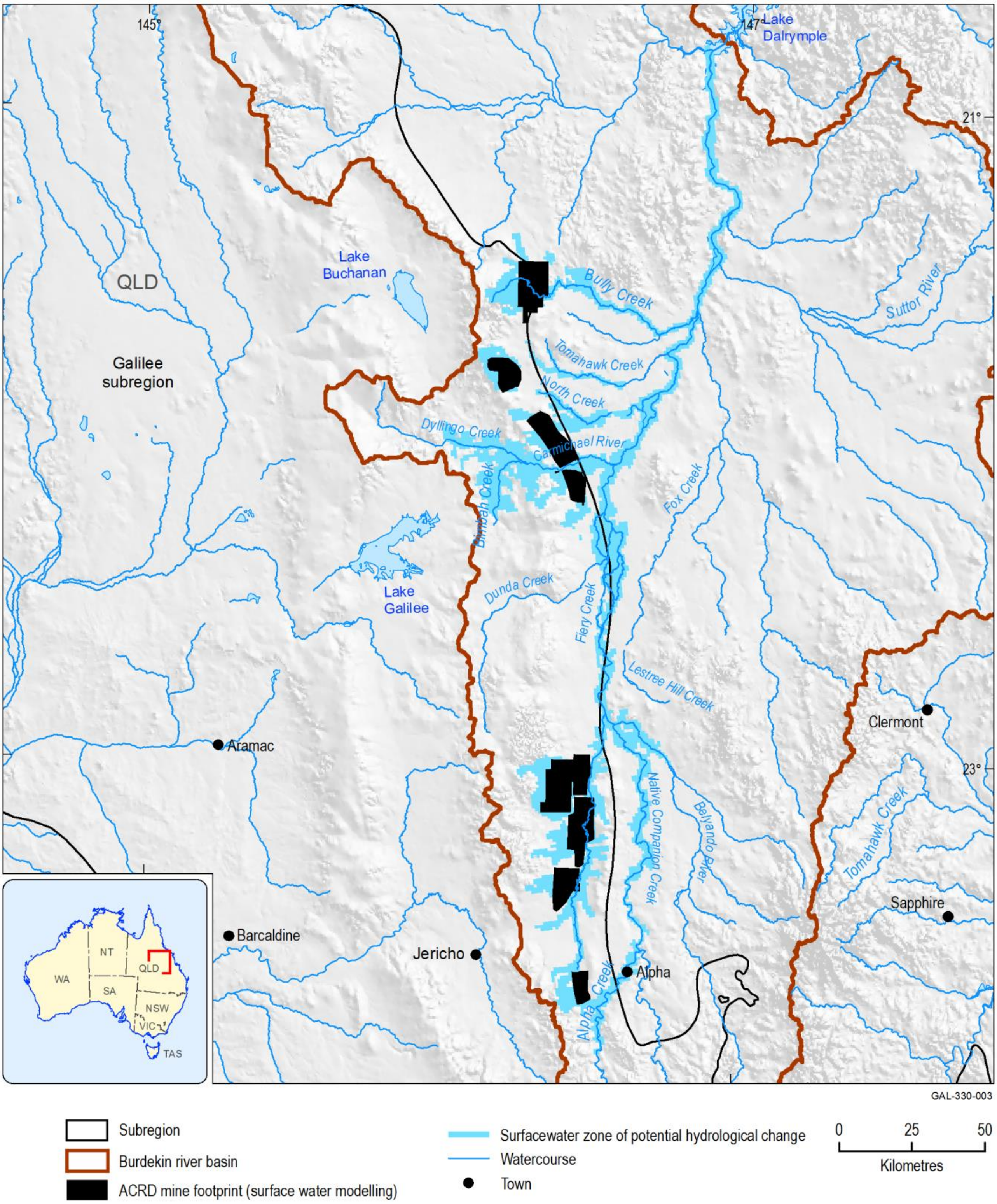

Figure 21 Surface water zone of potential hydrological change for the Galilee subregion

Mine names are shown on Figure 20. Due to variations in the timing of the respective surface water and groundwater modelling workflows undertaken for this bioregional assessment, and the different emphasis placed on defining the extent of mining operations, there may be minor differences in the size and shape of some mine footprints used, respectively, for the surface water and groundwater modelling.
ACRD = additional coal resource development
Data: Bioregional Assessment Programme (Dataset 1, Dataset 5, Dataset 6)

3.3.1.3 Zone of potential hydrological change

Hydrological changes assessed as part of the BA for the Galilee subregion are summarised for the zone of potential hydrological change. This is derived from the union of the groundwater zone of potential hydrological change (Figure 20) and the surface water zone of potential hydrological change (Figure 21), and is shown in Figure 22. The Galilee zone of potential hydrological change covers an area of about 14,030 km^2, which is less than 3% of the entire Galilee assessment extent. Within the zone there are approximately 6285 km of streams (of which 96% are classed as temporary streams in the landscape classification), and about 46% of these may potentially be impacted due to coal resource development (Section 3.3.3). The remaining streams are generally low-order ephemeral watercourses (commonly in upland areas), and although impacts to these were not specifically modelled there are multiple lines of evidence (e.g. depth to watertable, remotely sensed Landsat data) that indicate low potential for hydrological changes to occur due to additional coal resource development. For reporting purposes in this product, two separate reporting areas, one in the north and one in the south (Table 10), are defined to provide greater resolution of the potential hydrological impacts.

The zone of potential hydrological change is the first filter applied to landscape classes and water-dependent assets in the Galilee subregion as part of a ‘rule-out’ process for the impact and risk analysis. Landscape classes and assets that are completely outside the zone are *very unlikely* (less than 5% chance) to be impacted due to additional coal resource development and consequently these do not have qualitative landscape models or receptor impact models. As previously mentioned, the exception to this general rule is for springs or bores that may access deeper aquifers that are not specifically considered in developing the zone of potential hydrological change. The potential impacts on these types of water-dependent assets are further discussed in Section 3.4.3 and Section 3.5.3.

Applying the rule-out process as an initial step in the impact and risk analysis identifies the landscape classes that occur in the zone and that may potentially be impacted due to additional coal resource development. Importantly though, this does not definitively mean that all landscape classes and assets within the zone will be impacted, only that the potential for impact cannot be discounted and further analysis may be required. This subsequent phase of assessment is the focus of the more detailed impact analysis undertaken in this product. In these cases, qualitative mathematical models and/or receptor impact models are used to assess the potential impact of the modelled hydrological changes on relevant ecosystems. Details of the qualitative mathematical models and receptor impact models are provided in companion product 2.7 for the Galilee subregion (Ickowicz et al., 2018), including the main evidence to support the development of these types of ecosystem models. The specific application of the receptor impact modelling described in Ickowicz et al. (2018) to many of the landscape classes in the Galilee zone of potential hydrological change is presented in Section 3.4.

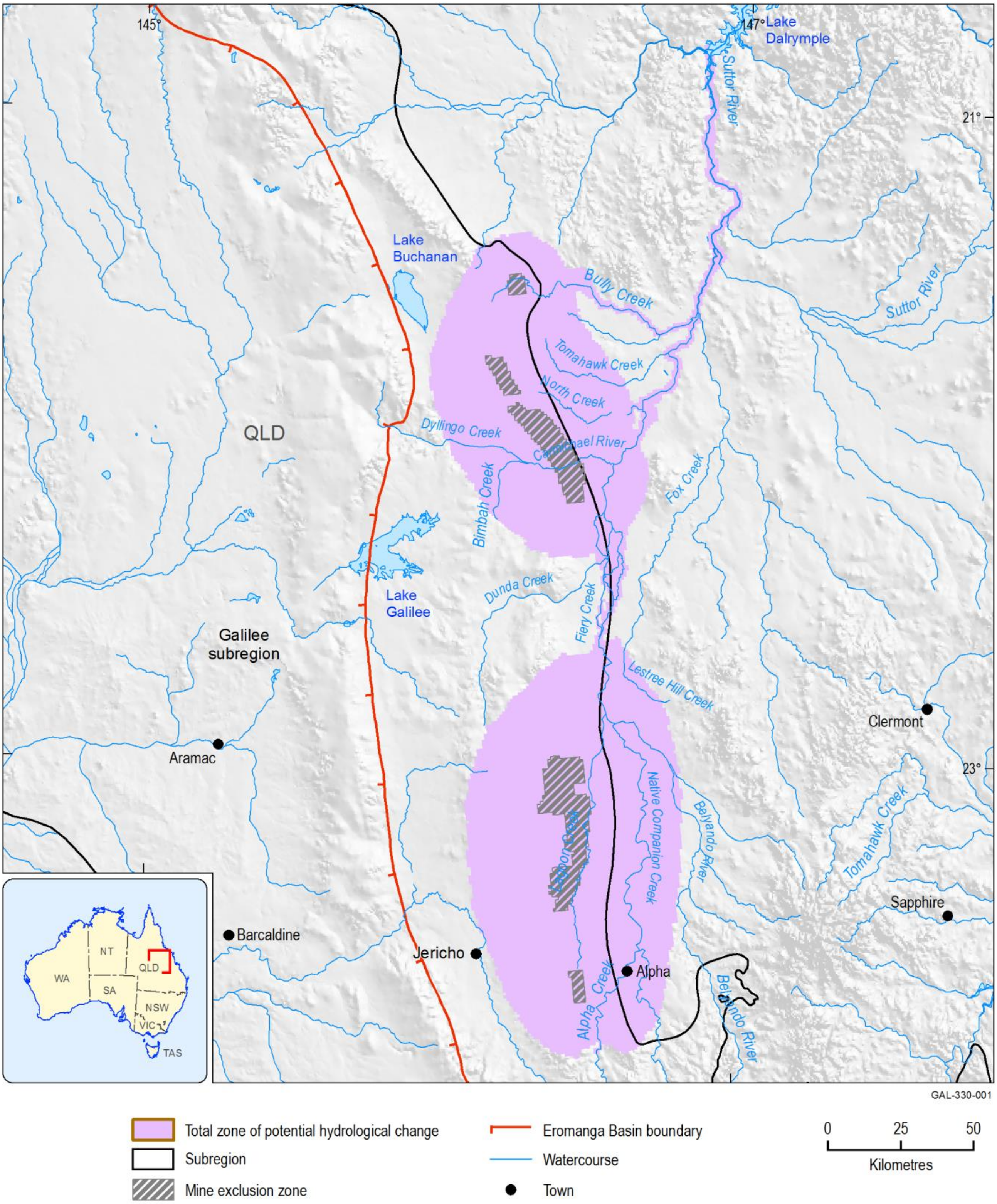

Figure 22 Zone of potential hydrological change for the Galilee subregion

Data: Bioregional Assessment Programme (Dataset 1), Geoscience Australia (Dataset 3)

3.3.1.3.1 Mine exclusion zone

The mine exclusion zone defined for the Galilee subregion is based on the open-cut mine footprints and the areas above underground longwall mines within the zone of potential hydrological change (Figure 22). The mine exclusion zone identifies areas within the zone that are within, or proximal to, areas of active mining, and where:

- modelled drawdowns from the regional-scale AEM are highly uncertain due to the very steep groundwater gradients that will exist at the mine working interface
- changes in drawdown are inevitable where the mine pits intersect the regional watertable
- 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
- impacts are predominantly site scale, and assumed to be adequately addressed through existing development approval processes, and hence not the primary focus of BAs.

The modelled estimates of drawdown in the mine exclusion zone are considered unreliable for use in the receptor impact modelling. In most cases, the areas underlain by the mine exclusion zone will have a consistent 10 m of drawdown due to the implementation of the mining activity upon the uppermost aquifer in the AEM for the Galilee subregion (companion product 2.6.2 (Peeters et al., 2018)). In total, the mine exclusion zone within the zone of potential hydrological change (which includes the footprints of all seven of the proposed coal mines modelled in this BA) covers an area of 986 km^2.

In the impacts on landscape classes and assets sections (Section 3.4 and Section 3.5, respectively), the initial rule-out assessment summarises what is in the zone of potential hydrological change and, within that, what is in the mine exclusion zone. For landscape classes and assets that have a groundwater dependency, lengths and areas were differentiated by attribute class for areas within the zone of potential hydrological change, but no differentiation by attribute class was undertaken for such features in the mine exclusion zone.

3.3.1.3.2 Reporting areas

The zone of potential hydrological change has two discrete drawdown areas that correspond to the main areas potentially impacted due to additional coal resource development. Two separate reporting areas, which encompass the drawdown and potentially impacted surface water network associated with distinct mining clusters (north and south), have been defined to summarise results (Figure 22). In the Belyando river basin, the two groundwater drawdown areas are connected by the surface water zone of potential hydrological change. This means that results reported for the northern part of the zone may include some hydrological changes that have propagated from further upstream, thereby reflecting cumulative hydrological impacts across the zone (Table 10).

Table 10 Reporting areas and modelled additional coal resource development

Reporting area	Additional coal resource development (modelled)	Comments
Northern	Carmichael, China Stone, Hyde Park	Includes all modelled areas of potential impact downstream of surface water model node 44, extending along reaches of the Belyando and Suttor rivers to Lake Dalrymple (Burdekin Falls Dam)
Southern	South Galilee, China First, Alpha, Kevin's Corner	Restricted to the area of the southern groundwater zone, upstream of surface water model node 44 (Figure 12)

3.3.1.3.3 Presentation of surface water changes

The seven coal mines that are the focus of the numerical modelling for this BA are clustered at the central-eastern margin of the Galilee Basin. The mines are aligned along a north-trending axis that extends for nearly 250 km from the southern-most mine (South Galilee) to the northern-most mine (Hyde Park). Within this area are the edges of several distinct boundaries developed during the course of the BA for the Galilee subregion, including the respective boundaries for the subregion, assessment extent and zone of potential hydrological change (Figure 23). One consequence of having multiple proximal boundaries in this area is that it is very difficult to clearly display node and interpolated surface water modelling results (i.e. on maps) along much of the stream network, especially at the scale required to display the entire surface water modelling domain.

To overcome what would otherwise appear as a selection of cluttered and hard-to-read surface water maps, the various administrative boundaries that occur in this area are deliberately not included on all of the surface water maps presented in this product. Removing these boundaries, several of which also overlap with each other, means that the critical surface water modelling results at individual nodes, as well as the adjacent interpolated stream reaches, are more clearly displayed. To put these results into the context of the various boundary locations, readers are advised to visually cross-check locations with the various boundaries as depicted in Figure 23.

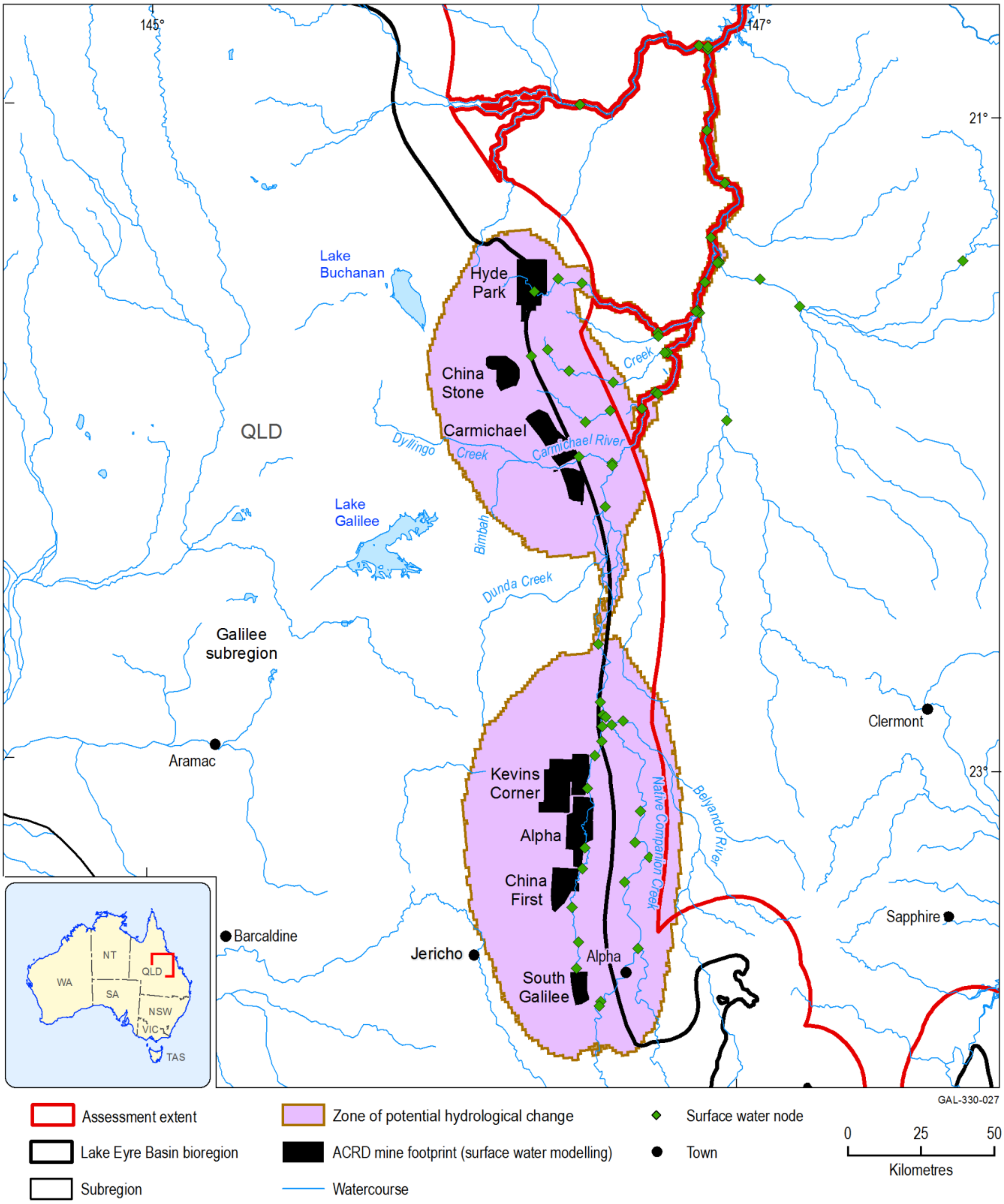

Figure 23 Summary of various boundaries and surface water model node locations for the central-eastern Galilee subregion, around the area of modelled additional coal resource developments

ACRD = additional coal resource development
Bioregional Assessment Programme (Dataset 1, Dataset 6)

3.3.2 Potential groundwater changes

In assessing potential impacts on groundwater, changes are summarised by the hydrological response variable, *dmax*, which is the maximum difference in drawdown, obtained by choosing the maximum of the time series of differences between two futures. These *dmax* values are presented for the baseline (difference from a 'no development' model run) and due to additional coal resource development (difference from the baseline run). As there are no coal resource developments in the baseline for the Galilee subregion, the drawdowns under the baseline essentially represent the 'no development' model run.

Thresholds of greater than 0.2, 2 and 5 m of drawdown have been adopted to summarise groundwater modelling results across all BAs, as they represent meaningful changes for managing groundwater resources in NSW and Queensland. In Queensland, 'make good' obligations for groundwater bores affected by mining operations or CSG extraction apply under Queensland's *Water Act 2000*, where water pressure is predicted to fall by more than 5 m for consolidated aquifers, such as sandstone, and 2 m for unconsolidated aquifers, such as sand. Additionally, Queensland's *Water Act 2000* also requires prevention or mitigation options to be developed for springs where predicted pressure reductions are greater than 0.2 m.

Groundwater drawdown results for the uppermost aquifer (Quaternary alluvium and Cenozoic sediments) modelled in the Galilee subregion are in Table 11 and shown in Figure 24, mapping the spatial extent of drawdown at the 5th, 50th and 95th percentiles of all modelling runs (as explained in companion product 2.6.2 for the Galilee subregion (Peeters et al., 2018) there were 10,000 different parameter combinations (i.e. model runs) evaluated using the AEM). These drawdown predictions are due to additional coal resource development. For additional drawdown greater than 0.2 m, the area of drawdown associated with the 5th percentile (2820 km^2) can be interpreted as representing the extent of drawdown greater than 0.2 m when the model parameters reflect lower pumping rates and/or lower hydraulic conductivities of the various aquifers and aquitards. In contrast, the area of drawdown associated with the 95th percentile (13,364 km^2) includes the model predictions based on the main aquifer parameters (e.g. hydraulic conductivity and specific storage) nearer the upper limits of their expected ranges. Groundwater drawdown predictions indicate that drawdowns of greater than 5 m are *very likely* (greater than 95% chance; 5th percentile) to occur in the immediate vicinity of open-cut and underground mining areas due to additional coal resource development outlined in Table 10. The median area (50th percentile) potentially impacted by greater than 5 m of drawdown is 1782 km^2, which includes the 986 km^2 mine exclusion zone.

Cumulative exceedance plots provide a useful means to visualise areas exposed to differing levels of drawdown across the range of probabilistic results (Figure 25). As outlined in Section 2.6.2.5 of companion product 2.6.2 (Peeters et al., 2018), the maximum limit for additional drawdown in the AEM developed for this BA is constrained to 10 m in the uppermost alluvial aquifer along the boundary of each mine footprint. In the AEM, the 10 m level represents the complete dewatering of the Cenozoic sediment and Quaternary alluvial aquifer in each of the seven proposed coal mining areas.

Table 11 Surface area (km^2) and stream lengths (km) potentially exposed to varying levels of additional drawdown in the zone of potential hydrological change

Extent	Reporting area	Extent in zone of potential hydrological change	Extent in mine exclusion zone	Extent with additional drawdown ≥0.2 m			Extent with additional drawdown ≥2 m			Extent with additional drawdown ≥5 m		
				5th	50th	95th	5th	50th	95th	5th	50th	95th
Area (km^2)	Northern	6,100	431	1157	2083	5,466	657	1100	1803	445	686	1080
	Southern	7,930	555	1663	3069	7,898	940	1617	2623	584	1097	1631
	Total	**14,030**	**986**	**2820**	**5152**	**13,364**	**1596**	**2717**	**4426**	**1029**	**1782**	**2711**
Stream length (km)	Northern	3,030	157	400	839	2,324	209	371	701	160	227	362
	Southern	3,255	278	773	1330	3,232	462	741	1146	327	510	736
	Total	**6,285**	**435**	**1173**	**2169**	**5,556**	**670**	**1112**	**1847**	**487**	**737**	**1097**

Due to rounding, some totals reported here may not correspond exactly with the sum of the separate numbers. The area potentially exposed to ≥0.2, ≥2 and ≥5 m additional drawdown for the 5th, 50th and 95th percentile estimates of the maximum difference in drawdown (*dmax*) between the coal resource development pathway (CRDP) and baseline, due to additional coal resource development. Drawdowns in the mine exclusion zones cannot be quantified with confidence.
Data: Bioregional Assessment Programme (Dataset 1)

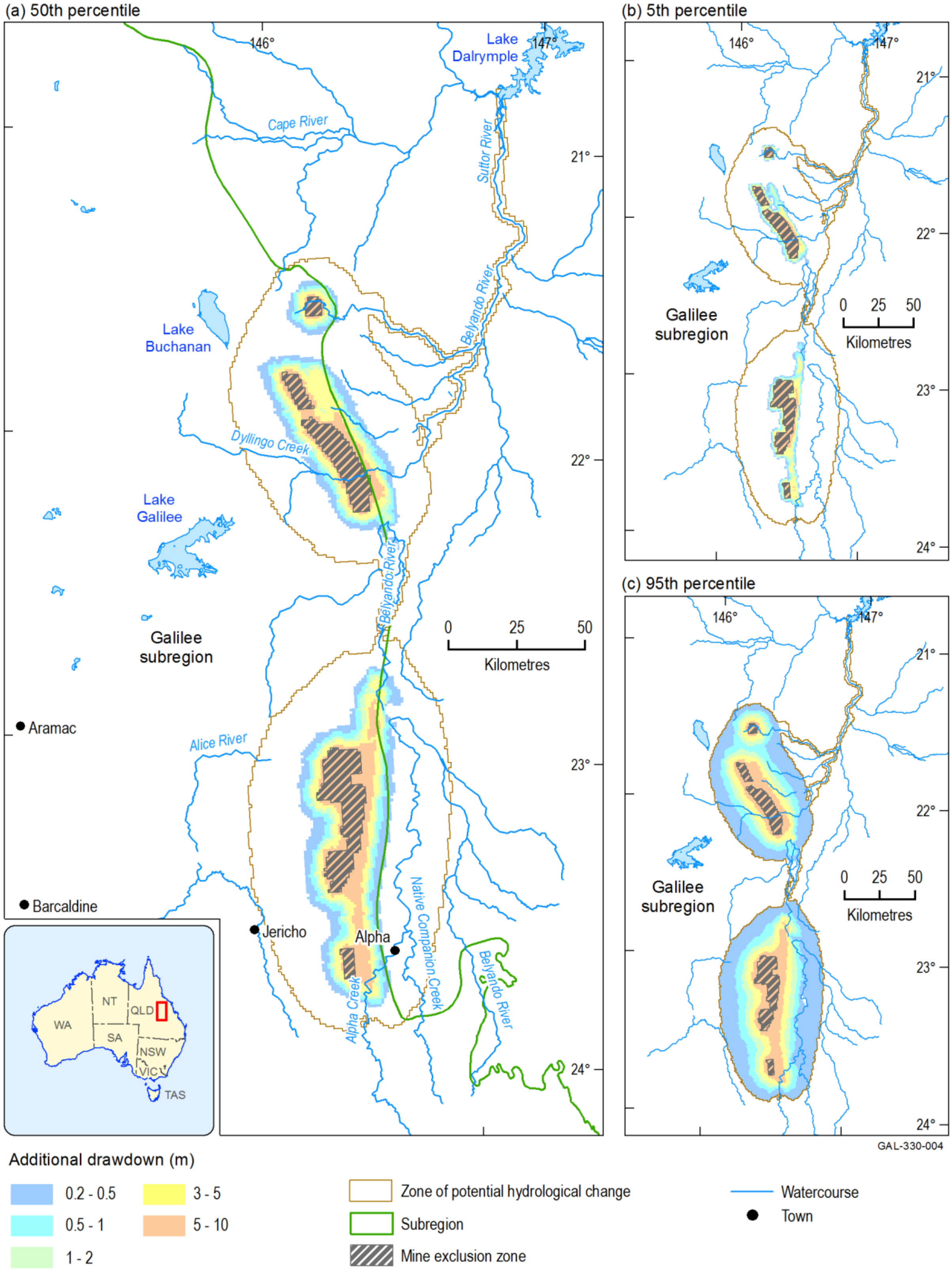

Figure 24 Additional drawdown (m) in the Quaternary alluvium and Cenozoic sediment aquifer, shown for probabilistic results at the 5th, 50th and 95th percentile of all groundwater modelling runs

Additional drawdown is the maximum difference in drawdown (*dmax*) between the coal resource development pathway (CRDP) and baseline, due to additional coal resource development. For the Galilee subregion there are no coal resource developments in the baseline, as there were no commercially producing coal mines or coal seam gas fields as at December 2012.
Data: Bioregional Assessment Programme (Dataset 1)

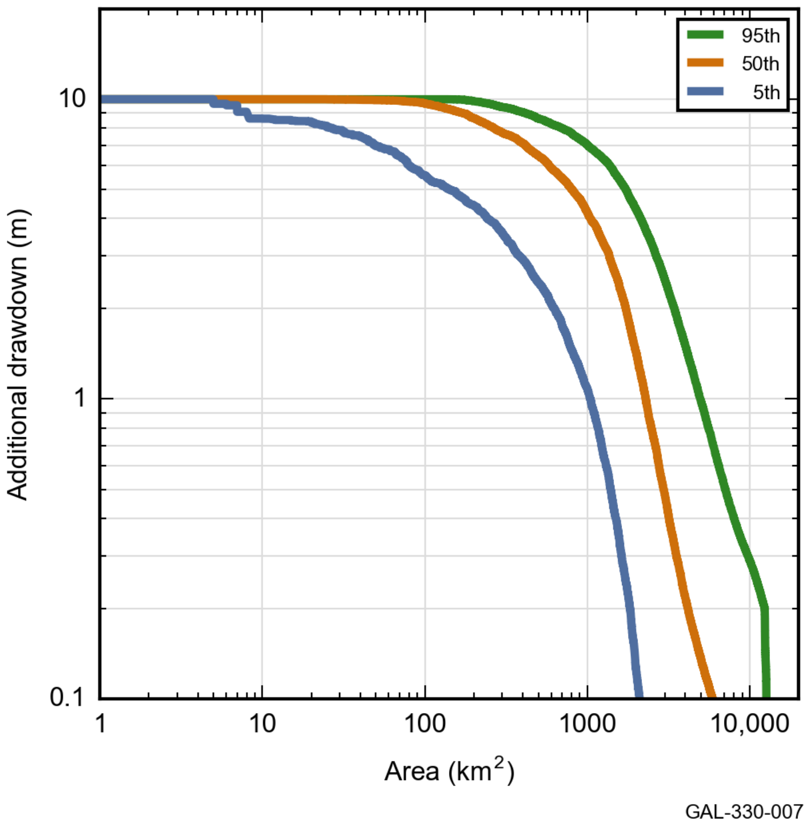

Figure 25 Cumulative exceedance plot of area of drawdown (for AEM layer 1, the Quaternary alluvium and Cenozoic sediment aquifer) in the zone of potential hydrological change due to additional coal resource development for the 5th (blue), 50th (orange) and 95th (green) percentile of all modelling results

Additional drawdown is the maximum difference in drawdown (*dmax*) between the coal resource development pathway (CRDP) and baseline, due to additional coal resource development. Drawdown under the baseline for the Galilee subregion does not include any coal resource developments, as there were no commercially producing coal mines as at December 2012.
Data: Bioregional Assessment Programme (Dataset 1)

3.3.2.1.1 Exploring conceptual uncertainty and applying regional-scale groundwater models to local-scale impact assessment

In the context of this BA, evaluating the impacts to groundwater systems due to additional coal resource development relies on the probabilistic drawdown results generated from the AEM (as outlined in companion product 2.6.2 for the Galilee subregion (Peeters et al., 2018)). The groundwater model is based on a simplified hydrogeological conceptualisation of the main aquifers and aquitards (Section 3.2.3) that occur in and around the area of the seven coal mines that have been the focus of the modelling. This modelling approach is well suited to the primary BA objective of regional-scale, cumulative impact analysis across the Galilee assessment extent. In particular, the fast model run times allow for the evaluation of a very wide range of parameter combinations, and support the comprehensive uncertainty analysis.

With the available knowledge of the hydrogeological architecture and groundwater flow systems in the central-eastern Galilee subregion, the simplified conceptual framework that underpins the AEM (Figure 11) is regarded by the Assessment team as an appropriate basis for probabilistically determining the groundwater component of the zone of potential hydrological change. This approach allows for the evaluation of cumulative groundwater impacts due to multiple future mining operations. Consistent with the precautionary approach adopted by the BAs, there is a high level of confidence in the suitability of the zone for ruling out impacts to water-dependent assets and ecosystems (i.e. outside of the zone impacts are considered *very unlikely* to occur). This is because the modelling approach identifies the most sensitive model parameters and specifies a suitably wide (and conservative) parameter range that is biased towards large hydrological change predictions. Consequently, outside of the zone, the modelling predicts small probabilities (less than 5% chance) of very small changes (less than 0.2 m drawdown) to groundwater levels.

The strength of the AEM is clearly targeted towards the type of regional-scale analysis required for the BA for the Galilee subregion. However, the existing data and knowledge of the basin's hydrogeology and groundwater systems was relatively limited at the outset of the BA. In addition, there was further uncertainty around many aspects of the proposed coal resource developments, and the way that the natural hydrological systems would likely respond to such development pressures. Overall, these various sources of uncertainty have meant that the conceptual system-level understanding supporting the modelling is of relatively low resolution. In addition, the AEM has limited capability to represent spatially varying thickness, hydraulic parameters and spatial extents of the different aquifers and aquitards (if known), and is unable to incorporate any local-scale hydrogeological data or information into the general conceptual framework (e.g. local faults or variably thick aquifers cannot be specified in the AEM configuration, even if they are known to exist).

The limitations of the AEM effectively mean that it is not well suited to making highly accurate local-scale predictions of drawdown impact for some areas within the zone of potential hydrological change. This is reflected in the commonly large uncertainty intervals that occur at some locations in the model domain where predicted changes are relatively substantial. Certainly, the Assessment team cautions against the wholesale adoption of the point-scale predictions presented in companion product 2.6.2 (Peeters et al., 2018) without undertaking further local-scale analysis to incorporate higher resolution data and knowledge that will then allow for more accurate quantification of hydrological impacts.

The relatively low resolution, regional-scale conceptualisation that underpins the drawdown predictions from the AEM means that the results at some individual locations in the zone are likely to be overestimated. There are several explanations for these overestimated drawdowns, with one of the main reasons being the way that the coal mining operations (i.e. dewatering) are implemented in the AEM. Consistent with the regional conceptualisation, coal mines can dewater from the confined upper Permian coal measures, as well as from the unconfined shallow Cenozoic sediment aquifer in the vicinity of the mines (companion product 2.6.2 (Peeters et al., 2018)). Thus, there are two main pathways for drawdown to propagate to aquifers throughout the AEM domain:

3. lateral propagation of drawdown through the Quaternary alluvium and Cenozoic sediment layer and potentially also downwards to underlying hydrostratigraphic units such as the Clematis Group. This pathway simulates aquifer drawdown and drainage that can occur around open-cut mines where they intersect shallow (near-surface) aquifers
4. laterally (at depth) through the upper Permian coal measures and then vertically upwards through the overlying Rewan Group aquitard, and then into other shallower aquifers such as the Clematis Group, as well as the Quaternary alluvium and Cenozoic sediments.

As explained in Section 2.6.2.8.2 of companion product 2.6.2 for the Galilee subregion (Peeters et al., 2018), this assumption is deemed appropriate for the regional-scale analysis used to define the zone of potential hydrological change, especially given the wide spatial extent and substantial thickness of Quaternary alluvium and Cenozoic sediment cover throughout the zone (Figure 27). However, it is unlikely to be a valid conceptualisation in areas where this unconsolidated sediment aquifer does not occur (or where it exists only in isolated areas that are not laterally contiguous with the mines), given that the first drawdown pathway mentioned above cannot exist under these circumstances.

Companion product 2.6.2 (Peeters et al., 2018) highlighted that a relatively simple change in the conceptualisation used in the AEM for the Galilee subregion can produce substantially different probabilistic drawdown predictions at individual locations. To reveal the extent to which alternative conceptual models can influence groundwater predictions within the zone, the AEM was run 10,000 times for two different approaches (with detailed results and discussion presented in Section 2.6.2.8 of companion product 2.6.2 (Peeters et al., 2018)). The original conceptualisation allowed the AEM to simulate drawdown via the two pathways mentioned above (i.e. pathway 1 and pathway 2). This approach simulates 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 layers via intervening aquitards. The second approach (the alternative conceptualisation), only allowed for drawdown to occur via pathway 2, which 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 (which is impeded by the aquitard layers of the Rewan Group and the low permeability basal layer of the Cenozoic sediments).

Focusing on results at three specific locations near the Carmichael River (receptor locations GAL_021, GAL_037 and GAL_043), the results presented in Figure 26 indicate that removing the constant drawdown condition in the alluvial/sediment aquifer (which simulates the effects of completely dewatering this upper aquifer due to mining) causes large variations in the predicted drawdown (*dmax*) at GAL_021 and GAL_037 (i.e. difference shown between the original and alternative conceptualisations). The median *dmax* values at the Carmichael GDE location decrease from 0.29 m to 0.02 m, while at Doongmabulla Springs, the median *dmax* values drop from 0.88 m to 0.18 m. The *dmax* values at Mellaluka Springs are not noticeably affected by the conceptual model change, as drawdown at these springs is only dependent on changes in the upper Permian coal measures.

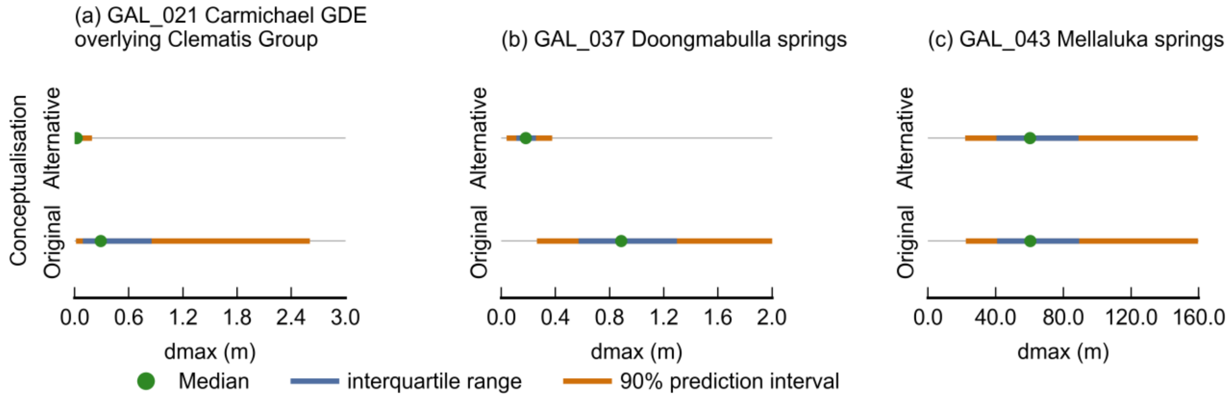

Figure 26 Boxplots of *dmax* for the original and alternative conceptualisation at (a) GAL_021 Carmichael GDE overlying Clematis Group, (b) GAL_037 Doongmabulla Springs and (c) GAL_043 Mellaluka Springs

As explained in the preceding text, the original conceptualisation has two potential drawdown pathways emanating from the various coal mining operations, whereas the alternative conceptualisation involves only a single drawdown pathway via the upper Permian coal measures. Consequently, drawdown predictions for any model nodes in AEM layer 1 (Quaternary alluvium and Cenozoic sediments), such as GAL_021, and AEM layer 3 (Clematis Group), such as GAL_037, will have smaller *dmax* values for the alternative conceptualisation than for the original conceptualisation. However, *dmax* values are the same for any model nodes in the upper Permian coal measures. Additional drawdown is *dmax*, the maximum difference in drawdown between the coal resource development pathway (CRDP) and baseline, due to additional coal resource development.
GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 7)

As discussed in companion product 2.6.2 (Peeters et al., 2018), the variation in model results in Figure 26 highlights that at local sites near the mines, in the unconfined aquifer (Quaternary alluvium and Cenozoic sediments) and the underlying confined Clematis aquifer, most of the simulated drawdown is caused by the constant drawdown boundary in the unconfined aquifer (which assumes the existence of a laterally continuous unconfined aquifer). In areas where this assumption is not valid (e.g. in areas of outcropping Triassic rock units), the predictions can be overestimated by up to an order of magnitude. Despite its closer proximity to the mine, the *dmax* values at the Carmichael GDE (GAL_021) are smaller than at Doongmabulla Springs (GAL_037). This is because the model node associated with Doongmabulla Springs is situated in the model layer containing the confined Clematis Group aquifer, where the storage is orders of magnitude smaller than in the overlying unconfined aquifer in which the Carmichael GDE model node is situated. For the same change in groundwater flux, the smaller storage will lead to a larger drawdown. Further discussion about potential impacts at Doongmabulla Springs, factoring in the drawdown results of the alternative conceptualisations presented above (and discussed in more detail in companion product 2.6.2 (Peeters et al., 2018)), is presented in Section 3.4.3 and Section 3.5.2.

Other factors that potentially lead to overestimated drawdown extents or predictions for the Quaternary alluvium and Cenozoic sediment aquifer, as well as the Clematis Group aquifer include:

- The uppermost model layer(alluvium and sediment aquifer) does not actually exist across the entire zone of potential hydrological change (as shown in Figure 27) as a continuous 10 m thick and evenly distributed layer with the same hydraulic properties (i.e. this upper aquifer is not an isotropic and homogenous layer as represented in the model). Thus, the model over estimates the areal extent of drawdown in the upper aquifer layer, as it assumes that drawdown can propagate throughout a laterally continuous and homogenous shallow sediment layer that does not actually exist in some areas of the zone.

- In areas where the Permian or Triassic rock units occur at the surface (i.e. areas where no Cenozoic sediments exist, as shown in Figure 27), the generally lower hydraulic conductivities of these weathered and/or consolidated rock units are likely to impede propagation of modelled drawdown in the unconfined aquifer. For example, in the southern zone, a ridge of Late Carboniferous to Permian sedimentary rocks forms a prominent topographic high that is likely to form an effective barrier to continuous groundwater connection in the uppermost aquifer. This ridgeline separates the Alpha Creek – Native Companion Creek valley from the Lagoon Creek – Sandy Creek valley to the west (in the area where the southern cluster of coal mines is proposed, see Figure 27).

The simulated changes in surface water – groundwater exchange flux are also likely to be overestimated. In addition to the assumption that the unconfined aquifer is continuous between every mine pit and the Belyando River, it assumes that the Belyando River system is a regional discharge feature in which there is always water available.

Considering the information presented above, model results in companion product 2.6.2 (Peeters et al., 2018) are likely to be most applicable in areas where there are laterally extensive sheets of Cenozoic sediments with saturated thickness of at least 10 m. In the zone of potential hydrological change, these areas are most likely to occur east of the outcropping Triassic rock units of the Moolayember Formation, Clematis Group and Rewan Group, along the eastern flank of the Great Dividing Range (these are shown in Figure 27 as either the yellow or pale orange areas in the central and eastern parts of the zone). Areas of the zone where the layer 1 drawdown results from the AEM may be less applicable are where extensive outcrop areas of pre-Cenozoic rocks occur (e.g. in areas of Triassic rock units such as the Moolayember Formation and Rewan Group, which are shown in darker green in Figure 27), or where the Quaternary alluvium is restricted to confined valleys, and does not exist as an extensive sheet-like layer.

Table 12 compares the extents of the main stratigraphic units in the zone of potential hydrological change for two different sources of geological data that cover the Galilee Basin, namely the *National surface geology of Australia 2012* dataset (Geoscience Australia, Dataset 8), and the *Geology of Queensland 2012* dataset (Geological Survey of Queensland, Dataset 9). For these two surface geology datasets, the respective areal extents of the Quaternary alluvium and Cenozoic sediments, the various Galilee Basin units (Moolayember Formation, Clematis Group – Warang Sandstone and Dunda beds – Rewan Group) and the older Carboniferous rock units are approximately similar (Table 12). However, at local scales there may be important differences in the areal extents of the main stratigraphic units within the zone of potential hydrological change. For example, the 2012 national surface geology dataset published at 1 million scale (Geoscience Australia, Dataset 8) indicates that Cenozoic sediments occur continuously along most of the Carmichael River valley and its tributaries (although the map does not indicate variations in alluvial sediment thickness along the valley). In contrast, the Queensland Geological Survey’s 2012 state geology dataset (published at 2 million scale) does not indicate that any alluvium occurs along the valley of the Carmichael River.

Local variations in geology within the zone of potential hydrological change are further highlighted from more detailed geological mapping, such as finer-scale individual mapsheets at 100,000 scale. For example, on the Mount Tutah mapsheet (DME, 2008) there are notable differences in the distribution of Galilee Basin stratigraphic units and Cenozoic sediments, such as outcrop areas classified as Rewan Group on coarser-scale maps depicted as Moolayember Formation outcrop at 100,000 scale. This is an example of one of the many complexities that can arise when downscaling regional mapping and modelling results to local features. As outlined in companion product 2.1-2.2 for the Galilee subregion (Evans et al., 2018a), there is clearly the need for coordinated revision and refinement of geological mapping for the central-eastern margin of the Galilee Basin (see Section 3.7.4 for further details on future research opportunities). New data and interpretations arising from such work would help to improve any future conceptualisation of local-scale groundwater modelling and impact analysis in this area. As an example, some of the ongoing geological mapping work outlined in Hansen and Uroda (2017) could be used as part of future investigations to further improve understanding of the local hydrogeology and geology in areas near the eastern margin of the Galilee Basin.

Table 12 Comparison of main geological units mapped at surface within the zone of potential hydrological change

Stratigraphic unit	Percentage of area (%) based on National surface geology of Australia 2012 dataset (1 million scale)	Percentage of area (%) based on Geology of Queensland 2012 dataset (2 million scale)
Quaternary alluvium and other Cenozoic sediments	80%	74%
Cenozoic volcanic rocks	na	1%
Moolayember Formation	4%	6%
Clematis Group – Warang Sandstone	8%	7%
Dunda beds – Rewan Group	5%	6%
Upper Permian coal units	1%	1%
Joe Joe Group	<1%	1%
Carboniferous sedimentary rocks (undifferentiated)	1%	3%
Other	1%	<1%

na = not applicable
Data: Bioregional Assessment Programme (Dataset 8, Dataset 9)

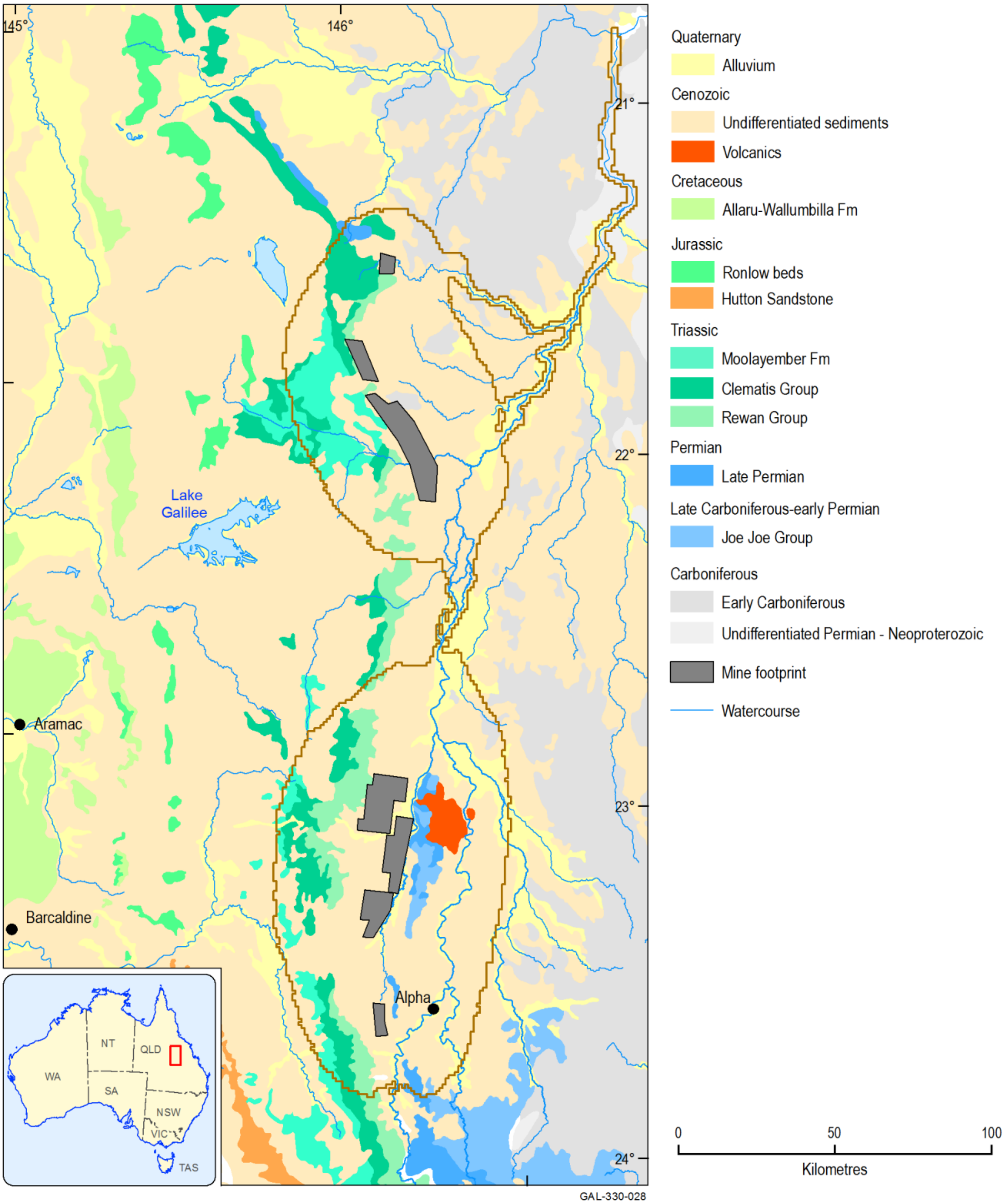

Figure 27 Surface geology within the zone of potential hydrological change, highlighting the abundance of Quaternary alluvium and Cenozoic sediments associated with the Belyando River and its tributaries

Data: Bioregional Assessment Programme (Dataset 2), Geological Survey of Queensland (Dataset 9)

3.3.2.1.2 Applying groundwater modelling results for impact and risk analysis of the Galilee subregion

Throughout this product, the modelling results generated by applying the original groundwater conceptualisation (as previously discussed in Section 3.3.2.1.1) are primarily used for the impact and risk analysis. This conceptualisation is considered to be the most appropriate for assessing the regional-scale, cumulative impacts of coal resource development on hydrology and ecosystems in the Galilee assessment extent, and is thus used as the basis for defining the groundwater component of the zone of potential hydrological change and undertaking the analysis presented throughout this section (Section 3.3) and Section 3.4 (impacts and risks to landscape classes). However, for some specific ecological assets (e.g. some springs), the analysis presented in Section 3.5 may utilise the groundwater results from the alternative conceptualisation. This is done in cases where, on the basis of the available evidence, the Assessment team considers that the results generated by the alternative conceptualisation are more locally applicable than those from the original conceptualisation. In particular, detailed analysis of potential impacts to assets that occur within the 'Springs' landscape group are presented in Section 3.5.2.6, where the results from the two groundwater model conceptualisations are compared to better understand the likely groundwater responses for some spring-related assets.

A final important point here is that the AEM outputs from the alternative conceptualisation have not been used in this BA to define any type of 'alternative zone of potential hydrological change.' This is because the primary purpose of the zone is to rule out areas of the assessment extent from potential impact due to additional coal resource development. As explained previously, the drawdown predictions in the Quaternary alluvium and Cenozoic sediment layer (AEM layer 1) from the alternative conceptualisation will always cover a much smaller range (i.e. from 5th to 95th percentile results) at any particular point than the range from the original conceptualisation. This effectively means that the extent of the zone (as developed for this BA using the original conceptualisation) will completely enclose the area that would be defined on the basis of the 0.2 m drawdown threshold at the 95th percentile using the alternative approach. Thus, there is no need to develop an 'alternative zone' for the purposes of this BA as it would be substantially smaller in extent than the existing zone, and would likely also further complicate the presentation of results from this BA.

3.3.3 Potential surface water changes

The hydrological response variables generated from the surface water modelling are listed in companion product 2.6.1 for the Galilee subregion (Karim et al., 2018b). Three of the eight hydrological response variables were selected for further analysis, and were chosen to represent changes in low-flow regime (ZFD – zero-flow days), high-flow regime (FD – high-flow days) and mean annual flow (AF) due to additional coal resource development. The model values for the additional coal resource development reflect the maximum difference between streamflow time series under the CRDP and baseline (which has no coal resource development) from the top 10% of simulations (i.e. 347) for each hydrological response variable.

3.3.3.1 Zero-flow days

As defined in companion product 2.6.1 (Karim et al., 2018b), a zero-flow day in the BA for the Galilee subregion is one when streamflow is less than 1 ML/day from the simulated 90-year period (2013 to 2102) for that stream. The modelled increases in the number of zero-flow days due to additional coal resource development in the Galilee zone of potential hydrological change are compiled in Table 13, and shown spatially in Figure 28. Streams denoted as 'unquantified potential hydrological change' are likely to experience an increase in zero-flow days due to additional coal resource development. However, results from the nearby upstream or downstream model nodes cannot be reliably interpolated to these reaches due to assumed (but non-modelled) hydrological changes along the reach (e.g. from tributary inflows) or from more direct impacts of coal mining operations. An indication of the potential increases in zero-flow days in the 'potential hydrological change' reaches near mining operations can be inferred from stream reaches immediately upstream and/or downstream, where the potential increases in zero-flow days have been quantified.

At the 95th percentile, about 18% (or 1108 km) of the entire stream network (6285 km) in the surface water zone of potential hydrological change is predicted to experience increases of at least 3 days per year in the number of zero-flow days (as per the zero-flow threshold definition in Table 9). This includes Sandy Creek – Lagoon Creek, which runs adjacent to the southern cluster of mines; parts of the Belyando River downstream of its confluence with Sandy Creek to Lake Dalrymple (Burdekin Falls Dam); the Carmichael River downstream of the proposed Carmichael Coal Mine; and several of the east-flowing creeks that drain the northern reporting area, for example, North Creek and Bully Creek. Modelling suggests it is *very unlikely* (less than 5% chance) that there will be increases in zero-flow days due to additional coal resource development in the Cape River or the reaches of the Suttor River that are upstream of its junction with the Belyando River.

The median stream length with at least 3 days per year increase in zero-flow days is only slightly less than the total stream length at the 95th percentile, with 1034 km of streams exceeding the minimum zero-flow day threshold at the median result. Another 1781 km of streams are flagged as potentially impacted in the surface water zone, but surface water changes could not be quantified for these reaches due to various reasons (as previously explained in Section 3.3.1.2). The cumulative exceedance plots of stream length with additional zero-flow days in Figure 29 and the underpinning data in Table 13 indicate the progressive decrease in impacted stream lengths at higher thresholds. For example, about 956 km of streams have at least an increase of 20 days per year of zero flow at the 95th percentile, whereas 798 km of modelled streams have an increase of at least 80 days per year (95th percentile). Increases in zero-flow days above the 200-day maximum range shown in Figure 28 are only evident at the 95th percentile, with 591 km of streams predicted to experience at least this amount of impact. These large increases in zero-flow days mainly occur in the northern reporting area, and potentially affect a near-continuous stretch of the Belyando River over several hundred kilometres (Figure 28). In contrast, the Belyando River is not expected to be impacted due to additional coal resource development in the southern part of the zone, until it reaches the junction with Native Companion Creek.

Modelled increases in the number of zero-flow days are largest along the main reaches of the Belyando River and the part of the Suttor River downstream of its junction with the Belyando (Figure 28). This indicates that changes in the low-flow regime are likely to be more substantial for reaches where impacts from multiple mining operations can combine and cumulatively affect downstream sections of the main river system (as opposed to smaller tributaries that may occur closer to individual mines, but are not influenced by multiple mining operations). In analysing these low-flow modelling results, it is important to be aware that many reaches of the Belyando and Suttor rivers that show a 5% chance of more than an additional 200 zero-flow days (Figure 28) may not actually flow for 200 days (or more) in most years. However, in some very wet years, these rivers can receive considerable inflows and it is possible for over 200 days of streamflow to occur. For example, available stream gauge data for the Belyando River at the Gregory Development Road Crossing (Queensland gauge 120301B) from late May 2005 to late November 2007 indicate that streamflow occurred at this site approximately 250 days per year over this period (Queensland Government, 2017). Hence, the apparent anomalous increase in zero-flow days observed from the hydrological modelling occurs entirely as a result of the potential for these particularly wet years to occur across the 90-year simulation period. As the surface water modelling in the BAs focuses on the maximum change in zero-flow days due to additional coal resource development, the reporting is biased towards these wet years when the maximum changes in the low-flow regime can occur. This means that the maximum reduction in zero-flow days is most likely to occur in a very wet year, around the time when the maximum mine footprint is developed.

Table 13 Stream length (km) potentially exposed to varying increases in zero-flow days in the zone of potential hydrological change

Reporting area	Length in zone of potential hydrological change (km)	Length potentially impacted but change not quantified (km)	Length with ≥3 day increase in zero-flow days per year (km)			Length with ≥20 day increase in zero-flow days per year (km)			Length with ≥80 day increase in zero-flow days per year (km)			Length with ≥200 day increase in zero-flow days per year (km)		
			5th	50th	95th	5th	50th	95th	5th	50th	95th	5th	50th	95th
Northern	3030	1050	256	617	692	183	524	547	0	0	524	0	0	524
Southern	3255	731	91	416	416	0	67	409	0	0	274	0	0	67
Total	**6285**	**1781**	**347**	**1034**	**1108**	**183**	**591**	**956**	**0**	**0**	**798**	**0**	**0**	**591**

Due to rounding, some totals reported here may not correspond exactly with the sum of the separate numbers.
Data: Bioregional Assessment Programme (Dataset 1)

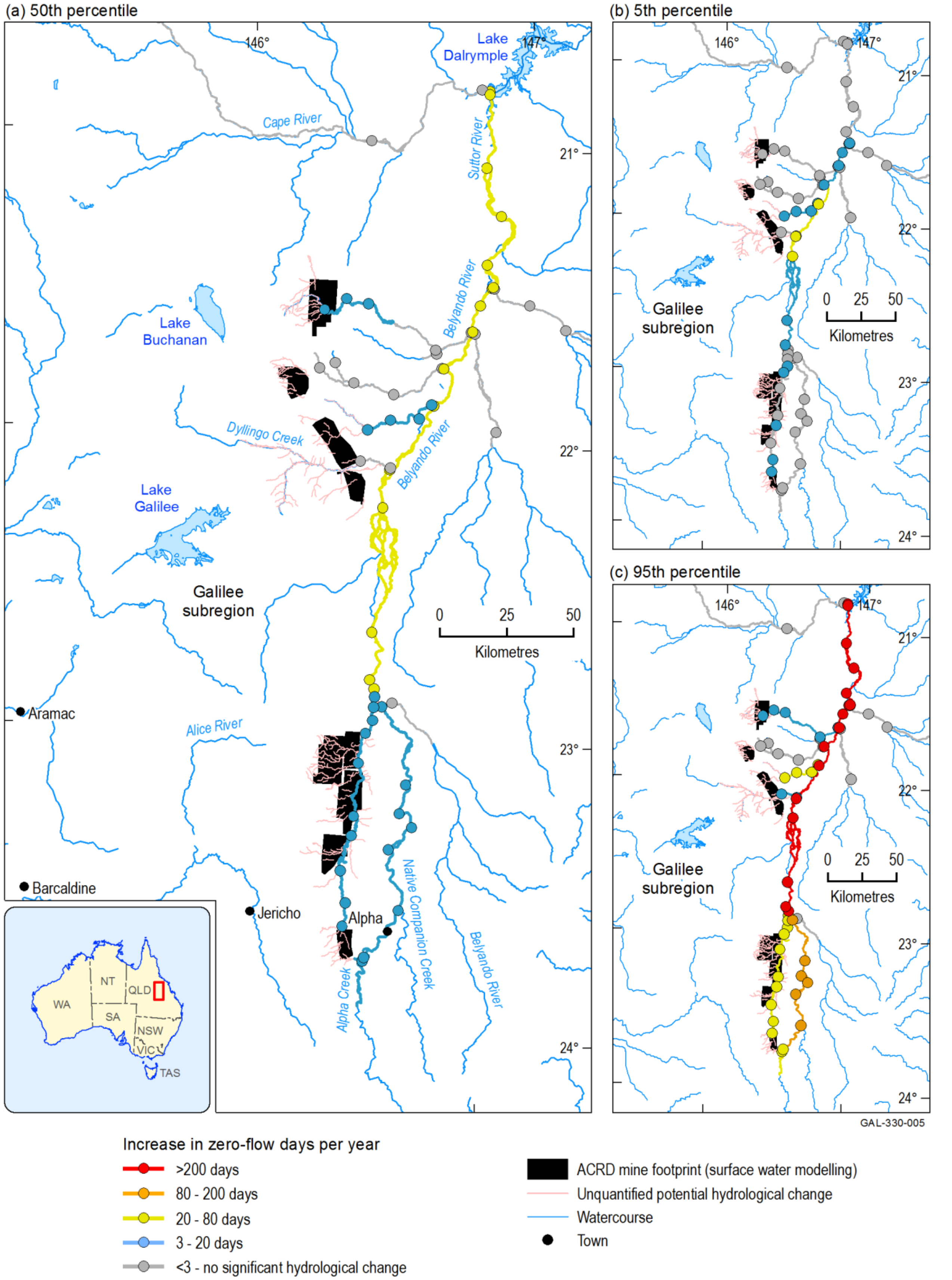

Figure 28 Increases in the number of zero-flow days due to additional coal resource development

ACRD = additional coal resource development

Data: Bioregional Assessment Programme (Dataset 1, Dataset 6)

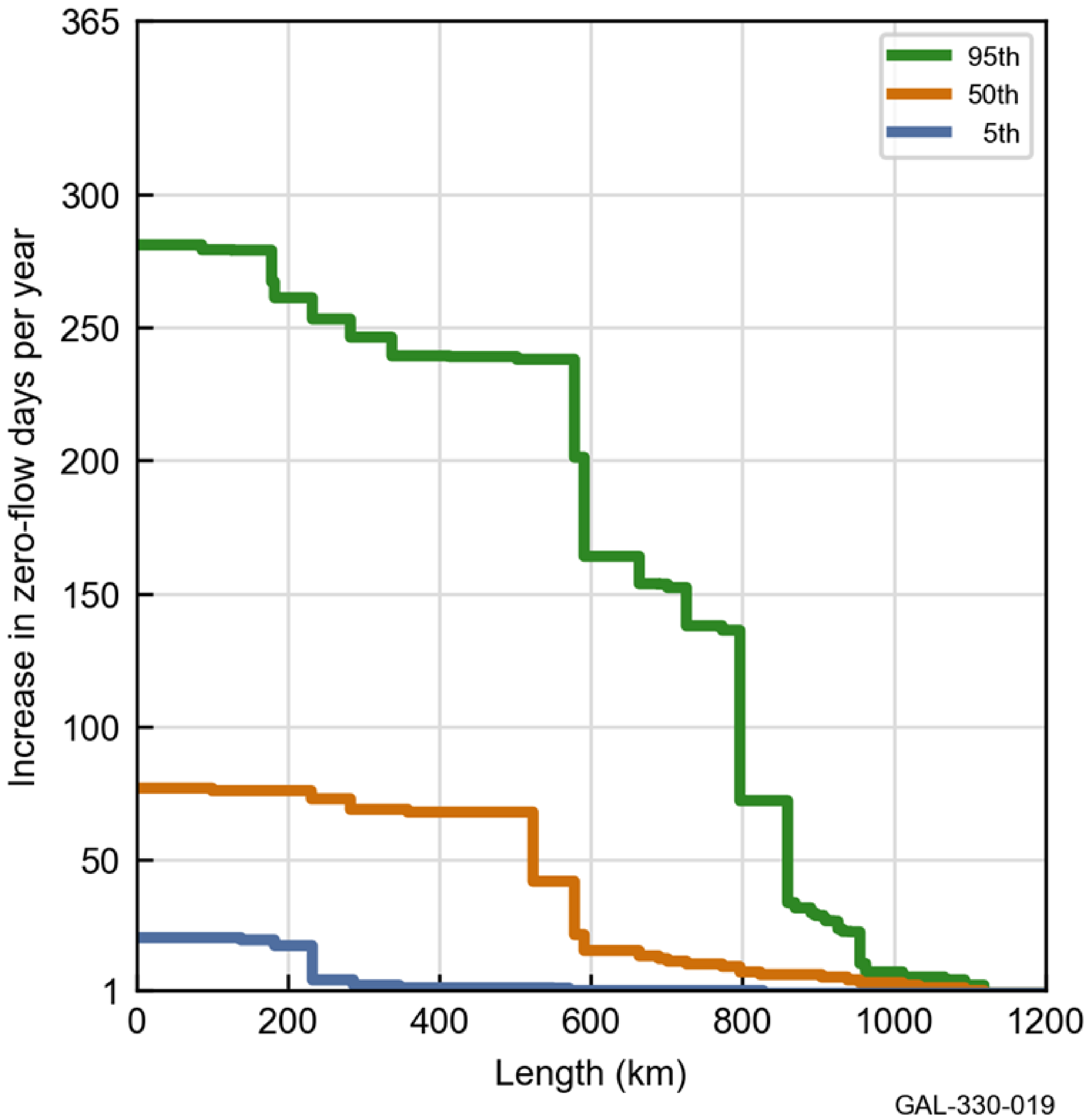

Figure 29 Cumulative exceedance plot of the increase in the number of zero-flow days due to additional coal resource development for 5th (blue), 50th (orange) and 95th (green) percentiles

Data: Bioregional Assessment Programme (Dataset 1)

To understand the significance of the modelled increases in zero-flow days, it is useful to look at them in the context of the interannual variability in zero-flow days due to climate. In other words, are the predicted increases due to additional coal resource development within the natural range of variability of the longer-term flow regime in this river basin? If so, then this may suggest that the system is adapted to the range of possible increases that may be expected due to additional coal resource development. Alternatively, are the modelled increases potentially able to shift the system outside of the range of hydrological variability it experiences under the baseline climate? If the latter case, the system may be less able to adapt to the changes in hydrology due to additional coal resource development.

The maximum increase in the number of zero-flow days due to additional coal resource development relative to the interannual variability in zero-flow days under the baseline has been adopted to provide some degree of context around the modelled changes. This ratio is shown qualitatively for each surface water model node in Figure 30. Table 14 provides the ratio ranges for zero-flow days, high-flow days and annual flow volume that were selected for each qualitative ratio class in Figure 30. It is important to be aware that the changes shown in Figure 30 represent the maximum change due to additional coal resource development in a single year relative to the interannual variability across 90 years (2013 to 2102) under the baseline. Thus, it is not a comparison of distributions, but an assessment of whether the change due to additional coal resource development, in the year of maximum difference between the CRDP and the baseline, is within the range of natural variability. If the maximum change is small relative to the interannual variability due to climate (e.g. an increase of 3 days relative to a baseline range of 20 to 50 days), then the risk of impacts from the changes in zero-flow days is likely to be low. If the maximum change is comparable to or greater than the interannual variability due to climate (e.g. an increase of 200 days relative to a baseline range of 20 to 50 days), then there is a greater risk of impact on the landscape classes and assets that rely on this water source.

Table 14 Ratio of increase in the number of zero-flow days (ZFD), high-flow days (FD) and annual flow volume (AF) due to additional coal resource development to the interannual variability in low-flow days under the baseline

Qualitative ratio class	Ratio range
No significant change	ZFD <3 days FD ≥3 days AF ≥1%
Less than interannual variability	<0.5
Comparable to interannual variability	0.5–1.5
Greater than interannual variability	>1.5

FD = high-flow days – in previous products, this is referred to as 'flood days'

At the 5th percentile (Figure 30b), the predicted changes in zero-flow days represent no significant change or are less than the interannual variability at all model nodes. At the 50th percentile (Figure 30a), the modelled changes are mostly less than the baseline variability, except for the nodes on the northern-most stretches of the Belyando and Suttor rivers upstream of Lake Dalrymple, particularly for the nodes downstream of the Belyando River junction with the Suttor River. Along this stretch, the zero-flow day changes are largely comparable to the baseline interannual variability (i.e. the model nodes shown in yellow in Figure 30a). In contrast, results at the 95th percentile (Figure 30c) indicate that much of the Belyando River (and the Suttor River downstream of the Belyando junction) is expected to be impacted by increases in zero-flow days above the baseline interannual variability, especially in the northern reporting area (i.e. model nodes shown in red in Figure 30c). In the southern part of the zone, the predicted increases in zero-flow days are less than or comparable to the interannual variability typically experienced under baseline conditions.

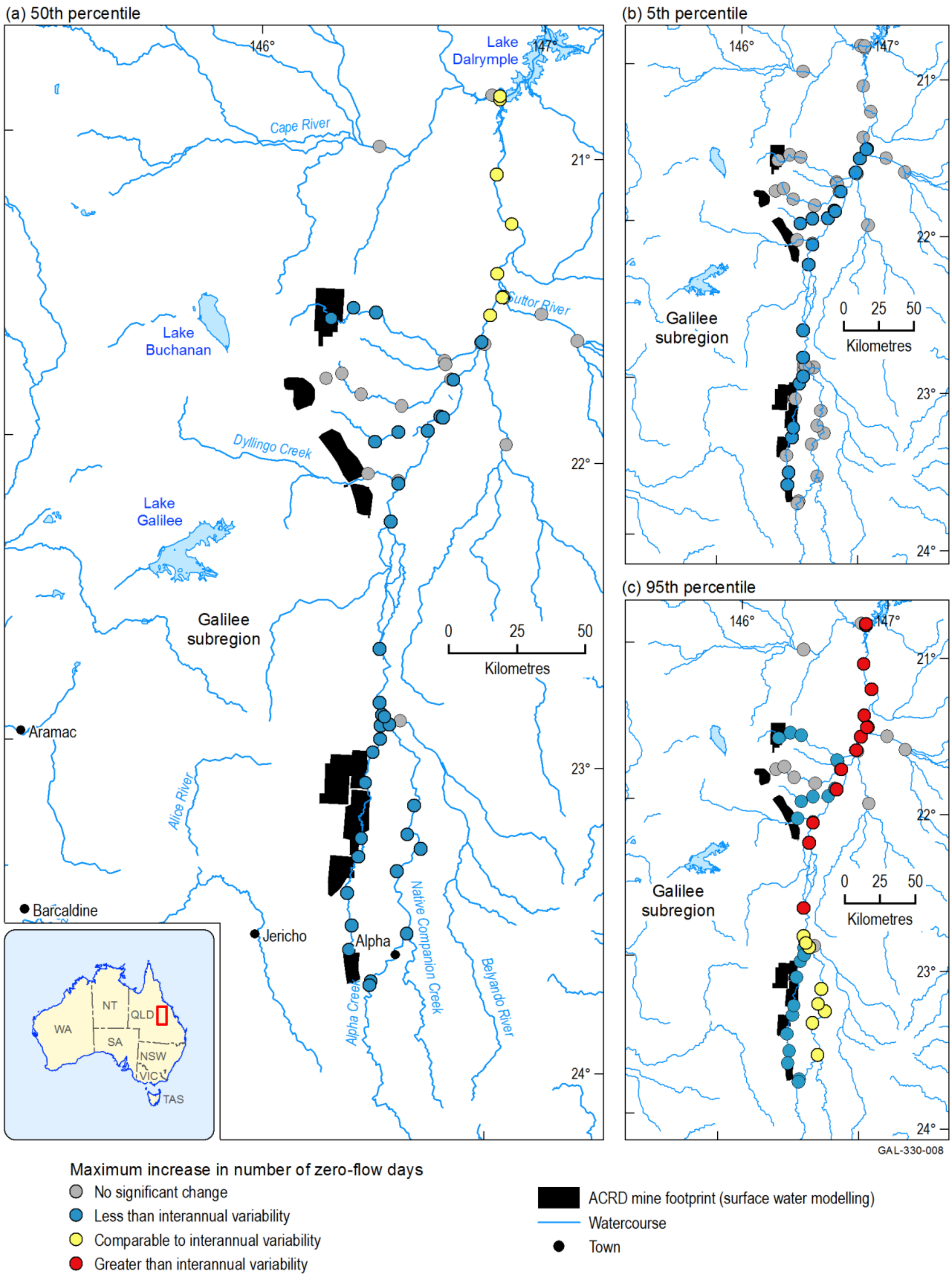

Figure 30 Ratio of change in zero-flow days due to additional coal resource development to the interannual variability in zero-flow days under the baseline

The extent of the coal resource developments in the coal resource development pathway (CRDP) is the union of the extents in the baseline and in the additional coal resource development (ACRD).
Data: Bioregional Assessment Programme (Dataset 1, Dataset 6, Dataset 10)

3.3.3.2 High-flow days

As stated in companion submethodology M06 (as listed in Table 1) for surface water modelling (Viney, 2016), a high-flow day is defined as one in which the streamflow exceeds the 90th percentile of flow from the simulated 90-year period (2013 to 2102) for that stream. The modelled reductions in the number of high-flow days for the 5th, 50th and 95th percentiles due to additional coal resource development in the Galilee subregion are shown in Figure 31. Reductions in high-flow days of at least 3 days per year are *very likely* (greater than 95% chance) along Lagoon Creek – Sandy Creek, where it runs adjacent to the proposed coal mines at China First, Alpha and Kevin's Corner in the southern part of the zone, and in the northern part of the zone along North Creek. For the median result, similar nodes and reaches at Lagoon Creek – Sandy Creek and North Creek are expected to experience reductions in high-flow days of between 10 and 20 days each year. Most of Bully Creek (which has the proposed Hyde Park Coal Mine in the headwater area) is also expected to have reductions of at least 3 days of high-flow days per year. Most other parts of the modelled stream network at the 5th and 50th percentiles are not expected to have significant hydrological changes. It is only at the 95th percentile of all modelling runs that any streams (totalling less than 200 km) will have reductions in high-flow days in excess of 50 days per year (Table 15); these are mainly confined to the aforementioned stretches of Lagoon Creek – Sandy Creek in the southern zone, and North Creek in the northern zone. Interestingly, the most northern nodes and reaches of the Belyando – Suttor River (above Lake Dalrymple), which experienced the most substantial increases in zero-flow days of anywhere in the modelled stream network (at the 95th percentile), represent some of the least impacted of the modelled stream network when decreases in high-flow days are considered. These differences indicate that coal mining activities that impact directly on overland flow such as interception by open-cut pits are more likely to lead to reductions in high streamflow variables. Conversely, those activities that are mediated via groundwater (e.g. though depressurisation of aquifers) are more likely to lead to changes in low streamflow variables.

A cumulative exceedance plot of the reductions in high-flow days is shown in Figure 32, and the summary data are presented in Table 15 – including the length of potentially impacted but not quantified streams (which are not shown in Figure 31). At the 95th percentile, the total length of the modelled stream network potentially impacted by reductions of at least 3 high-flow days is 1430 km, and about 65% of these streams are in the northern part of the zone. In contrast, for streams that are predicted to have reductions in high-flow days of greater than 50 days per year, about 86% of the total occurs in the southern part of the zone (Table 15). A further 1460 km of streams are classified as potentially impacted but not quantified.

The comparison of maximum change in high-flow days due to additional coal resource development and interannual variability in high-flow days under the baseline (Figure 33) shows that at most nodes, the maximum change is relatively small compared to interannual variability and that the predicted changes are unlikely to increase the stress on these streams. Generally, the impact of additional coal resource development on high-flow days is not as great as it is on low-flow days. It is *very unlikely* that impacts on high-flow days at any model nodes will exceed the baseline interannual variability.

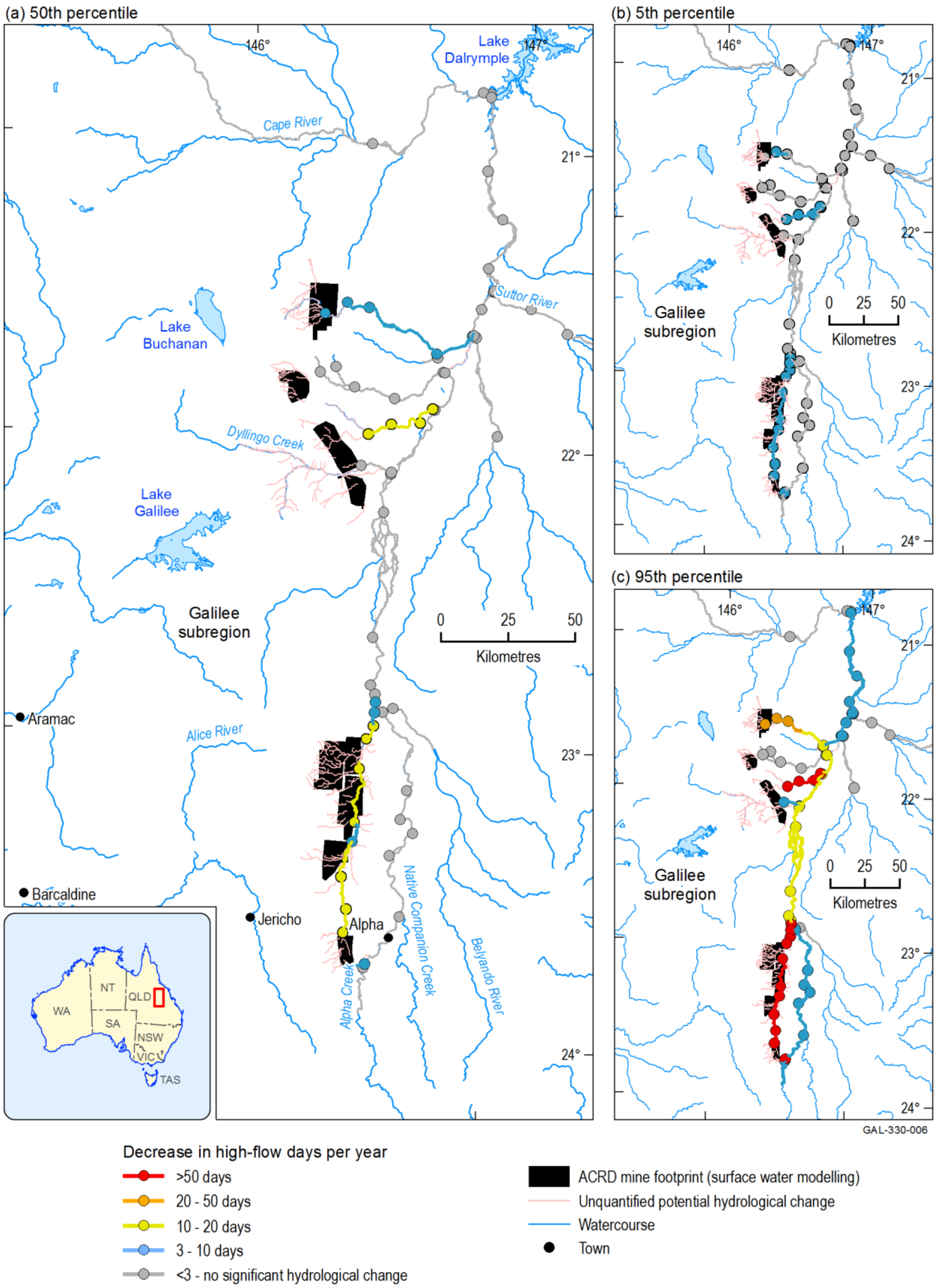

Figure 31 Decrease in the number of high-flow days due to additional coal resource development

Data: Bioregional Assessment Programme (Dataset 1, Dataset 6, Dataset 10)

Table 15 Stream length (km) potentially exposed to varying reductions in high-flow days in the zone of potential hydrological change

Reporting area	Length in zone of potential hydrological change (km)	Length potentially impacted but not change quantified (km)	Length with ≥3 day reduction in high-flow days per year (km)			Length with ≥10 day reduction in high-flow days per year (km)			Length with ≥20 day reduction in high-flow days per year (km)			Length with ≥50 day reduction in high-flow days per year (km)		
			5th	50th	95th	5th	50th	95th	5th	50th	95th	5th	50th	95th
Northern	3030	809	72	154	933	0	72	547	0	24	94	0	0	24
Southern	3255	650	158	158	497	0	158	228	0	120	158	0	0	158
Total	**6285**	**1460**	**231**	**313**	**1430**	**0**	**231**	**775**	**0**	**143**	**252**	**0**	**0**	**182**

Due to rounding, some totals reported here may not correspond exactly with the sum of the separate numbers.
Data: Bioregional Assessment Programme (Dataset 1)

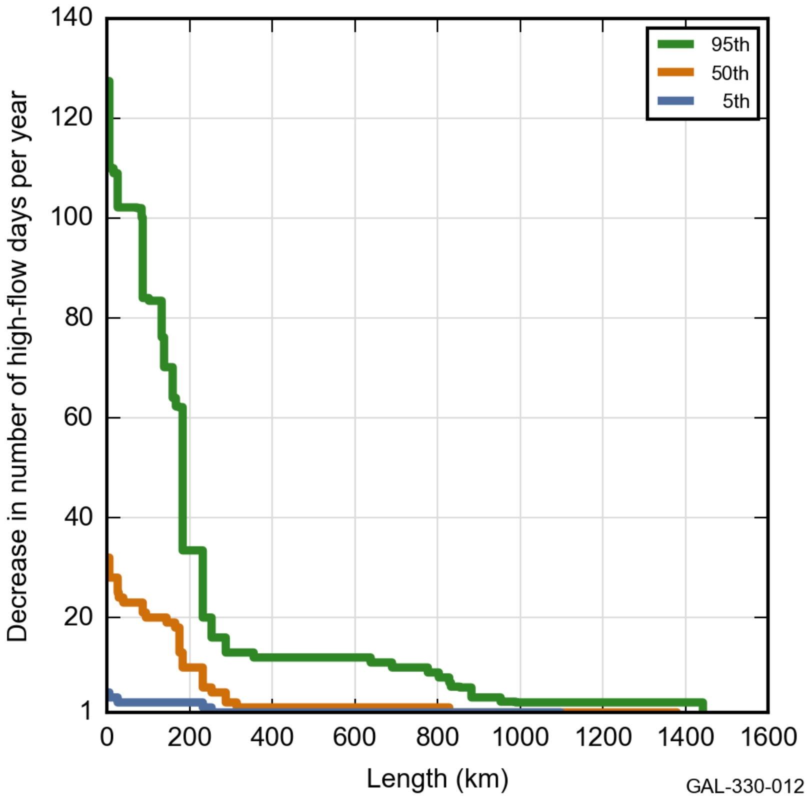

Figure 32 Cumulative exceedance plot of the reduction in the number of high-flow days due to additional coal resource development for 5th (blue), 50th (orange) and 95th (green) percentiles

Data: Bioregional Assessment Programme (Dataset 1)

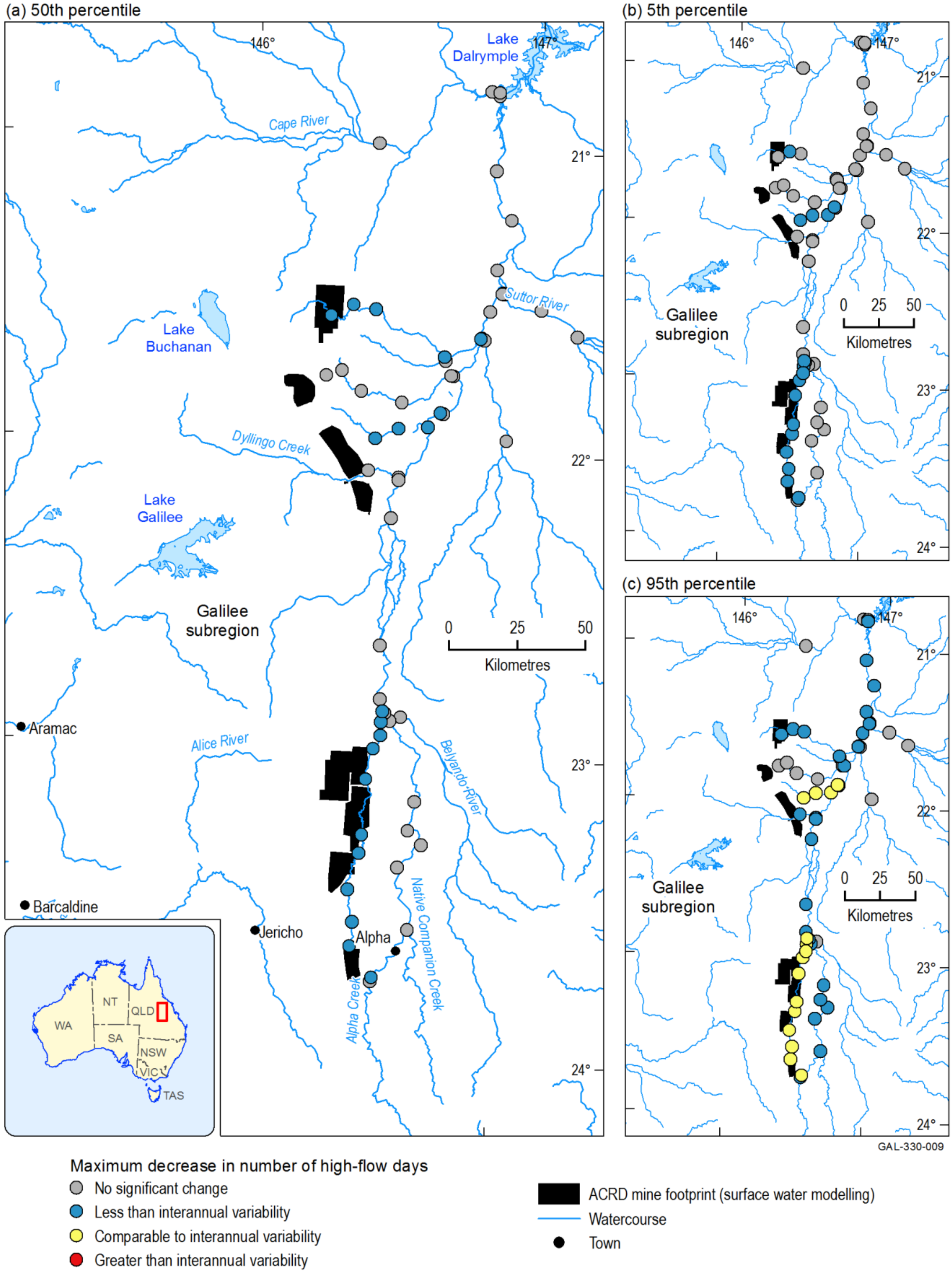

Figure 33 Ratio of change in high-flow days due to additional coal resource development to the interannual variability in high-flow days under the baseline

The extent of the coal resource developments in the coal resource development pathway (CRDP) is the union of the extents in the baseline and in the additional coal resource development (ACRD).
Data: Bioregional Assessment Programme (Dataset 1, Dataset 6, Dataset 10)

3.3.3.3 *Annual flow*

The annual flow (AF) represents the maximum percentage change in the mean annual flow volume (GL/year) over the simulated 90-year period (2013 to 2102) due to additional coal resource development. This is shown in Figure 34 for stream reaches in the surface water zone of potential hydrological change. A cumulative exceedance plot of the reduction in annual flow is shown in Figure 35, with summary data presented in Table 16. The spatial distribution of changes in annual flow show many similarities across the 5th, 50th and 95th percentiles, and these similarities are further emphasised by the high degree of overlap between individual lines in the cumulative exceedance plot (Figure 35).

The extent of the modelled stream network subject to at least a 1% reduction in mean annual flow volume at the 95th percentile is 886 km, with a median of 833 km. A further 1442 km of streams are potentially impacted by changes in annual flow, but changes in these streams could not be quantified. Only 6 km of the stream network is likely to experience greater than 20% reduction in annual flow volume, and this occurs just downstream of the proposed South Galilee Coal Mine on Tallarenha Creek (near node 3). These results are consistent at the 5th, 50th and 95th percentiles. Similarly, the 269 km of stream network expected to have greater than 5% reduction in annual flow is consistent regardless of the percentile. The streams that are predicted to have the greatest reductions in annual flow are:

- Tallarenha Creek – Lagoon Creek, where the stream starts near 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
- Bully Creek, some segments just downstream of the Hyde Park Coal Project.

The similarity of annual flow decreases for all three percentiles (at thresholds above 1% reduction) is because reduction in annual flow is driven primarily by direct interception of surface runoff by open-cut mines and areas of mine-site infrastructure. The probability of this reduction does not vary. Only a small component of the reduction in annual flow is driven by changes in baseflow due to reduced surface water – groundwater connectivity.

The maximum change in annual flow due to additional coal resource development relative to the interannual variability of annual flow under the baseline is shown for each surface water node in Figure 36. At all nodes for the 5th and 50th percentile results, the maximum change in annual flow due to additional coal resource development is either not significant or is less than the interannual variability under the baseline. It is only at the 95th percentile for the various surface water nodes that occur on Sandy Creek, North Creek and Bully Creek that the annual flow changes may be considered comparable to baseline variability (Figure 36).

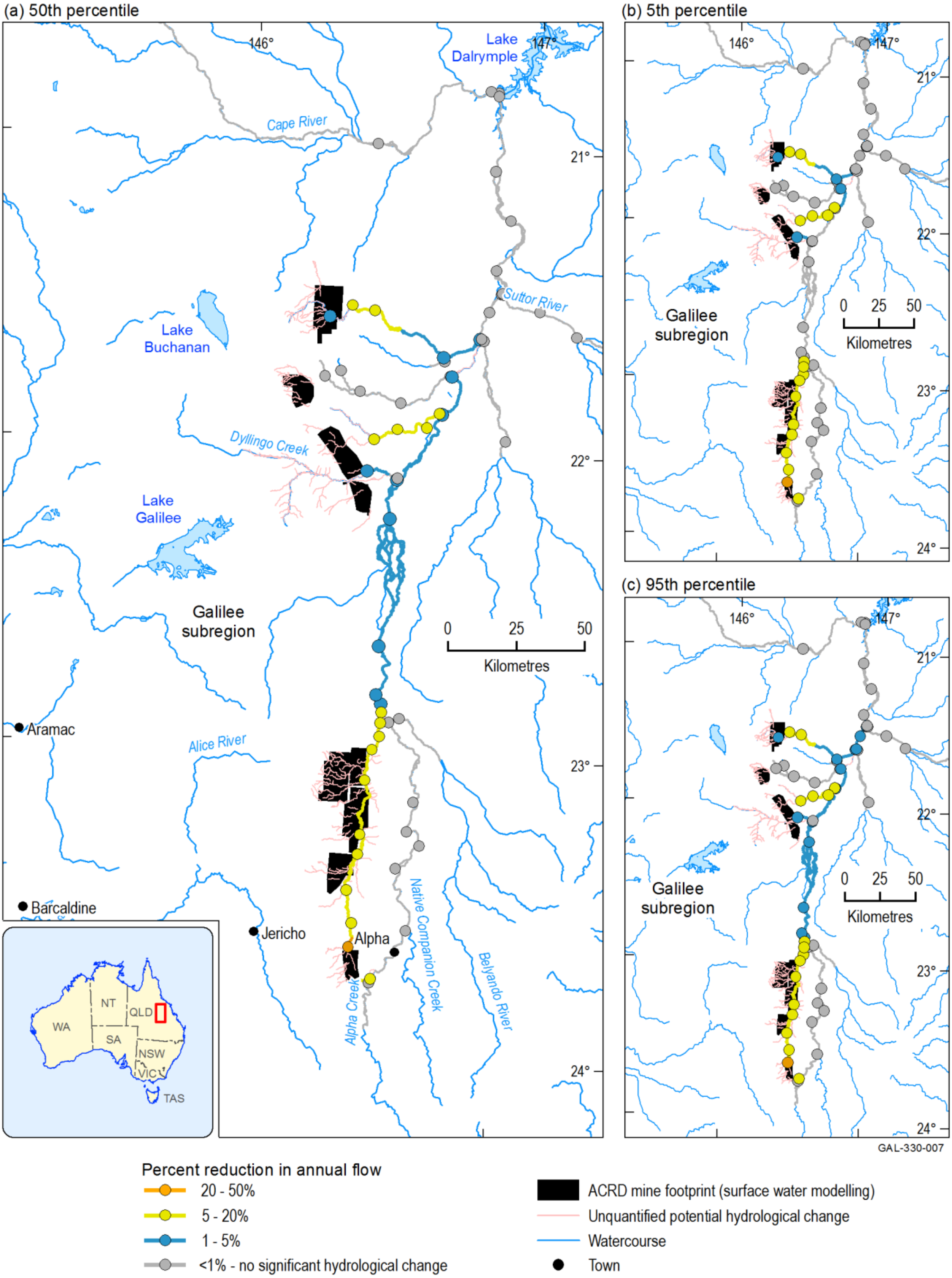

Figure 34 Decrease in annual flow due to additional coal resource development

The extent of the coal resource developments in the coal resource development pathway (CRDP) is the union of the extents in the baseline and in the additional coal resource development (ACRD).
Data: Bioregional Assessment Programme (Dataset 1, Dataset 6)

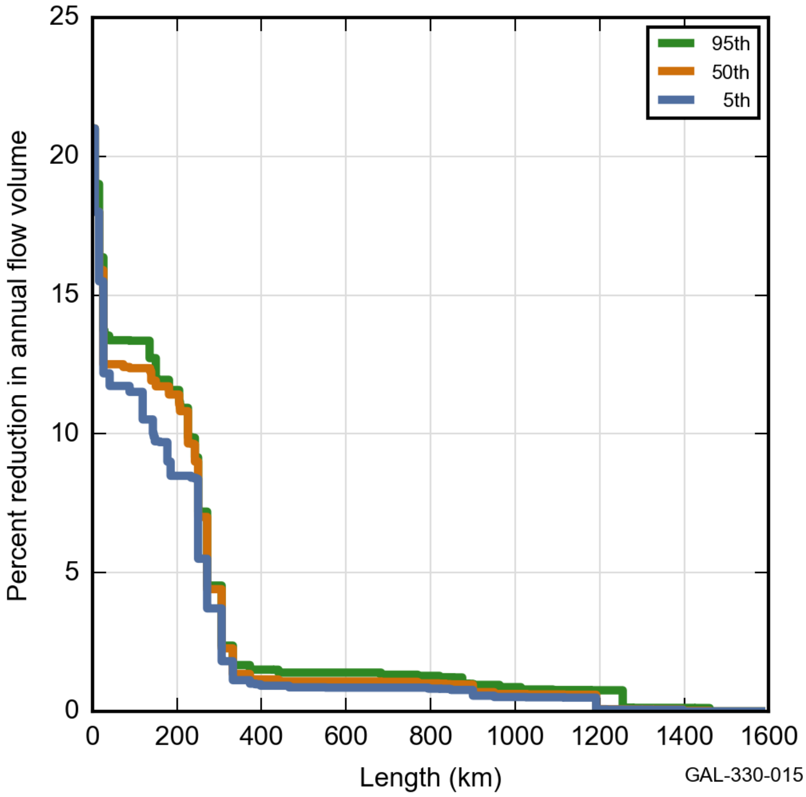

Figure 35 Cumulative exceedance plot of the percent reduction in annual flow due to additional coal resource development for 5th (blue), 50th (orange) and 95th (green) percentiles

Data: Bioregional Assessment Programme (Dataset 1)

Table 16 Stream length (km) potentially exposed to varying reductions in percentage annual flow in the zone of potential hydrological change

Reporting area	Length in zone of potential hydrological change (km)	Length potentially impacted but change not quantified (km)	Length with ≥1% reduction annual flow (km)			Length with ≥5% reduction annual flow (km)			Length with ≥20% reduction annual flow (km)			Length with ≥50% reduction annual flow (km)		
			5th	50th	95th	5th	50th	95th	5th	50th	95th	5th	50th	95th
Northern	3030	809	208	587	641	94	94	94	0	0	0	0	0	0
Southern	3255	633	176	245	245	176	176	176	6	6	6	0	0	0
Total	**6285**	**1442**	**384**	**833**	**886**	**269**	**269**	**269**	**6**	**6**	**6**	**0**	**0**	**0**

Due to rounding, some totals reported here may not correspond exactly with the sum of the separate numbers.
Data: Bioregional Assessment Programme (Dataset 1)

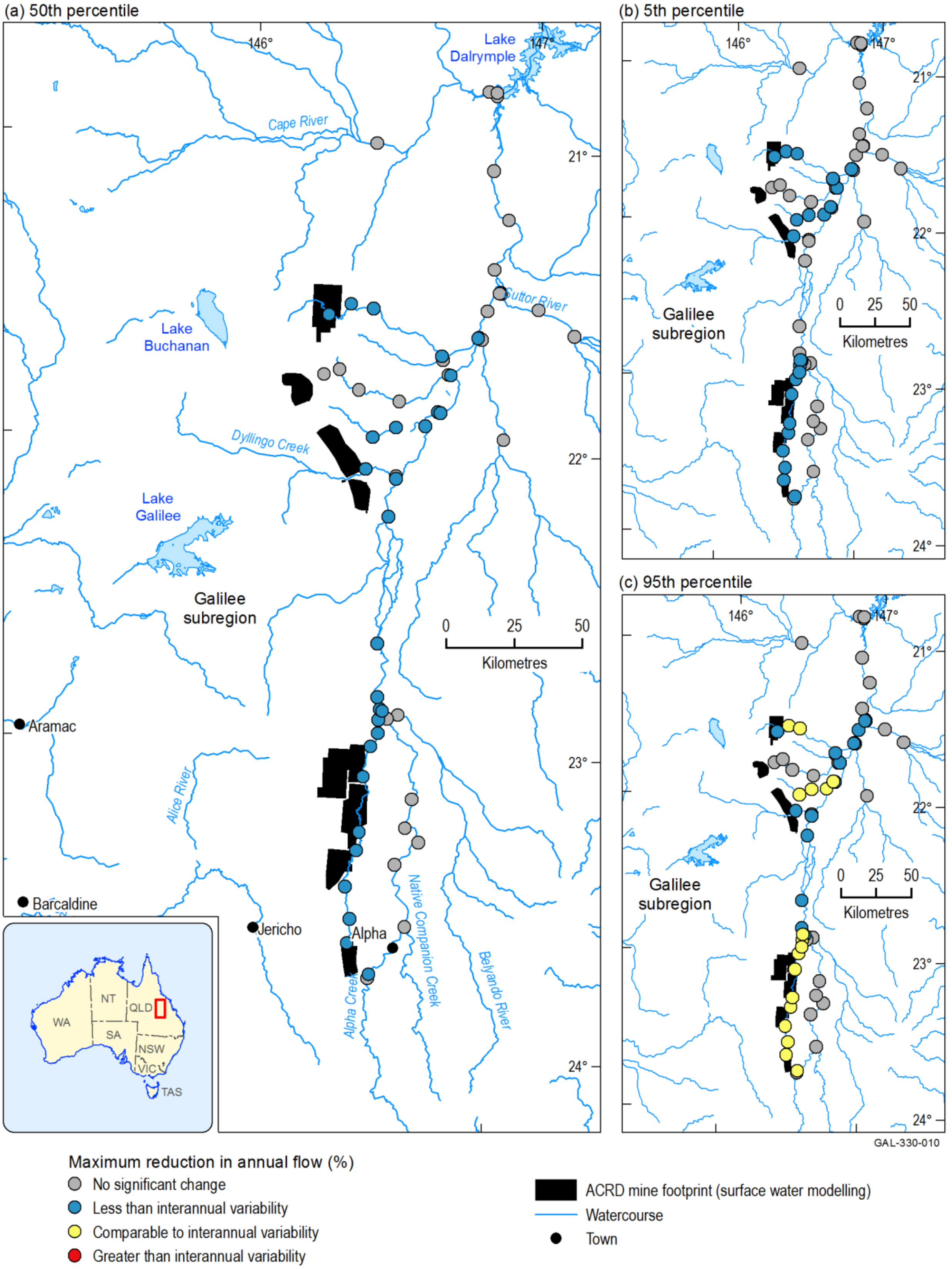

Figure 36 Ratio of change in annual flow due to additional coal resource development to the interannual variability in annual flow under the baseline

The extent of the coal resource developments in the coal resource development pathway (CRDP) is the union of the extents in the baseline and in the additional coal resource development (ACRD).
Data: Bioregional Assessment Programme (Dataset 1, Dataset 6, Dataset 10)

3.3.4 Potential water quality changes

Regional hydrological changes due to additional coal resource development could potentially impact surface water and groundwater quality. Although water quality was not modelled as part of this BA, the implications for water quality in the Galilee subregion are briefly considered in this section, in light of the previously discussed modelled changes due to additional coal resource development.

Relevant factors for assessing the potential for changes in regional groundwater and surface water quality from the seven additional coal resource developments in the Galilee subregion are:

- Natural streamflow in the Galilee subregion varies considerably, with long periods of little to no streamflow during times of low rainfall. This is likely to affect surface water quality (e.g. variations in salinity and turbidity) between wet and dry seasons.
- Approval conditions for off-site discharge of mine-related water are yet to be finalised (as of December 2017).
- No groundwater discharge off site is envisaged (e.g. it is not proposed as part of environmental impact statement (EIS) documentation), with most groundwater extracted as part of routine mine dewatering operations expected to be utilised on site for various mining and processing applications (see Section 2.5.2 in companion product 2.5 for the Galilee subregion (Karim et al., 2018a) for further information). Therefore, it is possible that salts derived from this groundwater will need to remain contained on site.
- Source of external water supplies for mines is yet to be finalised. Transferrals of large volumes of water will include dissolved solutes and may influence distribution of salt within the catchment, or possibly in other (nearby) catchments.
- Surface water salinity data are patchy, with large gaps (both spatial and temporal) between measurements in most of the streams in and near to the zone.
- Other than salinity information, there is very little available analytical data for minor, trace and organic analytes from groundwater and surface water in the zone of potential hydrological change.
- None of the additional coal resource developments propose to re-inject co-produced water into depressurised aquifers.
- Water quality impacts from non-modelled developments (see Section 3.6) will be additional to any potential water quality changes derived from modelled development areas, but are not further assessed here.

In the following sections the groundwater and surface water causal pathways that could potentially lead to regional water quality impacts are identified and the risk of impact is qualitatively assessed. The extent of influence and existing regulation and management practices are used to inform this assessment of risk.

3.3.4.1 Groundwater quality

Groundwater quality in the Galilee subregion is covered by the *Environmental Protection (Water) Policy 2009* (EPP (Water)), which achieves the objectives of Queensland's *Environmental*

Protection Act 1994. The groundwater modelling results presented in companion product 2.6.2 (Peeters et al., 2018) indicate that any potential groundwater impacts will be confined to hydrostratigraphic units assigned to the Galilee Basin (primarily the upper Permian coal measures, Rewan Group, and to a lesser extent the Clematis Group aquifer) and in areas where alluvium and Cenozoic sediments overlie the Galilee Basin aquifers. These conditions largely occur around the central-eastern margin of the Galilee Basin in the vicinity of the modelled additional coal resource development.

Changes in groundwater quality from coal resource development can occur as an indirect result of depressurisation and dewatering of aquifers and changes to subsurface physical pathways between aquifers, which may enhance leakage between aquifers that contain groundwater of different qualities. Changes in groundwater quality can also occur as a direct result of coal resource development and its associated operational water management practices, such as when water is deliberately injected into an aquifer or coal seam to manage surplus water, counter the effects of groundwater depressurisation or to facilitate the process of CSG extraction. Unless hydrologically isolated from their surroundings, the creation of coal stockpiles, rock dumps and tailings dams on coal mine sites can also result in leaching of contaminants to shallow groundwater systems. In all these cases, a hazard arises when the quality of the receiving water is changed such that it reduces its beneficial use value. BAs are concerned with the risk from non-accidental changes to water quality off site, which may be cumulative where different mining operations occur in proximity.

Table 17 lists potential causes of changes in groundwater quality from coal resource development in the Galilee subregion and identifies the potential for off-site impacts. Groundwater quality (including aquifer properties and groundwater composition) is potentially affected by up to eight causal pathways in the Galilee subregion. Effects on groundwater quality are localised within tenements, downstream watercourses and irrigated areas or target aquifers used to dispose of co-produced water. Risks will mainly be addressed by future mine water management and monitoring plans within tenements. In some areas of Queensland (e.g. around the Surat Basin), Healthy Waters Management Plans may also exist for potentially affected downstream watercourses. In the remainder of this section, the risk to water quality off site is considered in the context of the scale of the effect and existing regulatory controls.

Coal mines have the potential to change surface water – groundwater interactions. These changes are likely to be within tens of metres of a watercourse and so are not represented in the regional groundwater model developed for the Galilee subregion. Preferential flow paths can also be affected by changes to surface water – groundwater interactions (including changes to aquifer interconnectivity, mine expansion close to a river or lake, preferential drainage and recharge associated with post-closure water filling the pit). Mine developments that link aquifers and lead to preferential drainage can affect groundwater quality, but may be limited to the vicinity of open-cut pits. Changes to surface water – groundwater interactions can also change the timing and volume of baseflow contributions to streams, which can affect the stream ecosystem within and downstream of tenements. These changes are likely to be restricted to areas where direct interactions between watercourses and unconfined aquifers are possible.

While not specifically identified for each development, monitoring bores and dewatering bores are required for coal resource developments. The code of practice for constructing and abandoning coal seam gas wells and associated bores in Queensland (DNRM, 2013) was developed to ensure that all CSG wells and CSG water bores are constructed and abandoned to a minimum acceptable standard resulting in long-term well integrity, containment of gas and the protection of groundwater resources.

Fracturing above underground longwall panels due to removal of coal and hydraulic enhancement (of aquifers and aquitards) above the goaf potentially affects the rate, volume and timing of groundwater flow between aquifers. Enhanced aquifer connectivity has the potential to lead to mixing between different quality groundwater sources, or to locally enhance recharge of surface water to shallow aquifers. However, the degree of change in connectivity is dependent on site-specific conditions at each underground operation, and requires substantially more local-scale studies than what has been possible to undertake for this BA.

Dam construction and other water management structures that change natural surface drainage and runoff have the potential to affect groundwater recharge patterns, in turn affecting groundwater quality and quantity/volume. However, this is likely to be limited to watercourses within and downstream of tenements.

Table 17 Potential causes of changes in groundwater quality and potential for off-site impacts in the Galilee subregion

Causal pathway	Water quality concern	Scale	Off-site impacts in Galilee subregion
Subsurface depressurisation and dewatering for coal mines	Leakage between aquifers that diminishes the beneficial use value of a productive aquifer due to changes in water quality	Local to regional	Potential for off-site impacts from changes in the hydraulic gradients between connected aquifers of differing water quality
Failure of bore integrity	Leakage between aquifers that diminishes the beneficial use value of a productive aquifer due to changes in water quality	Local	Off-site impacts are unlikely. State regulation and best practice guidelines are in place to minimise potential adverse impacts from bore construction, use and abandonment practises
Subsurface fracturing above longwall panels	Leakage between aquifers and/or surface that diminishes the beneficial use value of a productive aquifer due to changes in water quality	Local	Potential for off-site impacts from possible enhanced connectivity between aquifers of differing water quality or increased recharge
Leaching from stockpiles, rock dumps, tailings dams, storage dams	Leaching of contaminants into aquifers that reduces the beneficial use value of a productive aquifer	Local	Potential for off-site impacts, but regulatory controls in place to minimise risk

3.3.4.2 Surface water quality

Surface water quality in the Galilee subregion is covered by the *Environmental Protection (Water) Policy 2009* (EPP (Water)), which achieves the objectives of Queensland's *Environmental Protection Act 1994*. The surface water zone of potential hydrological change is situated in the headwaters of the Burdekin river basin. Draft environmental values and water quality guidelines for the Burdekin river basin were released for consultation in March 2017 (Newham et al., 2017). These built on work undertaken as part of the *Burdekin Region Water Quality Improvement Plan 2016* (NQ Dry Tropics, 2016a). NQ Dry Tropics (2016b) also provides background information on water quality issues in the Burdekin river basin.

Changes in surface water quality from coal resource development can occur following disruptions to surface drainage from the removal of vegetation and disturbance of soil in construction of roads, site facilities, excavation of open-cut pits and landscaping of the site during production and rehabilitation. Bare surfaces increase the risk of erosion with potential to increase loads of total suspended solids in waterways. Consequently, adequate controls are an important component of managing enhanced erosion risks due to coal mining developments. In addition, the discharge of mine water into the stream network as part of operational water management is a potentially hazardous activity, especially if the quality of the discharged water lowers the quality of the receiving water below its current beneficial-use level. Similarly, any unintentional releases of mine water off site could also be considered as a potential hazard to surface water quality. However, such unintended release events are typically rare (e.g. potentially caused during major floods or in the event of unexpected dam failure), with approved design and containment strategies required to be developed in order to adequately address such aspects of mine site water management.

Depressurisation and dewatering of aquifers and changes to subsurface physical pathways between aquifers can lead to a change in baseflow to streams and potentially affect the water quality of the stream. Table 18 lists potential causes of changes in surface water quality from coal resource development in the Galilee subregion and identifies the potential for off-site impacts, having regard to the relevance of the causal pathway in the subregion and the likely scale of the effect.

Table 18 Potential causes of changes in surface water quality and potential for off-site impacts

Causal pathway	Water quality concern	Scale	Off-site impacts in Galilee subregion
Altering surface water system	Reduced surface water flows due to isolation of part of catchment resulting in reduced runoff to streams	Local to regional	Potential impacts are addressed by site-specific mine water management and monitoring plans within tenements. Managed through regulatory requirements attaching to mining operations plans.
Groundwater pumping enabling coal extraction	Change in baseflow to streams may diminish the beneficial use value of the surface water resource due to changes in water quality	Local to regional	There are potentially substantial off-site impacts and baseflow impacts.
Subsurface fracturing above longwall panels	Change in stream baseflow conditions (e.g. enhanced recharge to aquifers through fracturing) may diminish the beneficial use value of the surface water resource due to changes in water quality from reduced flows	Local	Potential impacts are addressed by site-specific mine water management and monitoring plans within tenements. Broader regional impacts may be assessed as part of specific water quality improvement plans, such as the one developed for the Burdekin Region in 2016 (NQ Dry Tropics, 2016a).

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 activities and processes. As of December 2017, conditions for off-site discharge of any excess water are yet to be finalised for the additional coal resource development. Site-specific discharge conditions will form part of future mine approval conditions.

All of the modelled coal mining projects in the Galilee subregion are situated in the headwaters of the Belyando river basin. From the perspective of the greater Burdekin river basin, the mean annual stream discharge from the Belyando River accounts for about 10% of the total discharge volume of the Burdekin River (NQ Dry Tropics, 2016a). During the period 2005 to 2010, Bainbridge et al. (2014) estimated that the mean annual discharge contribution from the Belyando River was about 780 GL/year. In comparison, for the other main rivers above the Burdekin Falls Dam, the mean annual discharge was estimated as 740 GL/year for the Cape River, 820 GL/year for the Suttor River and 4500 GL/year for the Burdekin River (Bainbridge et al., 2014).

Sediment loads in the Belyando and Burdekin river basins vary significantly from year to year and are in part dependent on streamflow volumes (Bainbridge et al., 2014). Sediment loads increase in wetter years or during large cyclone events. For the 2005 to 2010 period, Bainbridge et al. (2014) estimated that the average sediment load contribution from the Belyando River to Lake Dalrymple (Burdekin Falls Dam) was 0.16 Mt/year. In comparison, the sediment contributions from the other main rivers were estimated to be: Cape River (0.27 Mt/year), Suttor River (0.25 Mt/year) and the Upper Burdekin River (5.23 Mt/yr). Thus, the Upper Burdekin River is clearly the main contributor to the overall sediment budget in the Burdekin river basin (above Lake Dalrymple).

It is estimated that the Burdekin Falls Dam (Lake Dalrymple) traps around 65% of the sediment and nutrient load from the combined input of the Upper Burdekin, Belyando, Suttor and Cape rivers (NQ Dry Tropics, 2016a). The trapping efficiency and effectiveness of the Burdekin Falls Dam has implications for the downstream dispersion of any extra sediment load that may occur due to future coal mining activity in the Belyando river basin.

The risk to regional surface water quality caused by changes in baseflow following depressurisation and dewatering of mines and/or changes in subsurface physical flow paths (e.g. from hydraulic enhancement above the goaf in longwall mines) will depend on the magnitude of the hydrological changes and the salinity of the groundwater relative to the salinity of the water in the stream into which it discharges. Modelling of the hydrological changes due to additional coal resource development in the Galilee subregion suggests some reduction in baseflow is likely to occur within the zone of potential hydrological change, thereby potentially leading to changes in water quality.

The magnitude and extent of water quality changes cannot be determined without specifically representing the key water quality parameters in the modelling. This remains an important knowledge gap for the Galilee subregion, particularly in the context of multiple large-scale mining developments that may potentially result in cumulative impacts to water quality (see Section 3.7.4 for further discussion about gaps and limitations relevant to this BA).

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3.4 Impacts on and risks to landscape classes

Summary

The diverse natural and human-modified ecosystems in the Galilee assessment extent were classified into 31 landscape classes, which were aggregated into 11 landscape groups based on their biophysical characteristics and dependence on groundwater and/or surface water. Landscape classes that occur outside of the zone of potential hydrological change are *very unlikely* (less than 5% chance) to be impacted by additional coal resource development and include more than 100,000 km^2 of groundwater-dependent vegetation, 387,000 km of streams, 8,900 km^2 of wetlands and 1,359 springs in the assessment extent. Receptor impact modelling was undertaken for five of the 11 landscape groups in the assessment extent.

Estimates of overall ecosystem risk integrate understanding from the conceptual model of causal pathways, hydrological and ecological modelling, and expert opinion. The strength of this approach lies in its ability to provide a measure of relative ecosystem risk, emphasising where further attention should focus using local-scale modelling. Importantly, this integrated analysis approach also provides clarity around the ecosystems that can be ruled out from further assessment on the basis of impacts being *very unlikely*.

'Springs' landscape group

Groundwater flow from springs supports endemic flora and fauna, the building of peat mounds and associated groundwater-dependent ecosystems. The Doongmabulla Springs complex includes 187 individual spring vents near the Carmichael River and its tributaries. The available hydrogeological evidence indicates that the Clematis Group aquifers, rather than the deeper Permian aquifers, are the primary source aquifers for these springs. Springs are not represented directly in the groundwater analytic element model (AEM), with drawdown estimated by comparing model layer drawdown (for the appropriate source aquifer) at the known location of the springs. Alternative AEM conceptualisations were used to evaluate the likely scale of overestimated drawdown predictions at some springs, including the Doongmabulla Springs complex. The original AEM conceptualisation predicts that drawdown due to additional coal resource development is *very likely* to exceed 0.2 m in the source aquifer of 181 of the 187 springs in this complex. However, estimates using the alternative AEM conceptualisation indicate that no springs are predicted to experience median additional drawdown in excess of 0.2 m.

In the Permian springs cluster**,** it is *very likely* that at least 5 springs and *very unlikely* that more than 7 springs will experience drawdown in excess of 5 m in the upper Permian coal measures due to additional coal resource development. Potentially affected springs include the Albro, Lignum, Storys and Mellaluka springs. Drawdown for the 12 springs in the Triassic springs cluster cannot be reliably estimated by the AEM, but is likely to fall within the range

predicted for the Clematis Group model layer. None of the other 1353 Great Artesian Basin (GAB) springs of the Eromanga Basin are in the zone of potential hydrological change.

'Streams, GDE' landscape group

Almost half of the streams in the zone of potential hydrological change are interpreted to be groundwater dependent (2801 km). Potential hydrological impacts include additional groundwater drawdown in excess of 5 m, increased low-flow days, increased low-flow spells and decreased overbank flows. Expert opinion, modelled hydrological changes and changes to ecological indicators, such as woody riparian vegetation and mayfly nymph density, indicate that up to 8% of groundwater-dependent streams (where quantifiable) in the zone of potential hydrological change are 'at some risk of ecological and hydrological changes'. This includes parts of Native Companion, North and Sandy creeks and the Belyando and Carmichael rivers.

Streams, non-GDE' landscape group

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. This includes most of the temporary streams (1028 km) in the zone of potential hydrological change that are potentially impacted but not represented in the surface water model, including parts of Bully, Lagoon, North, Sandy and Tomahawk creeks and Carmichael River. Potential hydrological changes include increased low-flow days and low-flow spells along up to 177 km of temporary streams in the zone. The analysis indicates that up to 0.5% of non-GDE streams with receptor impact modelling are 'at some risk of ecological and hydrological changes', mainly in downstream parts of the Belyando and Suttor rivers.

'Floodplain, terrestrial GDE' landscape group

Most groundwater-dependent vegetation in the zone of potential hydrological change occurs on floodplains (2433 km^2 or 64% of groundwater-dependent vegetation in the zone). It is *very unlikely* that more than 296 km^2 of groundwater-dependent vegetation on floodplains experiences more than 5 m of drawdown due to additional coal resource development. Over half of the groundwater-dependent ecosystems (716 km^2) in the zone are 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. Expert-derived estimates indicate that up to 3% of groundwater-dependent vegetation on floodplains are 'at some risk of ecological and hydrological changes' (where changes can be quantified), and these occur mainly along parts of Alpha, North, Sandy and Tallarenha creeks and the Belyando and Carmichael rivers.

'Non-floodplain, terrestrial GDE' landscape group

Approximately one-third of groundwater-dependent ecosystems in the zone (1189 km^2) rely on groundwater associated with clay plains, loamy and sandy plains, inland dunefields, or fine-grained and coarse-grained sedimentary rocks. It is *very unlikely* that more than 68 km^2 (or 2% of groundwater-dependent ecosystems in the zone) experiences more than 5 m of drawdown due to additional coal resource development. This landscape group is located outside of alluvial river and creek flats and is therefore unaffected by changes to surface water flow regimes. There is some level of risk of a small change in percent foliage cover to up to 5% of non-floodplain, groundwater-dependent ecosystems located outside of floodplains or wetlands, particularly near the proposed coal mines where additional drawdown is greatest.

3.4.1 Overview

3.4.1.1 Potentially impacted landscape classes

This section describes the impacts on and risks to landscape classes that may be impacted by hydrological changes resulting from additional coal resource development in the Galilee subregion. The section focuses on those landscape classes that may experience potential ecological impacts. Impacts on economic and sociocultural assets are addressed separately (see Section 3.5).

A landscape classification approach was used to characterise the diverse range of water-dependent assets into a smaller number of landscape classes for further analysis, and this is described in companion product 2.3 for the Galilee subregion (Evans et al., 2018b). Landscape classification involves the systematic grouping of geographical areas into distinct classes based on similarity in physical, biological and hydrological characteristics.

The Galilee assessment extent was classified into 31 landscape classes that were aggregated into 11 landscape groups based on their likely response to hydrological change (Figure 37). For example, five landscape groups are identical, with the exception of whether they support remnant or non-remnant vegetation. Water source identifies whether landscapes are groundwater-dependent ecosystems (GDEs), disconnected from the groundwater system or reliant only on incident rainfall and localised runoff (companion product 2.3 for the Galilee subregion (Evans et al., 2018b)).

Most ecosystems (73%) in the zone of potential hydrological change are classified as either 'Dryland' (8134 km^2) or 'Floodplain, non-wetland' (2098 km^2) landscape groups (Figure 38). These groups depend on incident rainfall and localised runoff for their water requirements and do not depend on access to groundwater or streams. Consequently, impacts and risks for these two landscape groups are not further assessed for the bioregional assessment (BA) for the Galilee subregion.

Of the remaining nine landscape groups, the impact and risk analysis focused on whether these ecosystems occur within the zone of potential hydrological change. Landscape classes that intersect the zone are considered potentially impacted by hydrological change due to additional coal resource development. By contrast, landscape classes that do not intersect the zone of potential hydrological change have been ruled out as *very unlikely* to be impacted due to additional coal resource development.

Most water-dependent ecosystems in the zone of potential hydrological change are identified as potentially groundwater dependent, including 3872 km^2 of GDEs (27% of the zone) and 2801 km of streams (45% of streams in the zone). Water-dependent landscape groups in the zone of potential hydrological change include 'Floodplain, terrestrial GDE' that covers 2433 km^2 (17% of the zone) and 'Non-floodplain, terrestrial GDE' that covers 1189 km^2 (8% of the zone). Water-dependent streams in the zone are classified as 'Streams, GDE' that covers 2801 km (45% of streams in the zone) and 'Streams, non-GDE' that covers 3484 km (55% of streams in the zone). Most streams in the zone are classified as 'Temporary, lowland stream' (3114 km or 49% of streams in the zone).

As noted in Section 3.3.1.1, about 6% (approximately 800 km^2) of the zone of potential hydrological change occurs beyond the eastern boundary of the Galilee assessment extent (Figure 38). Landscape classes were only developed in BAs within the area of the assessment extent, and this process was undertaken prior to defining the extent of the zone of potential hydrological change. Consequently, the spatial coverage of landscape classes and groups for the BA of the Galilee subregion does not include the 6% of the zone that occurs beyond the margins of the assessment extent.

Visual inspection of the mapped distribution of landscape groups near the eastern boundary of the assessment extent (Figure 38) suggests that most of this area contains ecosystems of the 'Dryland' and 'Floodplain, non-wetland' landscape groups (which is similar to the overall proportion of landscape groups that are mapped in the zone). However, small sections of 'Streams, GDE' ecosystems associated with the upper Belyando River and parts of Tomahawk and North creeks do intersect with this area of unmapped landscape groups in the zone. There may also be some small areas of 'Floodplain, terrestrial GDE' that occur sporadically throughout this area, although there are no known springs in the unmapped parts of the zone.

Although 6% of the zone lacks mapped landscape groups, for the purposes of reporting results throughout this product, the various proportions of landscape groups are related to the zone's entire extent of 14,030 km^2, and not just the area where landscape group mapping exists. Depending on exactly what types and extents of landscape groups occur in this unmapped area, this may mean that some landscape group proportions reported within the zone may vary slightly if the entire area of the zone had had landscape classes and groups mapped throughout. Likewise, the total areas and lengths reported for each landscape group in the zone do not account for any ecosystems that may occur in the unmapped areas.

The lack of landscape group mapping at the eastern-most margins of the zone is a recognised limitation of this BA and may mean that some specific results reported in this Section are slightly underestimated or overestimated. Despite this limitation, the Assessment team consider it highly unlikely to substantially alter the main findings of the landscape group analysis presented here, given the majority of the zone is adequately mapped, and the unmapped 6% appears likely to contain mostly 'Dryland' or 'Floodplain, non-wetland' ecosystems.

Receptor impact modelling (detailed in companion product 2.7 (Ickowicz et al., 2018)) was undertaken for five landscape groups in the zone of potential hydrological change, namely the 'Springs', 'Floodplain, terrestrial GDE', and 'Non-floodplain, terrestrial GDE' landscape groups, as well as for the 'Streams' composite grouping, which combines the 'Streams, GDE' and 'Streams, non-GDE' riverine landscape groups. The key outputs from the receptor impact modelling are: (i) a qualitative mathematical model / signed digraph that identities important ecosystem components and dependencies for the landscape group, and (ii) predictions of ecological responses to altered hydrological conditions by a small number of receptor impact variables which represent ecosystem indicators for the landscape group. Critically, the receptor impact variables relate to the predicted level of response across the entire landscape group, given the hydrological change modelled at a particular location. While these do not represent predictions at particular locations they provide a strong indication of when the hydrological change may be commensurate with potential ecosystem change. Importantly though, other types of relevant information acquired from expert opinion and qualitative mathematical models, and coupled with available understanding of hydrological systems and processes, should all be considered to ensure that the risk predictions are based upon as many lines of evidence as possible.

The remaining landscape groups that are potentially impacted cover very small areas within the zone of potential hydrological change and are not reported separately here. These are 'Floodplain, disconnected wetland' that covers 19 km^2 (0.1% of the zone), 'Floodplain, wetland GDE' that covers 153 km^2 (1% of the zone), 'Non-floodplain, disconnected wetland' that covers 4 km^2 (0.02% of the zone) and 'Non-floodplain, wetland GDE' that covers 0.2 km^2 (<0.01% of the zone). The decision not to pursue receptor impact modelling for these four landscape groups was mainly a prioritisation decision due to operational constraints of the BA, although proximity to the additional coal resource developments was considered as part of the prioritisation approach. Despite the lack of receptor impact modelling, it is important to acknowledge that these four landscape groups may potentially be impacted by future coal resource development. Any regulatory consideration around specific coal mining operations should thus consider these potentially impacted but not modelled landscape groups, particularly their areal extents and ecosystem characteristics within the zone of potential hydrological change (relative to their areal extent (and ecosystems) outside the zone but in the broader Galilee subregion).

3.4.1.2 Standing water levels in the zone of potential hydrological change

An important consideration in the assessment of potential impacts and risks to landscapes is the availability of groundwater to GDEs, including deep-rooted vegetation, stream baseflow and springs. However, groundwater availability is controlled by more than simply groundwater depth and requires an understanding of the connectivity between surficial and deeper aquifers, as well as the relative hydraulic pressure in different aquifers. For groundwater leakage to occur between aquifers or across aquitards, hydraulic pressure has to be either higher or lower than the pressure within an adjoining hydrogeological unit (i.e. a hydraulic gradient has to exist to create the potential for flow to occur). There also needs to be either a suitably permeable connective pathway (e.g. a fault or other type of geological structure), or a sufficient pressure differential to induce flow across lithological boundaries with hydraulic conductivities that are lower relative to that of adjoining aquifers. Major features of the various groundwater systems of the assessment extent are described in detail in companion product 2.1-2.2 (Evans et al., 2018a) and Section 2.3.2 of companion product 2.3 (Evans et al., 2018b) for the Galilee subregion.

One measure of depth to groundwater is the standing water level in a bore (i.e. the depth from a reference point at the surface (commonly the top of the bore casing) to water in a bore). It does not necessarily represent the level at which groundwater occurs naturally below surface, except under some unconfined aquifer conditions. Rather, it represents the level that groundwater will rise to in a bore due to pressures in the aquifer in which the bore screen is set. In this case, the bore acts as a zone of very high connectivity to the surface, allowing the groundwater to rise to its highest potential level. Depth to water level varies between individual bores and depends on a number of factors, including aquifer hydraulics and configuration, whether the bore is in a recharge or discharge area of an aquifer; climate, topographic location; and localised conditions, including well construction parameters and any nearby groundwater extraction.

Figure 39 (a and b) shows depth to standing water levels measured for bores screened in Cenozoic aquifers and various sedimentary rock aquifers of the Galilee Basin, both within and nearby to the zone of potential hydrological change. In many bores the depth to standing water, particularly in topographically elevated areas, is greater than 20 m. While there may be some exceptions (e.g. certain species of deep-rooted trees), most of the native vegetation within the zone of potential hydrological change is unlikely to utilise groundwater if depth to the watertable is greater than 20 m. Eamus et al. (2015) provided a review of GDEs and, among other aspects, their relationship to factors such as depth to groundwater.

Cenozoic sediments occur across much of the zone of potential hydrological change (Section 3.3). Bores screened in these aquifers tend to be located near major streams in the zone, such as Native Companion Creek and the Carmichael River (Figure 39a). Although standing water levels in Cenozoic sediments can occur within a few metres of the surface, no bores screened in Cenozoic aquifers have artesian pressures. Most bores in the zone of potential hydrological change (Figure 39b) are screened in sedimentary rock aquifers belonging to the Galilee Basin, such as the Clematis Group or upper Permian coal measures.

In the area where Dunda Creek joins the Belyando River (Figure 39a), and also along nearby stretches of the Carmichael River, standing water levels are generally less than 10 m below surface. Potentiometric surface mapping (of water levels for different aquifers) suggests that these areas may represent a zone of regional groundwater discharge from Galilee Basin aquifers (companion product 2.3 for the Galilee subregion (Evans et al., 2018b)). These areas also coincide with the occurrence of major spring complexes that source water from aquifers of the Galilee Basin (e.g. Doongmabulla Springs complex, Mellaluka Springs). In addition, reliable groundwater discharge occurs locally into the nearby Carmichael River, supplying some component of baseflow to the river. Further discussion of the application of remotely sensed imagery to assess groundwater input to springs and streams in this area is in Section 3.5.2.

The volume of groundwater that may discharge into Cenozoic aquifers beneath the Belyando River floodplain is dependent on the degree of connection between deeper Galilee Basin aquifers and shallow aquifers in Cenozoic sediments. The degree of connection is governed by a number of factors, some of which are outlined in companion product 2.1-2.2 (Evans et al., 2018a), companion product 2.3 (Evans et al., 2018b) and companion product 2.7 (Ickowicz et al., 2018) for the Galilee subregion. North of the Carmichael River, in the vicinity of the Belyando River floodplain, depth to groundwater is mostly greater than 20 m (Figure 39).

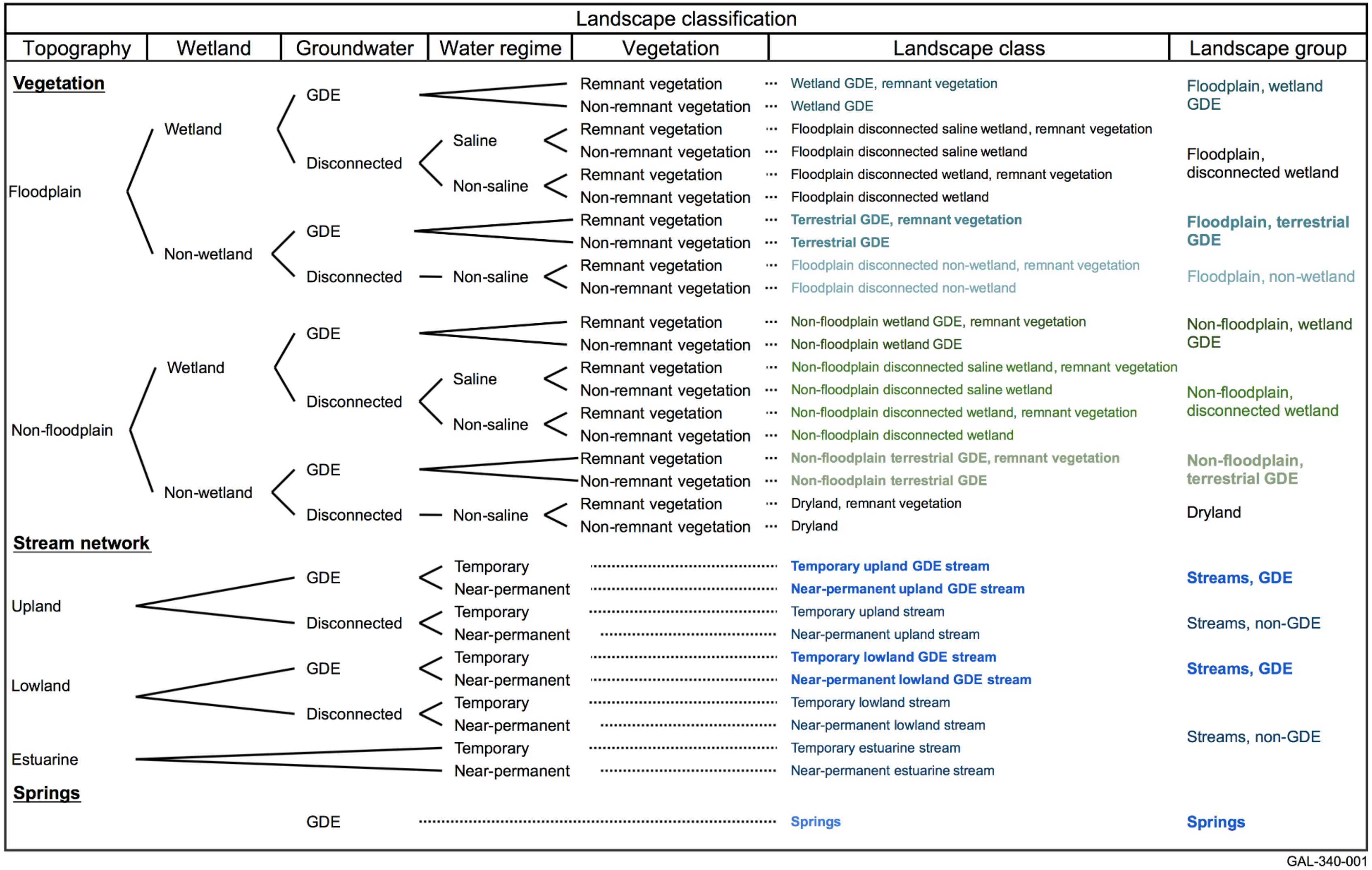

Figure 37 Schematic of the landscape classification approach developed for the Galilee subregion

GDE = groundwater-dependent ecosystem

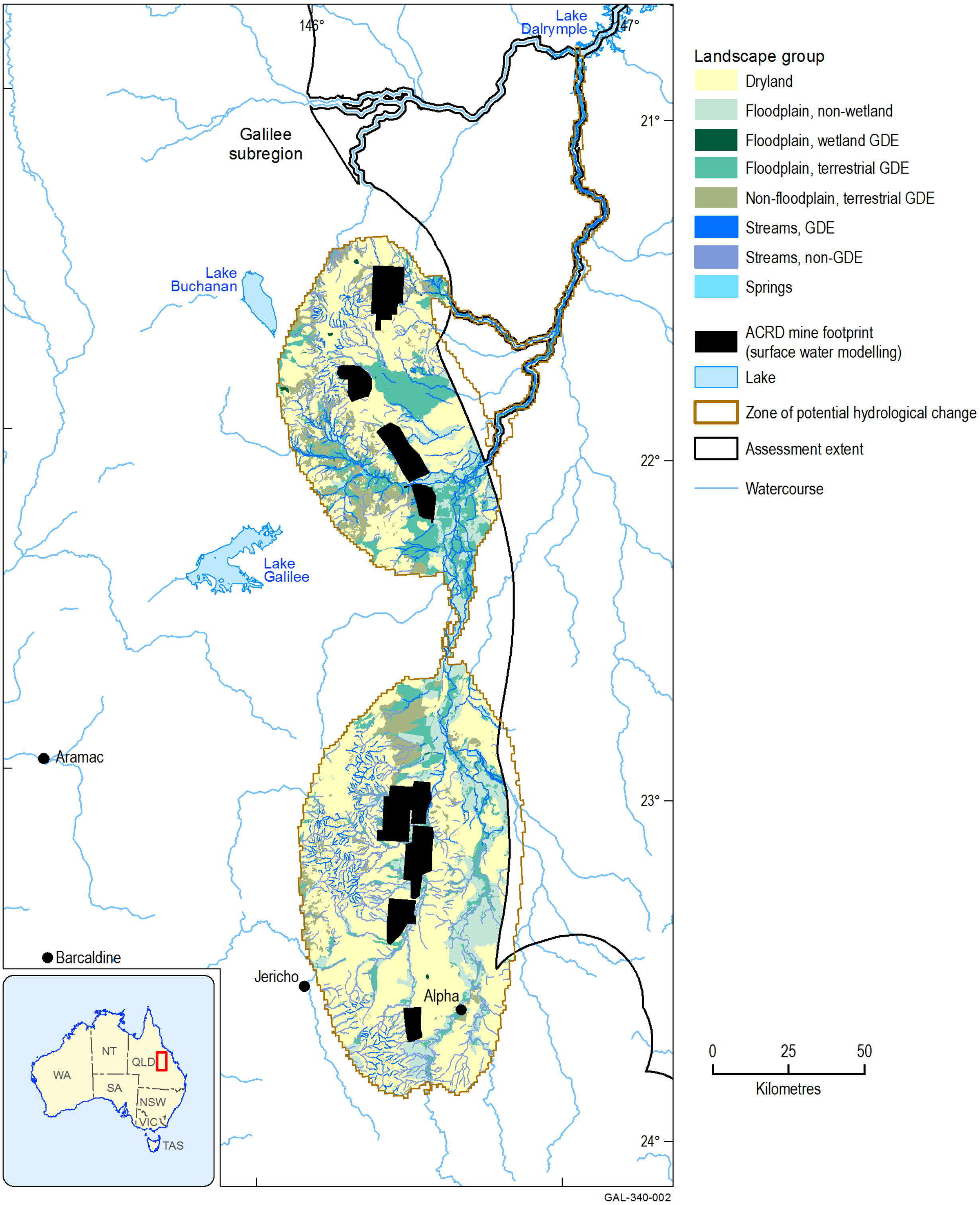

Figure 38 Landscape groups within the Galilee subregion zone of potential hydrological change

ACRD = additional coal resource development; GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 1, Dataset 2)

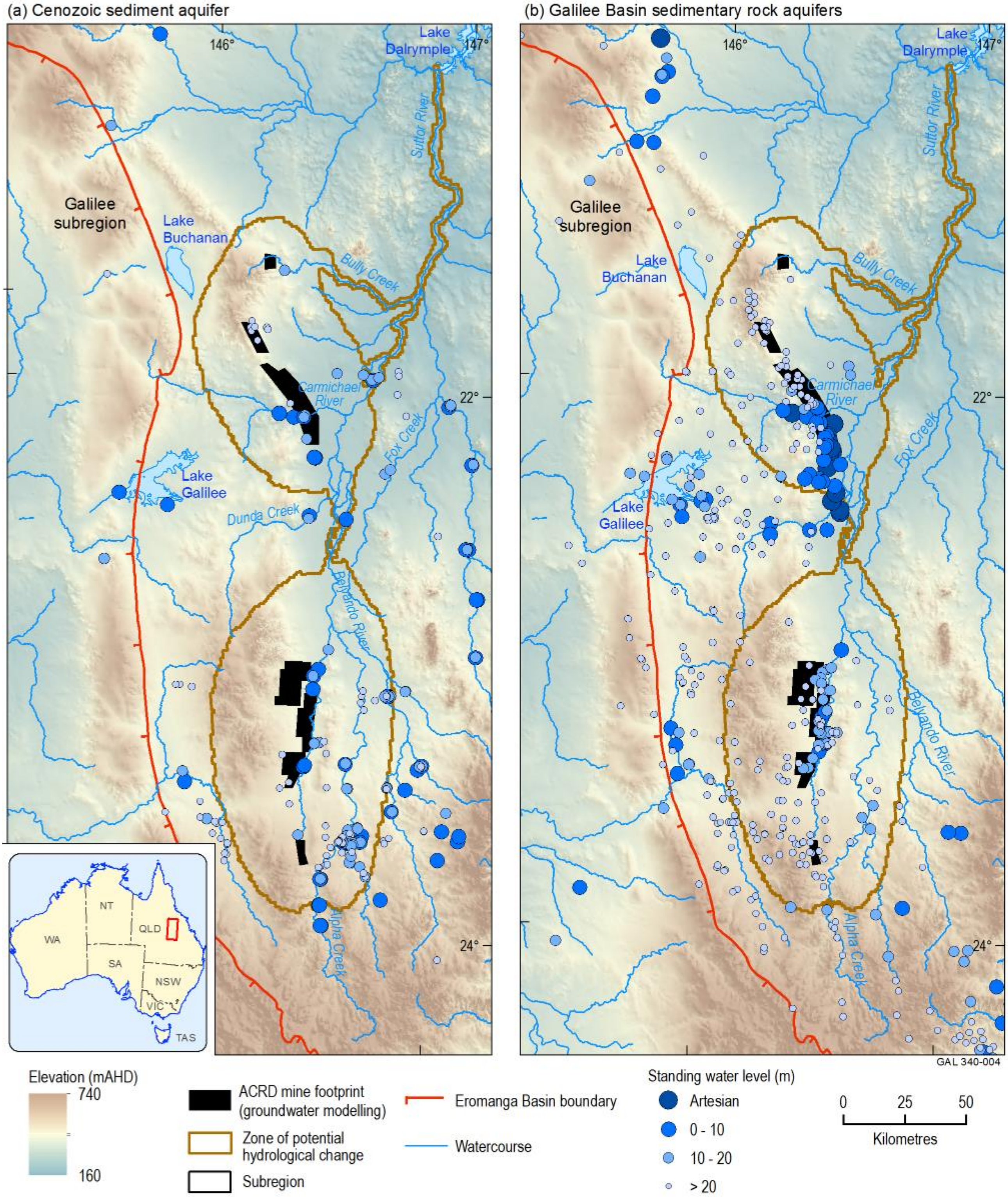

Figure 39 Standing water levels in (a) Cenozoic aquifers and (b) deeper Galilee Basin aquifers in the zone of potential hydrological change

Standing water level is a measure of the depth to water from a reference point, usually the top of the bore. It represents the potential level that groundwater may rise to if it is unimpeded by overlying geological layers.
The Galilee subregion boundary coincides with the margin of the geological Galilee Basin. The Eromanga Basin overlies the Galilee Basin to the west of the zone of potential hydrological change.
ACRD = additional coal resource development
Data: Bioregional Assessment Programme (Dataset 3)

3.4.2 Landscape classes that are unlikely to be impacted

Landscape classes in the Galilee assessment extent that occur outside the zone of potential hydrological change, where impacts are *very unlikely* (Table 19), include:

- 526,658 km^2 of remnant vegetation, including 360,204 km^2 in the 'Dryland'; 76,121 km^2 in the 'Floodplain, terrestrial GDE'; 59,555 km^2 in the 'Floodplain, non-wetland'; 19,348 km^2 in the 'Non-floodplain, terrestrial GDE'; 5,783 km^2 in the 'Floodplain, disconnected wetland'; 4,707 km^2 in the 'Floodplain, wetland GDE'; and 519 km^2 in the 'Non-floodplain, disconnected wetland' landscape groups
- 71,563 km^2 of non-remnant vegetation, including 51,319 km^2 in the 'Dryland'; 10,363 km^2 in the 'Floodplain, non-wetland'; 7,666 km^2 in the 'Non-floodplain, disconnected saline wetland'; 674 km^2 in the 'Floodplain, terrestrial GDE'; 346 km^2 in the 'Floodplain, disconnected wetland'; 263 km^2 in the 'Non-floodplain, terrestrial GDE'; and 98 km^2 in the 'Non-floodplain, wetland GDE' landscape groups
- 101,460 km^2 of groundwater-dependent vegetation, including 76,796 km^2 in the 'Floodplain, terrestrial GDE'; 19,611 km^2 in the 'Non-floodplain, terrestrial GDE'; 4,796 km^2 in the 'Floodplain, wetland GDE'; and 258 km^2 in the 'Non-floodplain, wetland GDE' landscape groups
- 387,170 km of streams, including 45,737 km of streams that are groundwater dependent ('Streams, GDE') and 341,433 km of streams that are not groundwater dependent ('Streams, non-GDE'). Streams outside of the zone predominantly have an intermittent or ephemeral water regime, including 'Temporary, lowland stream' (323,930 km), 'Temporary, lowland GDE stream' (38,735 km), 'Temporary, upland stream' (17,002 km) or 'Temporary upland GDE stream' (6,802 km) rather than a perennial or near-perennial water regime (552 km of streams)
- 20,373 km^2 of wetland vegetation, including 8133 km^2 of saline wetlands, 6129 km^2 in the 'Floodplain, disconnected wetland'; 4796 km^2 in the 'Floodplain, wetland GDE'; 1058 km^2 in the 'Non-floodplain, disconnected wetland' and 258 km^2 in the 'Non-floodplain, wetland GDE' landscape groups
- 1359 springs, including 6 springs in the Doongmabulla Springs complex and 1353 Great Artesian Basin (GAB) springs that are not otherwise described in the three clusters of springs within the zone (Section 3.4.3).

Table 19 Landscape groups and landscape classes showing, for each one, extent within the assessment extent, extent in zone of potential hydrological change and whether qualitative and/or receptor impact models have been prepared

The extent of each landscape class is either an area of vegetation (km^2), length of stream network (km) or count of springs (number).

Landscape group	Landscape class	Extent in assessment extent	Extent in zone of potential hydrological change	Qualitative mathematical model	Receptor impact model
Dryland	Dryland (km^2)	54,141	2,822	None	None
	Dryland, remnant vegetation (km^2)	365,516	5,312	None	None
Floodplain, disconnected wetland	Floodplain disconnected saline wetland (km^2)	207	0	None	None
	Floodplain disconnected saline wetland, remnant vegetation (km^2)	203	0	None	None
	Floodplain disconnected wetland (km^2)	358	12.0	None	None
	Floodplain disconnected wetland, remnant vegetation (km^2)	5,790	7.0	None	None
Floodplain, non-wetland	Floodplain disconnected non-wetland (km^2)	12,357	1,994	None	None
	Floodplain disconnected non-wetland, remnant vegetation (km^2)	59,659	104	None	None
Floodplain, terrestrial GDE	Terrestrial GDE (km^2)	750	75.2	Yes	Yes
	Terrestrial GDE, remnant vegetation (km^2)	78,479	2,358	Yes	Yes
Floodplain, wetland GDE	Wetland GDE (km^2)	93.2	5.1	None	None
	Wetland GDE, remnant vegetation (km^2)	4,855	148	None	None
Non-floodplain, disconnected wetland	Non-floodplain disconnected saline wetland (km^2)	7,666	0	None	None
	Non-floodplain disconnected saline wetland, remnant vegetation (km^2)	57.0	0	None	None
	Non-floodplain disconnected wetland (km^2)	541	1.9	None	None
	Non-floodplain disconnected wetland, remnant vegetation (km^2)	520	1.8	None	None
Non-floodplain, terrestrial GDE	Non-floodplain, terrestrial GDE (km^2)	268	5.5	Yes	Yes
	Non-floodplain, terrestrial GDE, remnant vegetation (km^2)	20,532	1,184	Yes	Yes
	Non-floodplain, wetland GDE (km^2)	97.6	0	None	None

Landscape group	Landscape class	Extent in assessment extent	Extent in zone of potential hydrological change	Qualitative mathematical model	Receptor impact model
Non-floodplain, wetland GDE	Non-floodplain, wetland GDE, remnant vegetation (km^2)	161	0.2	None	None
Streams, GDE	Near-permanent, lowland GDE stream (km)	408	253	Yes	Yes
	Near-permanent, upland GDE stream (km)	52.0	6.7	Yes	Yes
	Temporary, lowland GDE stream (km)	40,798	2,063	Yes	Yes
	Temporary, upland GDE stream (km)	7,280	478	Yes	Yes
Streams, non-GDE	Near-permanent, estuarine stream (km)	140	0	None	None
	Near-permanent, lowland stream (km)	116	4.0	Yes	Yes
	Near-permanent, upland stream (km)	100	1.1	Yes	Yes
	Temporary, estuarine stream (km)	150	0	None	None
	Temporary, lowland stream (km)	327,044	3,114	Yes	Yes
	Temporary, upland stream (km)	17,366	365	Yes	Yes
Springs	Springs (number)	1559	200	Yes	No
Total area (km^2)		**612,252**	**14,030**		
Total stream length (km)		**393,455**	**6,285**		
Total springs (number)		**1559**	**200**		

GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 1)

3.4.3 'Springs' landscape group

3.4.3.1 Description

The 'Springs' landscape group includes a number of spring types as detailed in Fensham et al. (2016). Broadly, Fensham et al. (2016) divided springs into two broad groups: discharge springs and recharge (also referred to as outcrop) springs (Figure 40).

Discharge springs occur where groundwater can discharge to the surface from a confined aquifer under hydrostatic pressure (i.e. the aquifer is artesian). Discharge through an aquitard may occur under a range of conditions including where:

- the confining aquitard is too thin or compromised in some other way (e.g. deep weathering lithological variations) to adequately confine the aquifer under prevailing hydrostatic pressures
- geological structures such as faults enable leakage towards the surface
- the aquifer abuts against basement rocks or another flow barrier, forcing groundwater flow upwards (Figure 40).

Discharge springs are located remote from the aquifer recharge zone, therefore, water flow to the spring is disconnected from local rainfall patterns and water chemistry tends to be alkaline with relatively high levels of dissolved solids (Fensham et al., 2016). Some discharge springs are characterised by groundwater scalds, where salts in the groundwater are precipitated from solution as water evaporates. In arid regions, these scalds are accentuated by the absence of periodic flushing due to overland flow, groundwater flow paths tend to be longer and springs are associated with regional-scale, confined groundwater systems (Figure 40).

Discharge springs are characterised by flat topography, mounded vents and absence of outcrop (Fensham et al., 2016). Discharge spring wetlands in the GAB are generally small, mostly less than 0.05 ha; however, a small number are greater than 1 ha (Fensham and Fairfax, 2003). Vegetation varies from site to site depending on moisture levels, but generally supports a ground layer of grasses, sedges and/or a mat of herbs. Discharge springs may host endemic flora and fauna, including 'The community of native species dependent on natural discharge of groundwater from the Great Artesian Basin', a nationally threatened ecological community, and various threatened species listed under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and under Queensland's *Nature Conservation Act 1992* (Nature Conservation Act) (Fensham et al., 2010).

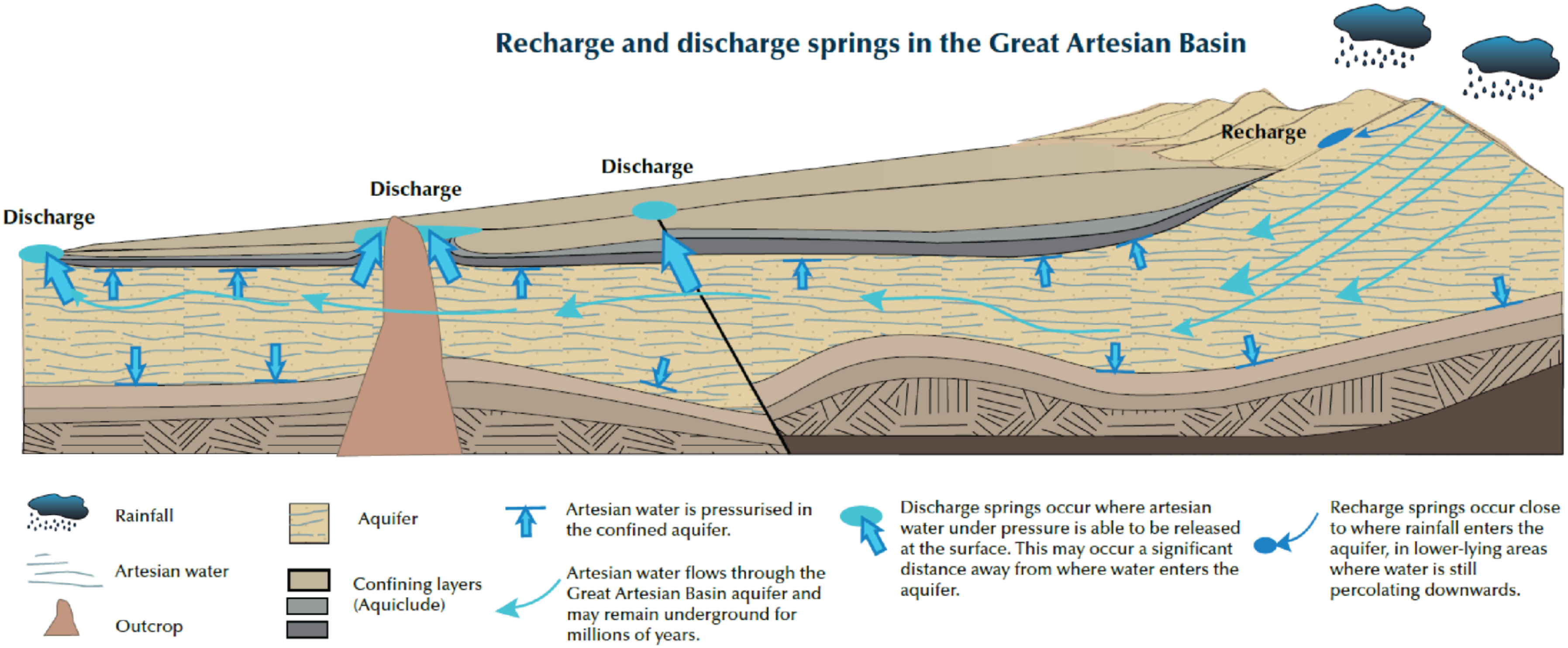

Figure 40 Pictorial representation of the hydrogeological characteristics of outcrop (recharge) and discharge springs

Discharge springs occur in areas where hydrostatic pressures in a confined aquifer are artesian, and where the overlying aquitard is compromised by stratigraphic thinning, geological structures, or the presence of a barrier that redirects regional groundwater flow. Recharge (or outcrop) springs are more commonly associated with unconfined aquifer conditions that occur at or near aquifer outcrop areas. Groundwater systems tend to be more local in scale.
Source: adapted from Queensland Department of Science, Information Technology and Innovation (Dataset 4),

Recharge (or outcrop) springs mainly occur in upland areas (Fensham et al., 2016) (Figure 40). Recharge springs form where groundwater discharges from the aquifer (commonly sandstone) in areas where the ground surface intersects with a saturated aquifer (Fensham et al., 2011; Fensham et al., 2016) in or near the outcrop of the aquifer. Water flow in recharge springs is dynamic and influenced by recent local rainfall patterns. Chemically, the water tends to be neutral or slightly acidic and contains low levels of dissolved solids (Fensham et al., 2016). Groundwater flow paths for recharge springs tend to be shorter and associated with more local-scale, unconfined groundwater systems (Figure 40).

Three distinct clusters of springs occur within the zone of potential hydrological change for the Galilee subregion:

- Doongmabulla Springs complex – including 187 individual vents that feed 160 separate wetlands. The springs form an isolated cluster of wetlands associated with the Carmichael River and its tributaries (Figure 41). Most wetlands (149 of 160) contain discharge springs and are located along the western edge of the complex. The western springs and spring groups are interpreted as being discharge springs based on flat topography, mounded vents and absence of outcrop (Fensham et al., 2016). Further east, recharge springs in the Doongmabulla Springs complex support 11 wetlands on gentle slopes of outcropping sandstone. The Doongmabulla Springs complex is described further in Section 3.4.3.1.1
- Permian springs cluster – springs where the source aquifer is a sedimentary unit of Permian age, principally the Colinlea Sandstone (part of the upper Permian coal measures), which has extensive outcrop on the footslopes of the Carnarvon Ranges. The Permian springs cluster includes both recharge (Albro group) and discharge springs (Lignum Spring, Storys Spring and Mellaluka Springs). Spring flows are low at Lignum Spring (about 0.5 L/min), moderate at Albro Springs (about 40 L/min) and high at Mellaluka Springs (about 1200 L/min). The Permian springs cluster does not support any spring endemic species (Fensham et al., 2016). Wetland vegetation is predominantly common and widespread, with no species of conservation significance. Fish fauna is limited to two common species
- Triassic springs cluster – recharge springs associated with sedimentary rocks of Triassic age, including gravity-fed outcrop springs emanating from fractures in local sandstone aquifers of the Dunda beds. The springs have all been heavily modified (Fensham et al., 2016), including two of the three Hector Springs that have been excavated to provide access for cattle watering. The plants and invertebrates that inhabit these springs are all common and widespread wetland species (Fensham et al., 2016). None are of conservation significance. The Triassic springs cluster does not include springs associated with the Doongmabulla Springs complex.

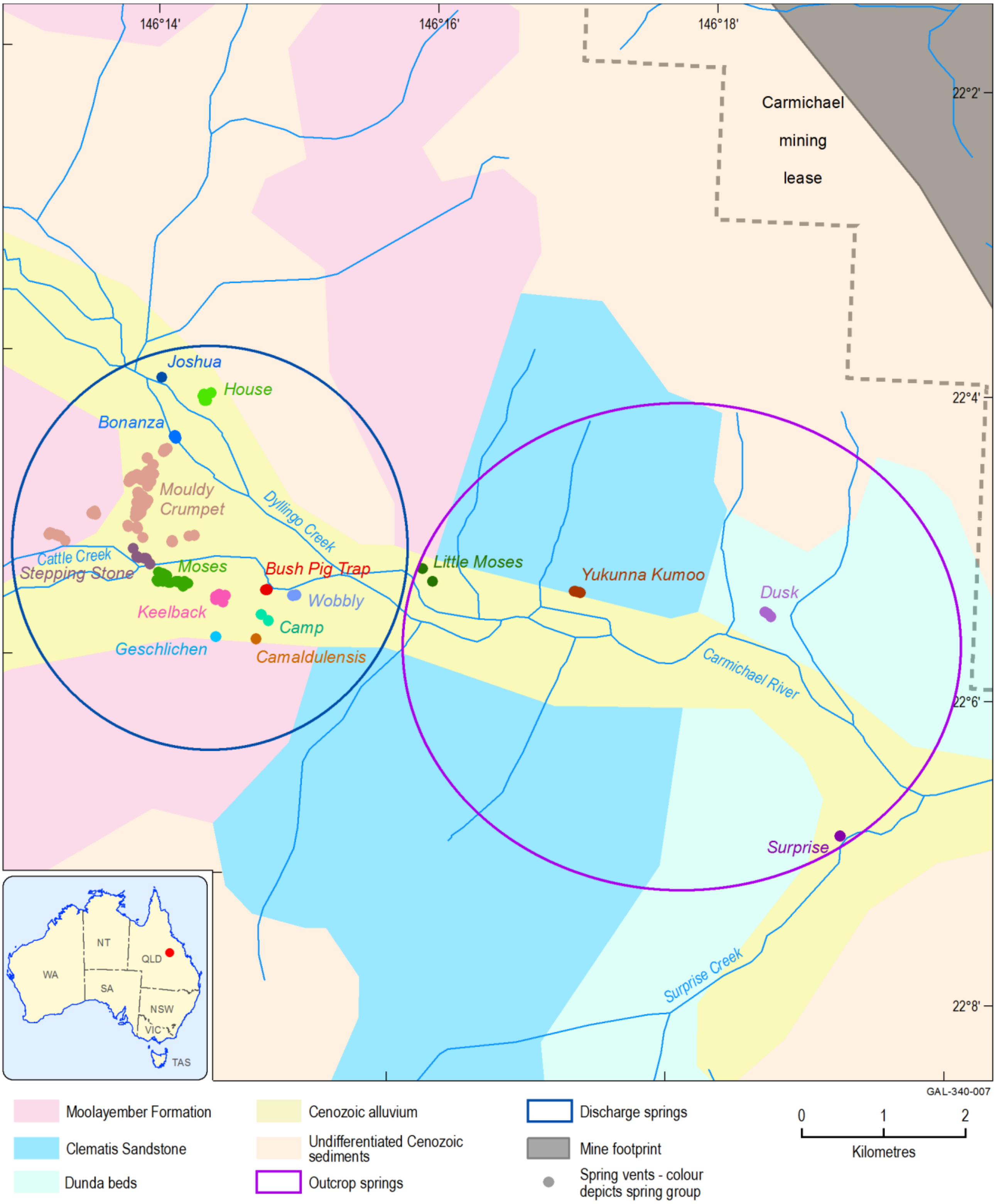

Figure 41 Doongmabulla Springs complex highlighting the name and location of individual spring vents

Data: Queensland Herbarium, Department of Science, Information Technology, Innovation and the Arts (Dataset 5); Queensland Department of Natural Resources and Mines (Dataset 6); Queensland Department of State Development, Infrastructure and Planning (Dataset 7)

3.4.3.1.1 Doongmabulla Springs complex

As outlined in companion product 2.3 for the Galilee subregion (Evans et al., 2018b), the identity of the source aquifer for the Doongmabulla Springs complex has been contentious and the subject of previous scientific dispute. Competing arguments for different source aquifer interpretations are presented by Currell (2016), Currell et al. (2017), Fensham et al. (2016), JBT Consulting (2015) and Webb (2015). Expert hydrogeological arguments (both for and against) provided as part of legal actions in the Queensland Land Court about the source aquifer for Doongmabulla Springs are summarised in Land Court of Queensland (2015a; 2015b). Importantly, in the context of this BA, assessing the potential impacts due to additional coal resource development on the Doongmabulla Springs complex depends on the interpretation of the source aquifer(s).

The groundwater source interpretation for the Doongmabulla Springs complex is based on various datasets, including sparse groundwater level and hydrochemistry data, regional surface and subsurface geological mapping, some drill-hole information and outputs from groundwater modelling. While there are noted points of contention (Land Court of Queensland 2015a; 2015b), the two interpretations for the source aquifer of the Doongmabulla Springs complex are summarised as:

a. Upper Permian coal measures source aquifer – Webb (2015) proposed that a significant contribution to groundwater discharge at Doongmabulla Springs is provided by the upper Permian coal measures, principally the Colinlea Sandstone. In this interpretation, geological structures such as faults and fractures provide connectivity from the deep upper Permian coal measures (here over 500 m below surface) through the relatively low-permeability Rewan Group aquitard to the Clematis Group aquifer and other near-surface hydrogeological units. Supporting evidence for this interpretation includes potentiometric data for the Colinlea Sandstone, which indicate convergence of groundwater flow in this unit towards the springs location, evidence of faults in the area around the proposed Carmichael Coal Mine from seismic reflection data, as well as scant evidence of major confining layers within the Triassic sandstones of this area (Currell et al., 2017). Further, some analysis of existing groundwater chemistry data had proven inconclusive in identifying the source aquifer for some of the vents in the Doongmabulla Springs complex (Webb, 2015).
b. Clematis Group source aquifer – JBT Consulting (2015) and GHD (2013a) considered the main spring source aquifer to be the Clematis Group (Clematis Sandstone and Warang Sandstone), which lies stratigraphically above the Rewan Group aquitard. This interpretation was based on available geological data and potentiometric mapping for the Clematis Group and other hydrogeological units in the area, as well as the known geomechanical and hydrogeological properties of the Rewan Group, and the low potential for faults to cross-cut the entire thickness of the Rewan Group aquitard. Recharge was conceptualised to occur from outcrop in nearby ranges (specifically Darkies Range), mainly to the north of the springs complex.

From analysis of the available hydrogeological data and information, the BA for the Galilee subregion (see companion product 2.3 for the Galilee subregion (Evans et al., 2018b)) considered the more likely source aquifer for the Doongmabulla Springs complex to be primarily the Clematis Group aquifer, with potentially some contribution of flow from the Dunda beds aquifer. The main reasons supporting this interpretation are:

- Potentiometric contour mapping for the Clematis Group aquifer indicates that regional groundwater flow focuses towards Dyllingo Creek and the Carmichael River valley, with the Doongmabulla Springs complex (companion product 2.1-2.2 (Evans et al., 2018a) and companion product 2.3 (Evans et al., 2018b) for the Galilee subregion) occurring at the lowest points in the potentiometric mapping for Clematis Group aquifer.
- Potentiometric contour mapping for upper Permian coal measures (specifically the Colinlea Sandstone) suggests that groundwater flow also focuses towards Carmichael River valley as well as parts of the Belyando River valley, east of Doongmabulla Springs complex (companion product 2.1-2.2 (Evans et al., 2018a) and companion product 2.3 (Evans et al., 2018b) for the Galilee subregion). However, in the vicinity of the Doongmabulla Springs complex the upper Permian coal measures are vertically separated from shallower aquifers such as the Clematis Group by the significant thickness (several hundred metres) of the Rewan Group aquitard. In contrast, the upper Permian coal measures are known to occur beneath Cenozoic sediment cover in the Belyando River valley in the vicinity of the proposed Carmichael Coal Mine. The Mellaluka Springs complex occurs in this area of the floodplain and represents a surface expression of discharge from these deeper Permian units.
- While there is hydraulic potential for some upwards leakage to occur across the Rewan Group aquitard from the upper Permian coal measures (for discussion see Section 2.3.2 in companion product 2.3 for the Galilee subregion (Evans et al., 2018b)), the Clematis Group aquifer has a more direct groundwater flow path and proximal hydrological connection to the Doongmabulla springs complex. Also, the bulk horizontal hydraulic conductivity of the Clematis Group aquifer is much higher, relative to the vertical conductivity of the underlying aquitard. Thus, the relatively high conductivity of the Clematis Group aquifer will likely permit a much greater volume of groundwater to be transmitted towards the springs than what may occur through the underlying aquitard.
- Several of the eastern-most spring groups included as part of the Doongmabulla Springs complex occur near areas of the Dunda beds outcrop (Figure 41). These are areas where the Clematis Group aquifer does not occur; hence, it is likely that the source aquifer for these springs is the Dunda beds aquifer (and not the Clematis Group aquifer).

Although the Assessment team considers that the available evidence supports the Clematis Group aquifer as the most likely groundwater source for the Doongmabulla Springs complex, there are some discrepancies with the available data in and around the zone of potential hydrological change (e.g. variability in the mapped extents of various geological units of the Galilee Basin (see Section 3.3)). In addition, the analysis undertaken for this BA has highlighted key geoscientific data and knowledge gaps, which are discussed further in Section 3.7, as well as in companion product 2.1-2.2 (Evans et al., 2018a) and companion product 2.3 (Evans et al., 2018b) for the Galilee subregion. Future targeted research to address these gaps would greatly assist with future management of the springs complex and better understanding its response to predicted levels of groundwater drawdown due to additional coal resource development. As an example, Section 3.5 highlights how remote sensing data have been utilised to determine the distribution and permanence of near-surface water at the Doongmabulla Springs complex over the past 30 years.

The BA conceptualisation of the Doongmabulla Springs complex, as detailed in this product and companion product 2.3 for the Galilee subregion (Evans et al., 2018b), differs somewhat from the conceptualisations published previously (as noted above). A key difference is that the BA conceptualisation emphasises how the characteristics of the aquifer source (e.g. confined or unconfined, and local versus regional flow system) may vary for different spring groups at different locations within the broader complex. For the spring complex as a whole, there is potential for contributions from local groundwater systems from unconfined portions of the Clematis Group and Dunda beds aquifers, as well as contributions from the regional groundwater flow system that occurs where the Clematis Group aquifer is confined by the Moolayember Formation aquitard.

The conceptual hydrogeological analysis undertaken for this BA indicates that the discharge springs (mound springs) in the western part of the Doongmabulla Springs complex (Figure 41) are fed by groundwater discharge from the confined Clematis Group aquifer by leakage through the overlying Moolayember Formation aquitard and thin alluvial cover. This occurs where the integrity of the Moolayember aquitard is compromised by decreased thickness of the aquitard towards its eastern contact with the Clematis Group, the variable effects of weathering and any local influence of geological structures. In the confined parts of the aquifer regional groundwater flow from westerly and southerly directions is focused towards the discharge springs. Outcrop springs in the Doongmabulla Springs complex occur on or near areas of outcrop for the Clematis Group and Dunda beds (see Figure 41). Local-scale groundwater systems may occur in these outcrop areas, with recharge occurring in nearby hills immediately east and north of the springs. Flow towards the outcrop springs is predominantly from the south and north, focused towards the valley of the Carmichael River. For the easternmost outcrop springs (e.g. Surprise and Dusk springs, Figure 41) the Dunda beds aquifer is interpreted as the most likely source aquifer. Here, it outcrops in nearby hills and underlies the alluvium in this part of the Carmichael River valley.

Discharge from all springs at the surface contributes directly to baseflow in the Carmichael River and to permanent pools (Section 3.5) in nearby drainage channels. There is also potential for groundwater from the Clematis Group and Dunda beds aquifers to discharge directly into the surficial alluvium in the Carmichael River valley (Figure 41).

3.4.3.2 Potential hydrological impacts

Springs are not represented directly in the AEM developed for the BA for the Galilee subregion (companion product 2.6.2 for the Galilee subregion (Peeters et al., 2018)). Instead, drawdown is estimated by comparing model layer drawdown at the location of the spring complex. This is a conservative approach that is considered to be appropriate for a regional-scale assessment as it may over estimate groundwater drawdown, given that groundwater discharge via the springs is not specifically included in the model.

The impact and risk analysis assumes that potential impacts and risks to springs in the assessment extent are associated with additional drawdown in the source aquifers represented by the following AEM layers:

- Doongmabulla Springs complex – as outlined above, drawdown in the Clematis Group aquifer model layer (using both original and alternative conceptualisations implemented in the model, as discussed in Section 3.3.2.1.1)
- Permian springs cluster – drawdown in the upper Permian coal measures. The Permian springs cluster is listed in the 'Galilee-Permian' region in the DSITIA spring location dataset (Queensland Herbarium, Department of Science, Information Technology, Innovation and the Arts, Dataset 5)
- Triassic springs cluster – drawdown in the Dunda beds source aquifer was not specifically estimated with the AEM. However, drawdown in the Dunda beds is likely to fall within the overall range predicted for the upper Permian coal measures and Clematis Group model layers, as the Dunda beds overlie the Rewan Group aquitard and underlie the Clematis Group aquifer. The Assessment team did not consider it valid to present drawdown results for these springs as the source aquifer was not explicitly modelled
- Other GAB springs – GAB springs nearest to the zone of potential hydrological change with source aquifers in the Eromanga Basin comprise part of the Barcaldine Springs supergroup. These springs occur outside of the modelled impact (Figure 42a) for the alluvial layer (which can overlie the GAB aquifer outcrop) and the Clematis Group aquifer (which underlies and is separated from GAB aquifers by the Moolayember Formation aquitard).

Additional drawdown with at least a 5% chance of exceeding 0.2 m is predicted in the source aquifer of 188 springs within the zone (out of the 1559 springs in the Galilee assessment extent) (Figure 42 and Figure 43). Modelled drawdown estimates for the main spring complexes within the zone are discussed further below.

3.4.3.2.1 Doongmabulla Springs complex

Using the modelled drawdowns for the Clematis Group aquifer from the original AEM conceptualisation, a total of 181 of the 187 springs of the Doongmabulla Springs complex have at least a 5% chance of exceeding 0.2 m of drawdown (Figure 43 and Table 20). As detailed in Section 3.3.2.1.1, the original AEM conceptualisation allows for drawdown from the mines to propagate to the Clematis Group aquifer via two distinct pathways, one through dewatering the deeper upper Permian coal measures and the other via draining the upper Quaternary alluvium and Cenozoic sediment aquifer. The median additional drawdown in excess of 0.2 m under this conceptualisation is also predicted to affect 181 springs in this complex. There is a 5% chance that 120 springs in this complex will experience drawdown in excess of 2 m in the Clematis Group aquifer, although there are no springs in the Doongmabulla Springs complex that are predicted to experience additional drawdown in excess of 5 m.

Using an alternative AEM conceptualisation, which allows for drawdown to propagate to the Clematis Group aquifer only via the deeper pathway from the upper Permian coal measures (see Section 3.3.2.1.1 for details), the groundwater modelling also predicts that 181 springs in the Doongmabulla Springs complex have a 5% chance of additional drawdown in excess of 0.2 m (Figure 43 and Table 20). However, estimates using this alternative AEM conceptualisation indicate that there are no springs in this complex predicted to experience median additional drawdown in excess of 0.2 m.

As outlined in Section 3.3.2.1.1, it is likely that the results from the original AEM conceptualisation over estimate drawdown in areas where the actual areal distribution and thickness of the alluvial layer is more restricted than implemented in the AEM, such as near the Doongmabulla Springs complex. This recognition led to the development of the alternative conceptualisation, which only allows for drawdown to occur from the deeper upper Permian coal measures through the regional aquitard pathway (i.e. no drawdown propagation occurs from the mines via the alluvium). The Assessment team considers that the alternative conceptualisation provides a better estimate of drawdown in the Clematis Group in areas where the alluvial layer does not occur as an extensive sheet-like layer that is in direct (and unimpeded) contact with the mining areas. However, this hypothesis would need to be further tested through a combination of field work and modelling, including analysis of groundwater samples for environmental tracers and isotopes, geophysical surveying, and more detailed local-scale groundwater modelling that incorporates any new understandings and conceptualisations derived from field work (see Section 3.7 for further discussion and recommendations).

3.4.3.2.2 Permian springs cluster

The median modelling result indicates that drawdown at all seven of the springs that access the upper Permian coal measures in the zone will exceed 0.2 m (Figure 43 and Table 20). The range of model predictions indicates that the number of springs predicted to experience additional drawdown in excess of 0.2, 2 and 5 m is between five and seven springs. Additional drawdown is *very likely* to exceed 5 m at five springs in the Permian springs cluster (Lignum, Storys and Mellaluka springs).

3.4.3.2.3 Triassic springs cluster

Drawdown for the 12 Triassic springs in the zone cannot be reliably estimated by the AEM (as the source aquifer is not specifically modelled), but is likely to fall within the range predicted for the Clematis Group model layer (Figure 43 and Table 20). Fensham et al. (2016) reported that the Greentree Spring has been inactive (dry) for a considerable time, possibly since the turn of the 20th century. In contrast, Hunter Springs is only known to have dried up once in living memory, at the end of a major drought in the 1940s (Fensham et al., 2016).

3.4.3.2.4 Other Great Artesian Basin (GAB) springs

None of the 1353 GAB springs with source aquifers that are part of the Eromanga Basin occur in the zone of potential hydrological change (Figure 42 and Table 20). These GAB aquifers are part of the hydrostratigraphic sequence of the Eromanga Basin (which is geologically younger and overlies much of the Galilee Basin in the subregion). Fensham et al. (2016) noted that 15% of GAB discharge springs included in the Barcaldine Springs supergroup are currently inactive.

As outlined in companion product 2.6.2 for the Galilee subregion (Peeters et al., 2018), caution should be used when comparing results from different groundwater models for a number of reasons including differences in model assumptions, conceptualisations, operation of modelling code and construction. Full conceptualisation details of other groundwater models in the Galilee subregion are described in companion product 2.6.2 for the Galilee subregion (Peeters et al., 2018) and summarised here for some selected springs.

Numerical groundwater modelling associated with the proposed Carmichael Coal Mine and Rail Project has identified potential impacts to the Doongmabulla Springs and Mellaluka Springs complexes (GHD, 2013b). Previous estimates of pressure reductions at various springs during the operational and post-closure phases of the Carmichael Coal Mine are up to 0.19 m at Joshua Spring during the operational phase, 0.12 m at Moses Springs and 0.05 m at Little Moses Spring (GHD, 2013b). These estimates are less than estimates of additional drawdown made with the original AEM conceptualisation used in the regional groundwater modelling approach for the BA, and are consistent with estimates made using the alternative conceptualisation (Figure 43 and Table 20). However, these results did not account for the potential hydrological effects of all of the proposed coal mines included in the additional coal resource development for this BA.

Previously predicted pressure reductions in the Mellaluka Springs complex during mine operations are 1.14 m at Mellaluka Springs, 2.34 m at Storys Spring and 8.22 m at Lignum Spring (Table 5 in GHD, 2013b). The pressure reduction becomes greater during the post-closure phase (likely to be around 2070) with pressure reductions of 9.07, 13.4 and 25.6 m, respectively, at the three springs (GHD, 2013b, Table 5). These estimates are less than the median additional drawdown predicted at Mellaluka Springs of approximately 60 m (e.g. model receptor GAL_043, confined upper Permian source aquifer) by either the original or alternative groundwater model conceptualisation reported in this Assessment (Figure 28 in companion product 2.6.2 for the Galilee subregion (Peeters et al., 2018)).

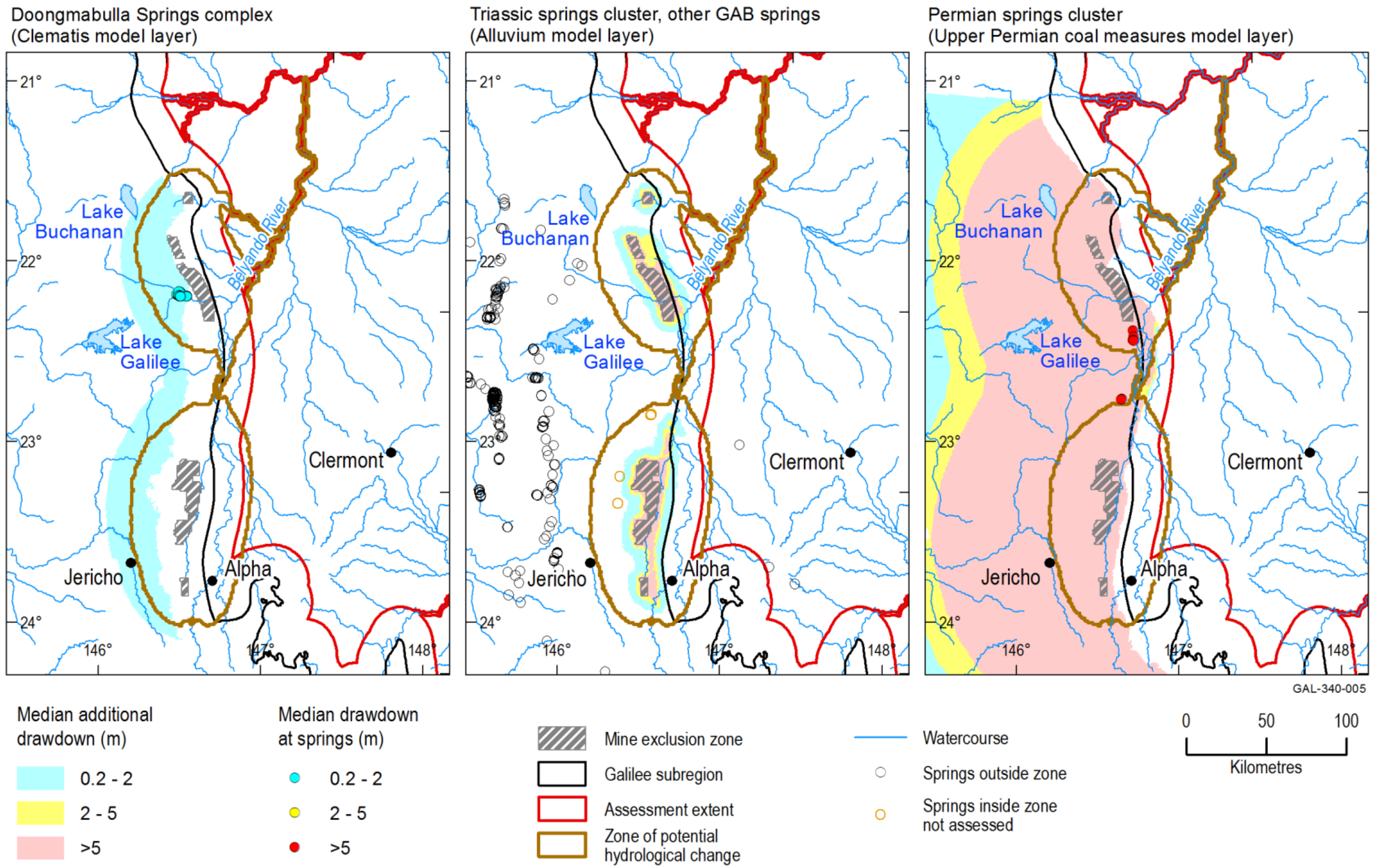

Figure 42 'Springs' landscape group: location of springs in the zone of potential hydrological change in the Galilee subregion

All results shown are based on the original conceptualisation used to assess drawdown using the analytic element model (AEM) for the Galilee subregion.
GAB = Great Artesian Basin
Data: Queensland Herbarium, Department of Science, Information Technology, Innovation and the Arts (Dataset 5); Bioregional Assessment Programme (Dataset 8, Dataset 9)

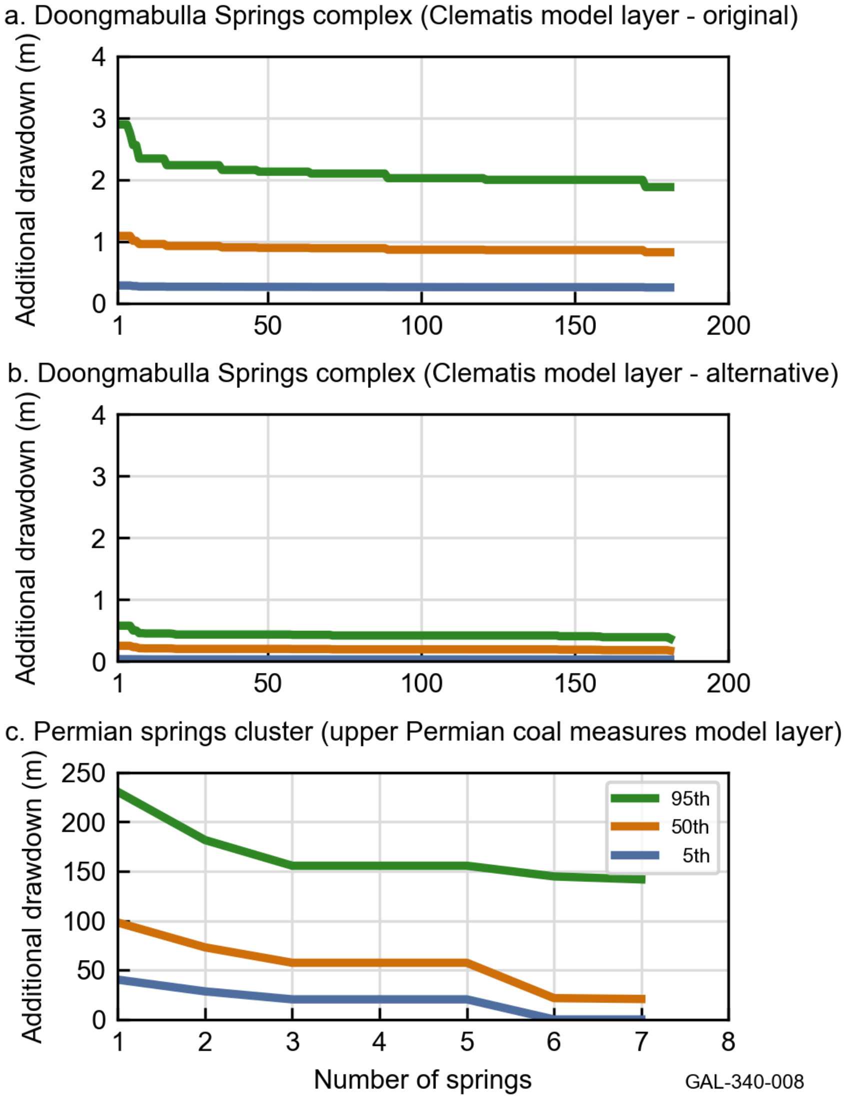

Figure 43 'Springs' landscape group: number of springs in the Doongmabulla Springs complex and Permian springs cluster potentially exposed to varying levels of additional drawdown in the zone of potential hydrological change

This analysis assumes that additional drawdown at springs in the Doongmabulla Springs complex is due to drawdown in the Clematis Group aquifer model layer, and drawdown at springs in the Permian springs cluster is due to drawdown in the upper Permian coal measures model layer. The modelling results for the Doongmabulla Springs complex are shown for both the original AEM conceptualisation (a) and the alternative AEM conceptualisation (b), as explained in the accompanying text.
Data: Queensland Herbarium, Department of Science, Information Technology, Innovation and the Arts (Dataset 5); Bioregional Assessment Programme (Dataset 8)

Table 20 'Springs' landscape group: number of springs (number) potentially exposed to varying levels of additional drawdown in the zone of potential hydrological change

Spring cluster	Number in assessment extent	Number in zone of potential hydrological change	Number with additional drawdown ≥0.2 m			Number with additional drawdown ≥2 m			Number with additional drawdown ≥5 m		
			5th	50th	95th	5th	50th	95th	5th	50th	95th
Doongmabulla Springs complex (original conceptualisation)	187	181	181	181	181	0	0	120	0	0	0
Permian springs cluster	7	7	5	7	7	5	7	7	5	7	7
Triassic springs cluster	12	12	NA	NA	NA	NA	NA	NA	NA	NA	NA
Other GAB springs	1353	0	0	0	0	0	0	0	0	0	0
Total springs	**1559**	**200**	**186**	**188**	**188**	**5**	**7**	**127**	**5**	**7**	**7**
Doongmabulla Springs complex (alternative conceptualisation)	187	181	0	0	181	0	0	0	0	0	0

This analysis assumes that additional drawdown at springs in the Doongmabulla Springs complex is due to drawdown in the Clematis Group aquifer model layer, and drawdown at springs in the Permian springs cluster is due to drawdown in the Betts Creek beds model layer. Drawdown at springs in the Triassic springs cluster cannot be estimated by the analytic element model (AEM) as the source aquifer was not specifically included in the model design.

The original conceptualisation for the AEM allows for two drawdown pathways (Section 3.3.2.1.1). These two pathways account for drawdown through the regional aquitard (Rewan Group) as well as near-surface drawdown/drainage through the surficial aquifer. As explained in this section and Section 3.3.2.1.1, the AEM results may be overly conservative for the Doongmabulla Springs complex. The alternative conceptualisation for the AEM only accounts for drawdown through the regional aquitard (Section 3.3.2.1.1). Further work would be required (as outlined in Section 3.7) to confirm if results from a regional-scale model can adequately account for local-scale influences on groundwater flow at the Doongmabulla Springs complex.

GAB = Great Artesian Basin; NA = not available

Data: Queensland Herbarium, Department of Science, Information Technology, Innovation and the Arts (Dataset 5); Bioregional Assessment Programme (Dataset 8)

3.4.3.3 Potential ecosystem impacts

A qualitative mathematical model was developed that described the general dynamics of the aquatic community associated with springs in the zone of potential hydrological change (see Section 2.7.3 in companion product 2.7 for the Galilee subregion (Ickowicz et al., 2018)). The experts identified that a critical factor in preserving the aquatic community is the rate of groundwater flow that maintains a damp or submerged state in the area around the spring vent and any associated spring pools down-gradient, such that this surface area does not become dry. An increase in water depth above this threshold[1] supports a wetted-area regime around the perimeter and downstream of the spring that is beneficial to emergent vegetation, the building of peat mounds, tail vegetation (i.e. vegetation at the outfall or tail end of a spring) and groundwater-dependent vegetation. Within the free-water area of a spring, an increase in water depth enhances primary production (i.e. phytoplankton, macrophytes and benthic algae) and habitat for aquatic grazers.

The modelled estimates of expected pressure reduction in aquifers within the ‘Springs’ landscape group indicate a high potential for ecosystem impact. The impact varies probabilistically with location but is predicted for the Doongmabulla Springs complex, Permian springs cluster and Triassic springs cluster. However, as explained in detail in companion product 2.7 for the Galilee subregion (Ickowicz et al., 2018), it was not possible to develop receptor impact models for the ‘Springs’ landscape group in the Galilee subregion.

At the Doongmabulla Springs complex, the predicted level of pressure reduction will affect water flows and decrease water availability to GDEs. However, the long-term impact of this pressure reduction on the springs and spring wetlands and the constituent biota is unclear or contestable. Section 3.5.2.6 provides further discussion on water-dependent assets at the Doongmabulla Springs complex and potential ecosystem impacts may affect these assets.

For the Permian springs cluster, including Mellaluka Springs, the predicted pressure reductions during mine operations are likely to reduce flows at the surface for all springs within the cluster. Hydrological impacts potentially will result in the loss of ecological functioning of these springs, and also affect their use as a reliable pastoral water supply.

At the Triassic springs cluster, drawdown cannot be reliably estimated by the AEM, but is likely to fall within the range predicted for the Clematis Group model layer. Therefore, the ecological consequences of predicted pressure reductions are less certain at the Triassic springs cluster.

[1] As explained in Section 2.7.3.2 of companion product 2.7 for the Galilee subregion (Ickowicz et al., 2018) the increase in water depth above the threshold is specified as the depth of water in the spring that is greater than the level required to maintain only a damp state (and thus is able to support a wetted area around the perimeter and down-gradient of the spring). In the two signed digraph models for the ‘Springs’ landscape group in Figure 13 and Figure 14 of Ickowicz et al. (2018) this critical model variable is denoted by the symbol ‘D>Dam’.

3.4.4 'Streams, GDE' landscape group

3.4.4.1 Description

The Galilee subregion includes the headwaters of six major surface water catchments: Cooper Creek – Bulloo, Diamantina, Flinders, Warrego, Burdekin and Fitzroy. Approximately 12% of all streams in the assessment extent are considered groundwater dependent (Table 19). Of the main river catchments, only the Burdekin river basin and the Cooper Creek – Bulloo river basin (Alice River) intersect the zone of potential hydrological change. Most watercourses in the zone of potential hydrological change are contained within the upper catchment of the Belyando River, part of the larger Burdekin river basin.

It is important to note the classification of streams as either groundwater dependent ('Streams, GDE') or non-groundwater dependent ('Streams, non-GDE') is based on the landscape classification approach adopted for the BA for the Galilee subregion. The methodology that underpins this classification is documented in Section 2.3.3 of companion product 2.3 for the Galilee subregion (Evans et al., 2018b). Information relating to the water source for all streams classified in the Galilee assessment extent was obtained from the Queensland Herbarium's GDEs and shallow watertable aquifer dataset (Queensland Herbarium, Department of Science, Information Technology, Innovation and the Arts, Dataset 10). This dataset was considered fit for purpose and adopted 'as is' for use in the BA without additional scrutiny. However, with the recent advent of the various Digital Earth Australia products described in Section 3.2.3.3, it may be possible to revisit this original classification and enhance the accuracy of the streams classification at some stage in the future (although this could not be done for this impact and risk analysis due to operational constraints).

Almost half of the 6285 km of streams in the zone of potential hydrological change are classed as groundwater dependent (2801 km or 45% of streams in the zone) (Table 19). The 'Streams, GDE' landscape group includes four landscape classes that are classified based on water regime (near-permanent or temporary) and landscape position (lowland or upland). Most streams in the zone of potential hydrological change have a temporary water regime. The 'Temporary, lowland GDE stream' landscape class includes 2063 km of streams and 'Temporary, upland GDE stream' landscape class includes 478 km of streams. The zone also includes 260 km of groundwater-dependent streams with a near-permanent water regime, including 253 km classified as 'Near-permanent, lowland GDE stream' and about 7 km classified as 'Near-permanent, upland GDE stream'.

Surface water – groundwater connectivity ranges from gaining or variably gaining to losing-disconnected (Figure 44). Shallow groundwater may discharge into rivers as baseflow from upward leakage from sandstone aquifers such as the Hooray Sandstone, Hutton Sandstone, Clematis Group and Ronlow beds (companion product 1.1 for the Galilee subregion (Evans et al., 2014, p. 113)).

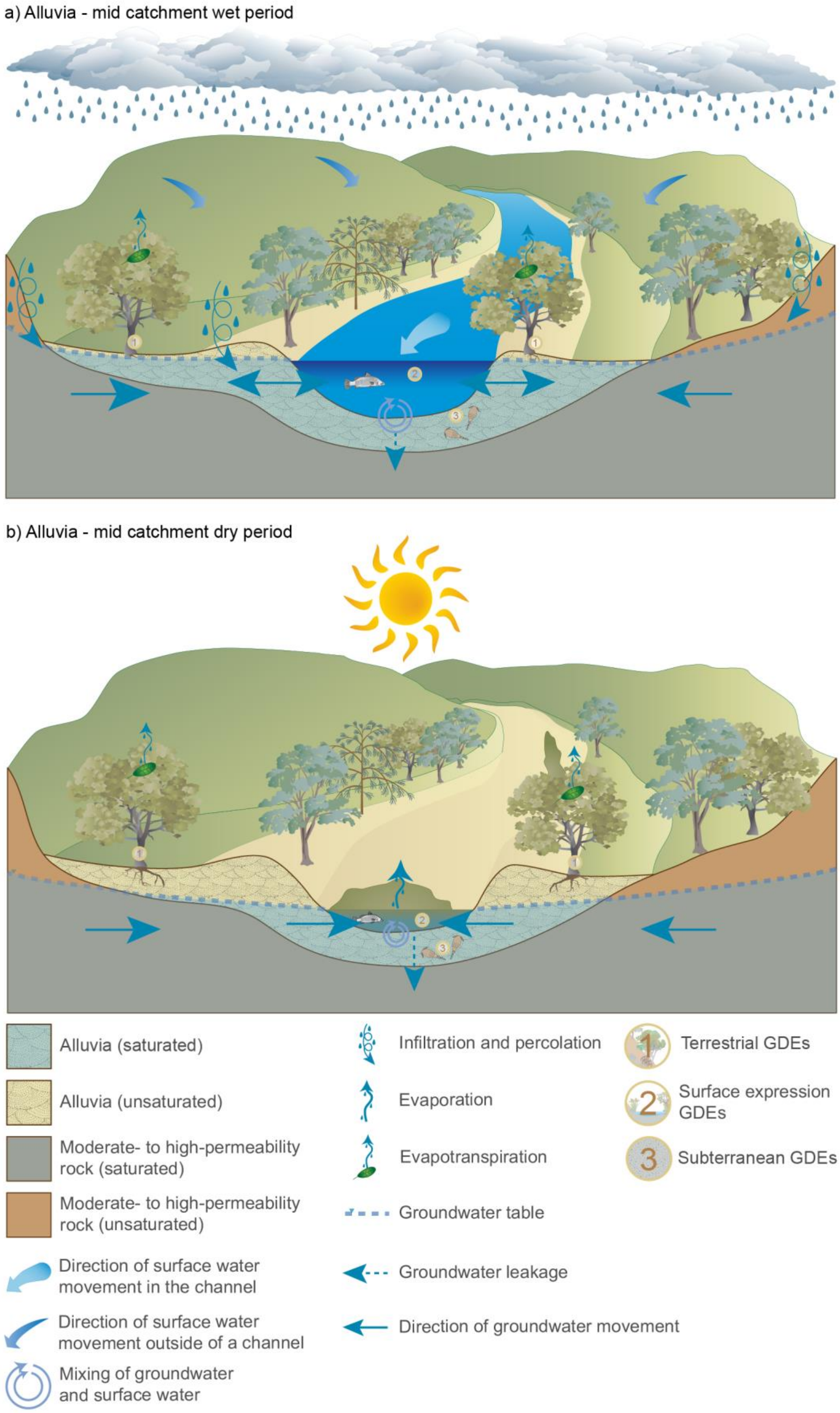

Figure 44 Conceptual model of a riverine landscape in the Galilee assessment extent showing seasonal variation in streamflow and surface water – groundwater connectivity

GDE = groundwater-dependent ecosystem

Source: adapted from Queensland Department of Science, Information Technology and Innovation (Dataset 4), © The State of Queensland (Department of Science, Information Technology and Innovation) 2015

Groundwater may also discharge into springs that create outflow pools in rivers. For instance, Fensham et al. (2016) noted that where outflow from Joshua Spring and the House Springs group (both part of the larger Doongmabulla Springs complex) converge, they provide the main water source of the Carmichael River for a distance of up to 20 km (Fensham et al., 2016). The analysis of time-series Landsat data (see Section 3.2 and Section 3.5 for details) indicates that some spring pools (e.g. Moses-Keelback and Wobbly springs pools) over the last 30 years have been temporally persistent during dry periods, providing strong evidence for their groundwater dependence.

Groundwater may also be important in providing moisture for terrestrial vegetation associated with the 'Streams, GDE' landscape group. This includes shallow groundwater (<20 m depth to watertable) that is transpired by deep-rooted riparian trees such as river red gums and other species (Section 2.3.2 of companion product 2.3 for the Galilee subregion (Evans et al., 2018b)).

Within the zone of potential hydrological change, annual streamflow shows a high degree of interannual variability (companion product 1.1 for the Galilee subregion (Evans et al., 2014)). Flows in a given year can vary from almost no flow to major floods. Mean monthly flow is also highly variable. Flows vary between months with minimal to no flow from July to October, while most flows occur between December and April. The streamflow regime within the zone is thus characterised as one of dry seasonal flows (Kennard et al., 2010).

Despite the influence of groundwater, the 'Streams, GDE' landscape group within the zone of potential hydrological change is characterised by a 'boom–bust' ecology. Specifically, diversity in the ecosystem is maintained by natural cycles of river flow and drying, driven by surface water inputs (Sternberg et al., 2015). Although the more arid rivers further west in the Galilee subregion are driven by highly unpredictable rainfall (e.g. Cooper Creek – Bullo River), the 'boom–bust' cycle in the Belyando river basin is more predictable and generally follows an annual hydrological cycle (Blanchette and Pearson, 2012, 2013). Ecological processes within the zone operate in an environmental context where there is seasonally predictable summer rainfall, which produces a resource pulse that is followed by a predictable period of drying. The drying phase is relatively consistent, that is, in an average year, uninterrupted by rainfall outside the summer months (Blanchette and Pearson, 2013).

During the months of high rainfall (generally between December and April), dry rivers begin to flow and seasonally isolated water-dependent habitats (e.g. waterholes) are connected. This annual period of in-channel flow, or flow pulses, may be associated with large floods producing overbank flow (see below) or it may occur independently in response to localised rainfall (Sheldon et al., 2010). Flooding occurs at unpredictable intervals in response to periods of very high rainfall (i.e. it is not an annual occurrence). During high rainfall periods, there is overbank flow and the environment becomes a large network of interconnected river channel and floodplain habitat. Overbank floods are used to identify the 'boom' phase in Australia's dryland rivers (e.g. Sheldon et al., 2010).

During the 'boom' phase, aquatic and terrestrial productivity is high. Dispersal of freshwater fauna occurs during this phase and important life-history stages are completed. A significant part of the aquatic fauna in this system is capable of long-distance dispersal, with animals recolonising areas from distant waterholes once movement pathways are opened by flooding. Fish are a prime example of such a group (e.g. Kerezsy et al., 2013). At the end of the wet phase, all of the waterholes are likely to be replenished and at their most ecologically productive.

Thus, the ‘Streams, GDE’ landscape group in the zone of potential hydrological change experiences annual in-channel flows each summer and floods at irregular intervals. In-channel flows are important for maintaining connectivity and dispersal of aquatic organisms; however, they do not feature the high primary productivity of overbank floods (Sheldon et al., 2010).

During the months of low or no rainfall (generally May to November) drying of the drainage system produces a series of waterholes and running reaches that have variable connectivity (Pusey and Arthington, 1996). Where the drying causes streams to cease to flow, shallow waterbodies dry out and a chain of pools, isolated pools or completely dry riverbeds result, depending on riverbed geomorphology. As conditions continue to dry, evaporation reduces the depth of each waterhole. Over time, changes to productivity and physico-chemical conditions occur, including changes to dissolved oxygen, conductivity and pH (Blanchette and Pearson, 2013). Groundwater inputs may maintain water levels in waterholes during this ‘bust’ phase.

Waterholes during low-flow or no-flow periods tend to be characterised by high turbidity and limited light penetration. Aquatic food webs in these waterholes are typically driven by energy inputs from filamentous algae that form as a highly productive band in the shallow littoral margins. Phytoplankton blooms and zooplankton may also be important parts of the aquatic food web during the ‘bust’ phase. The algae, phytoplankton and zooplankton support large populations of snails, crustaceans and fish (Bunn et al., 2003).

3.4.4.2 Potential hydrological impacts

Two receptor impact models were developed in the qualitative modelling workshops for the ‘Streams, GDE’ landscape group (companion product 2.7 for the Galilee subregion (Ickowicz et al., 2018)). One receptor impact model focused on the response of woody riparian vegetation to changes in flow regime and groundwater. The other examined the response of a high-flow macroinvertebrate (mayfly nymphs in the genus *Offadens,* family Baetidae) to changes in the flow regime.

For the ‘Woody riparian vegetation’ receptor impact model, the relevant hydrological response variables are:

- maximum difference in drawdown under the baseline future or under the coal resource development pathway future relative to the reference period (1983 to 2012) (dmaxRef)
- number of days per year with low flow (<10 ML/day), averaged over a 30-year period (LQD, subsequently referred to in this Section as ‘low-flow days’), using a modelled 10 ML/day threshold to represent a flow threshold of 1 ML/day used during the expert elicitation
- mean annual number of events with a peak daily flow exceeding the threshold (the peak daily flow in flood events with a return period of 2.0 years as defined from modelled baseline flow in the reference period (1983 to 2012)). This metric is designed to be approximately representative of the number of overbank flow events in future 30-year periods (EventsR2.0).

For the 'High-flow macroinvertebrate' receptor impact model, the hydrological response variables are:

- number of days per year with low flow (<10 ML/day), averaged over a 30-year period (LQD)
- maximum length of spells (in days per year) with low flow, averaged over a 30-year period (LME), using a modelled 10 ML/day threshold to represent an ecological flow threshold of 1 ML/day used during the expert elicitation.

3.4.4.2.1 Groundwater

Streams classified as 'Temporary, upland GDE stream' in the zone of potential hydrological change are located along the western edge of the zone, upstream of the proposed Hyde Park and China Stone coal mines in the north and upstream of the proposed Kevin's Corner, Alpha and South Galilee mines in the south (Figure 45). Streams classified as 'Temporary, lowland GDE stream' intersect and flow downstream of the seven proposed mines in the northern and southern parts of the zone of potential hydrological change.

Most of the groundwater-dependent streams in the zone of potential hydrological change have a temporary water regime (2541 of 2801 km). It is *very unlikely* that additional drawdown in excess of 0.2 m will affect more than 1597 km of streams classified as 'Temporary, lowland GDE stream' and 466 km of streams classified as 'Temporary, upland GDE stream' (Figure 46 and Table 21). None of the 260 km of groundwater-dependent streams with a near-permanent water regime are in areas where additional drawdown in excess of 0.2 m is predicted.

The median (50th percentile) estimate of greater than 2 m drawdown due to additional coal resource development is less extensive, potentially affecting 186 km, or 7% of groundwater-dependent streams in the zone (Table 21). Additional drawdown in excess of 5 m is *very unlikely* to affect more than 173 km of groundwater-dependent streams.

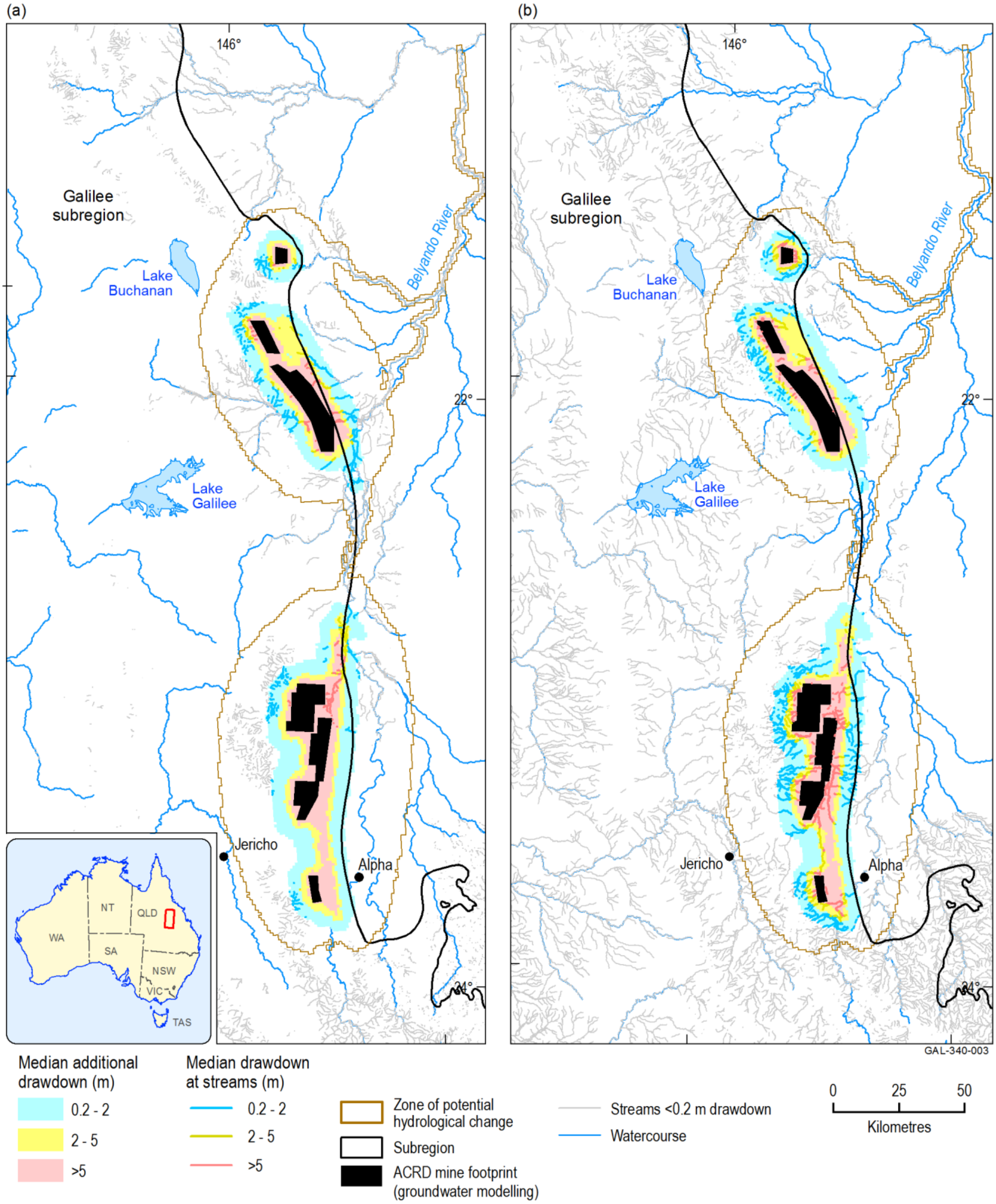

Figure 45 (a) 'Streams, GDE' and (b) 'Streams, non-GDE' landscape groups: location of streams in the zone of potential hydrological change in the Galilee subregion

ACRD = additional coal resource development; GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 9)

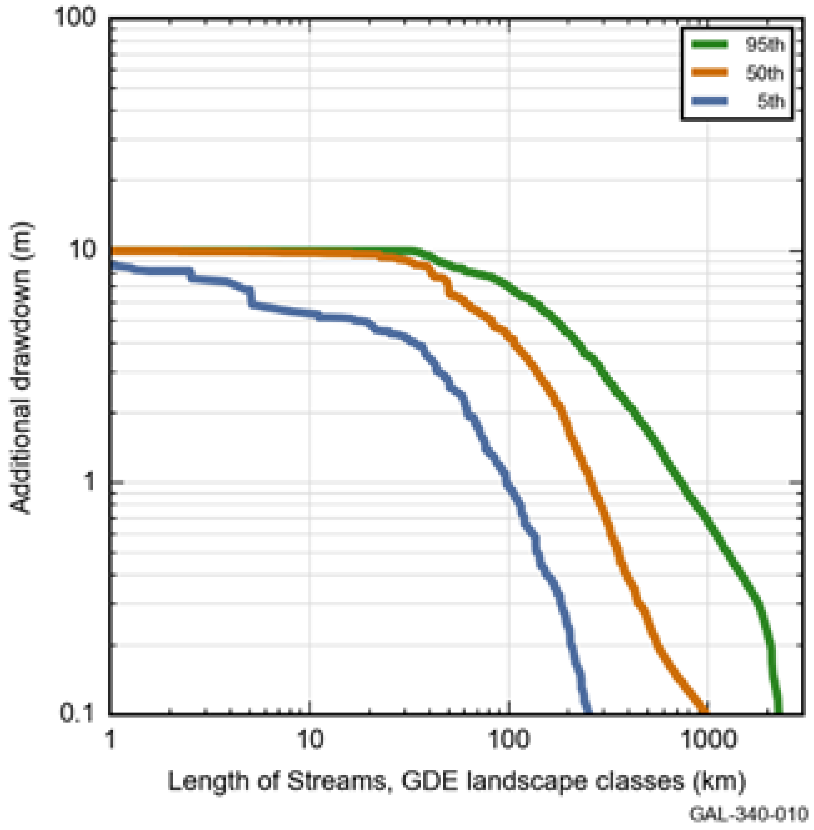

Figure 46 'Streams, GDE' landscape group: length (km) of groundwater-dependent streams potentially exposed to varying levels of additional drawdown in the zone of potential hydrological change

GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 1)

Table 21 'Streams, GDE' landscape group: length (km) of groundwater-dependent streams potentially exposed to varying levels of additional drawdown in the zone of potential hydrological change

Landscape class	Length in assessment extent	Length in zone of potential hydrological change	Length in mine exclusion zone	Length with additional drawdown ≥0.2 m			Length with additional drawdown ≥2 m			Length with additional drawdown ≥5 m		
				5th	50th	95th	5th	50th	95th	5th	50th	95th
Near-permanent, lowland GDE stream	408	253	0	0	0	0	0	0	0	0	0	0
Near-permanent, upland GDE stream	52.0	6.7	0	0	0	0	0	0	0	0	0	0
Temporary, lowland GDE stream	40,798	2063	62.5	181	427	1597	56.2	162	333	15.8	75.2	151
Temporary, upland GDE stream	7,280	478	4.6	24.4	128	466	5.6	24.4	94.1	0.4	6.9	21.7
Subtotal	**48,538**	**2801**	**67.0**	**205**	**555**	**2063**	**61.8**	**186**	**427**	**16.2**	**82.1**	**173**

Some totals reported here have been rounded.
GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 1)

3.4.4.2.2 Surface water

Roughly half of the groundwater-dependent streams in the zone of potential hydrological change are not predicted to experience changes to the surface water regime (Figure 47). This includes 1095 km of groundwater-dependent streams located in the groundwater zone of potential hydrological change, but outside of the surface water zone of potential hydrological change. There are 753 km of groundwater-dependent streams in the surface water zone of potential hydrological change that are potentially impacted but not quantified. This includes parts of Bimbah, Bully, Dyllingo and North creeks and the Carmichael and Belyando rivers in the northern zone, and Sandy Creek in the southern zone (Figure 48). Potential surface water impacts could not be quantified for these streams as they were not specifically included in the surface water modelling (i.e. no model nodes were assigned to these streams).

In 2042, it is *very unlikely* that more than 606 km of groundwater-dependent streams will be affected by increases in modelled low-flow days in excess of 3 days per year (Figure 48 and Table 22). This includes parts of Bully and North creeks, and the Belyando and Suttor rivers, in the northern part of the zone and Sandy Creek in the southern zone. Low-flow days are predicted to increase by more than 20 days per year in a 10-km stretch of North Creek in this time period. Coal resource development is predicted to increase the number of low-flow days by more than 3 days per year along 634 km of groundwater-dependent streams by 2102. This includes parts of the Belyando and Suttor rivers in the northern zone and Native Companion Creek and the Belyando River in the southern zone (Figure 49).

Increases to modelled average annual low-flow spells of more than 3 days are *very unlikely* to affect more than 101 km of groundwater-dependent streams by 2042 (Figure 48). This includes parts of Bully, North and Sandy creeks (Figure 48 and Table 23). In 2102, increased average annual low-flow spells of more than 3 days are *very unlikely* to affect more than 648 km of modelled groundwater-dependent streams, including much of the Belyando and Suttor rivers and Native Companion Creek in the surface water zone of potential hydrological change (Figure 49).

It is *very unlikely* that modelled overbank flows will decrease by more than 0.1 events per year along more than 101 km of groundwater-dependent streams in the zone of potential hydrological change (Figure 48 and Table 24). This includes parts of Bully, North and Sandy creeks and the Belyando and Suttor rivers. A reduction of 0.1 events per year means one fewer overbank flow events every 10 years on average. Based on the median estimate, the number of modelled overbank flows per year is predicted to decrease by more than 0.1 along 10 km, 0.05 along 61 km and 0.02 along 121 km of groundwater-dependent streams in the 30-year period preceding 2042. Predictions in the 30-year period preceding 2102 are less extensive; median estimates of the number of modelled overbank flows per year are predicted to decrease by more than 0.02 along less than 10 km of groundwater-dependent streams in the zone of potential hydrological change (Figure 49).

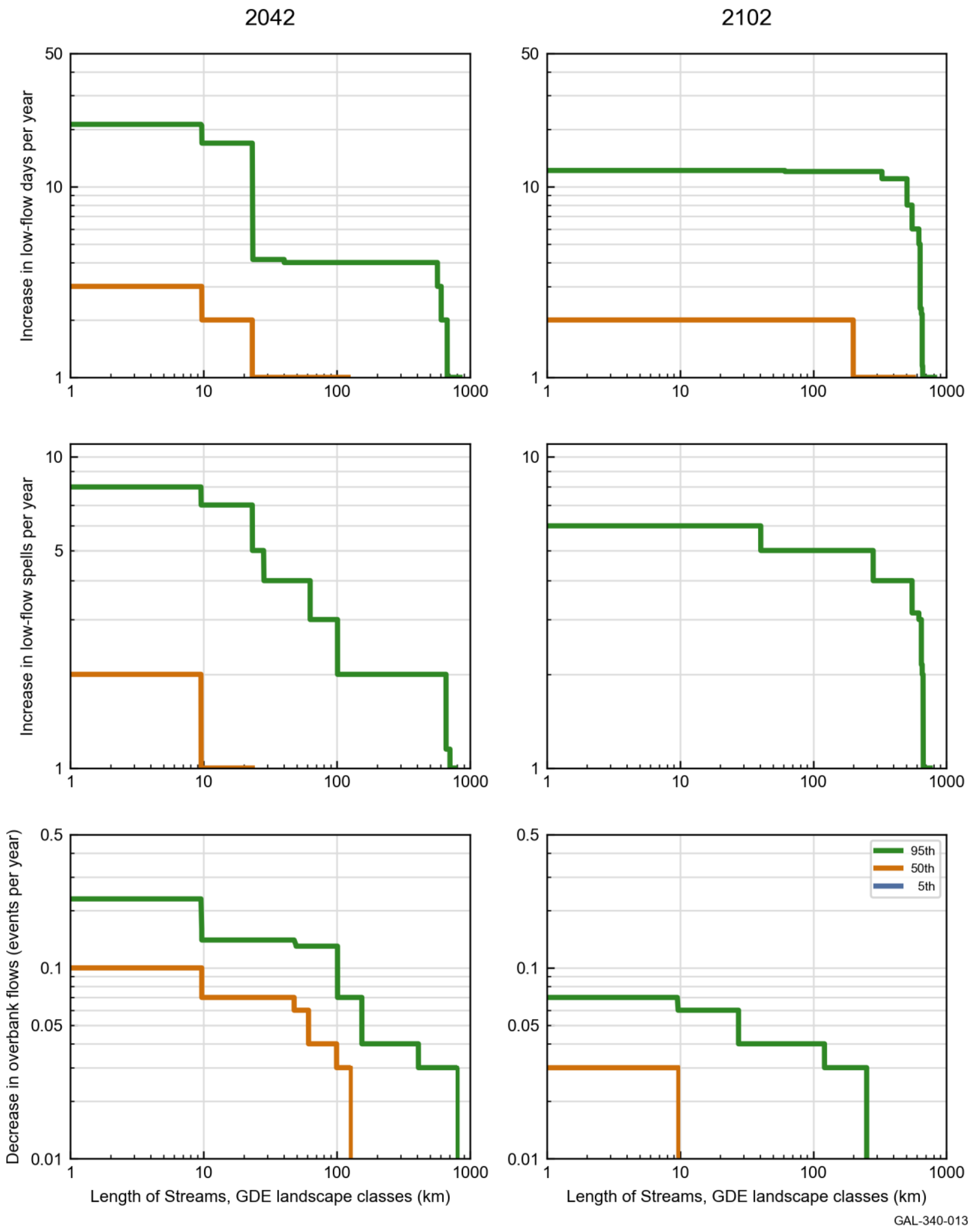

Figure 47 'Streams, GDE' landscape group: length (km) of groundwater-dependent streams potentially exposed to changes to low-flow days per year (LQD), low-flow spells per year (LME) and recurrence of overbank flows per year (EventR2.0) in 2042 and 2102 in the zone of potential hydrological change

There are no results for the 5th percentile of any of the hydrological response variables above in 2042 or 2102. This is because, as shown in Table 22, 23 and 24, there is zero stream length that exceeds any of the specified thresholds for increases in low-flow days, increases in low-flow spells, or decreases in overbank flow events at the 5th percentile of the modelling results.
GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 1)

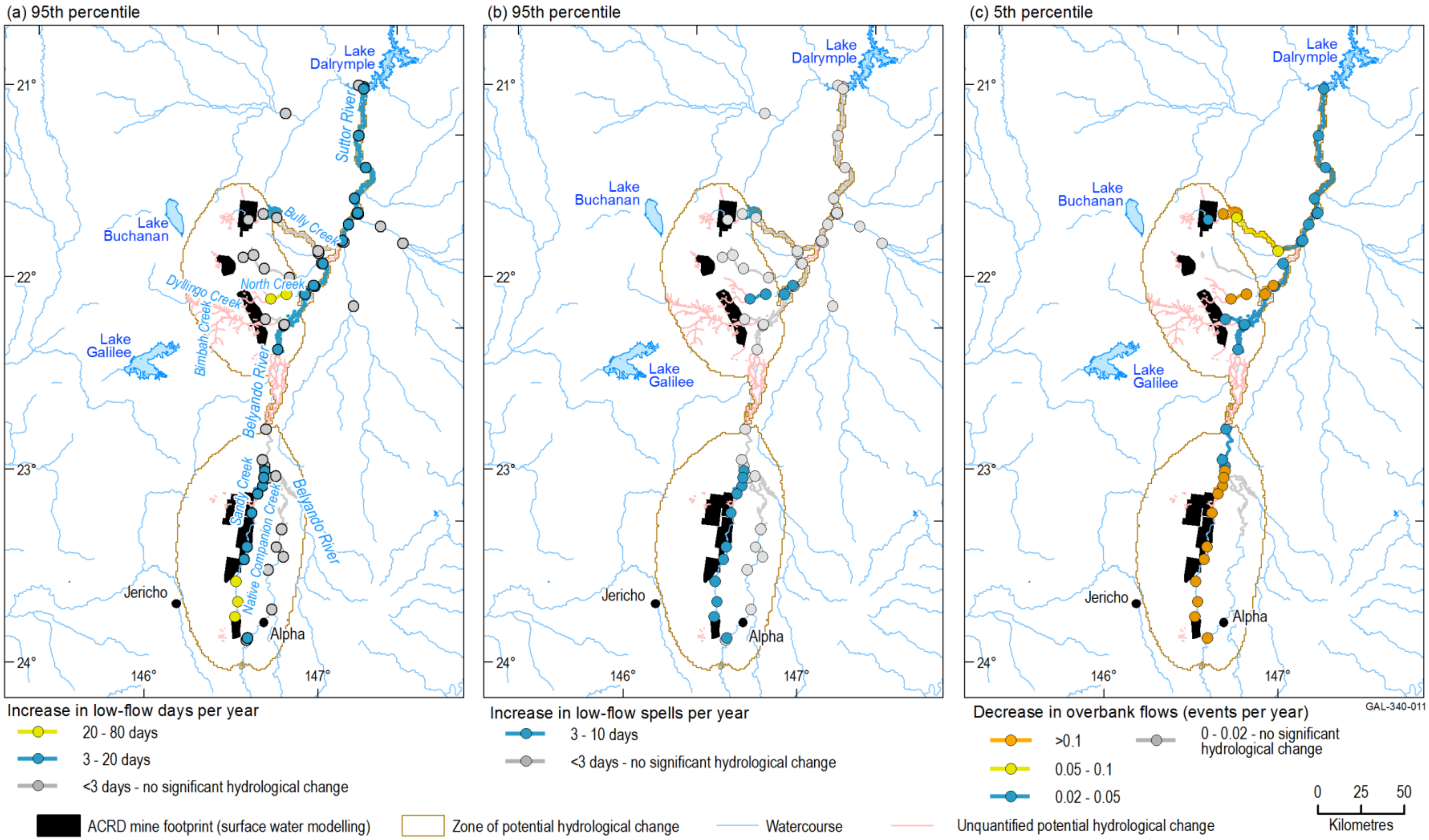

Figure 48 'Streams, GDE' landscape group: modelled (a) increase in low-flow days per year (LQD), (b) increase in low-flow spells per year (LME) and (c) decrease in overbank flows per year (EventsR2.0) in groundwater-dependent streams in 2042 in the zone of potential hydrological change

Maps show 95th percentile estimates of increases in low-flow days per year (averaged over 30 years) (LQD) and low-flow spells per year (LME) and 5th percentile estimates of decreases in overbank flows per year (EventsR2.0) to illustrate where maximum hydrological changes may occur. A reduction of 0.1 events per year means one fewer overbank flow events every 10 years.
ACRD = additional coal resource development; GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 9)

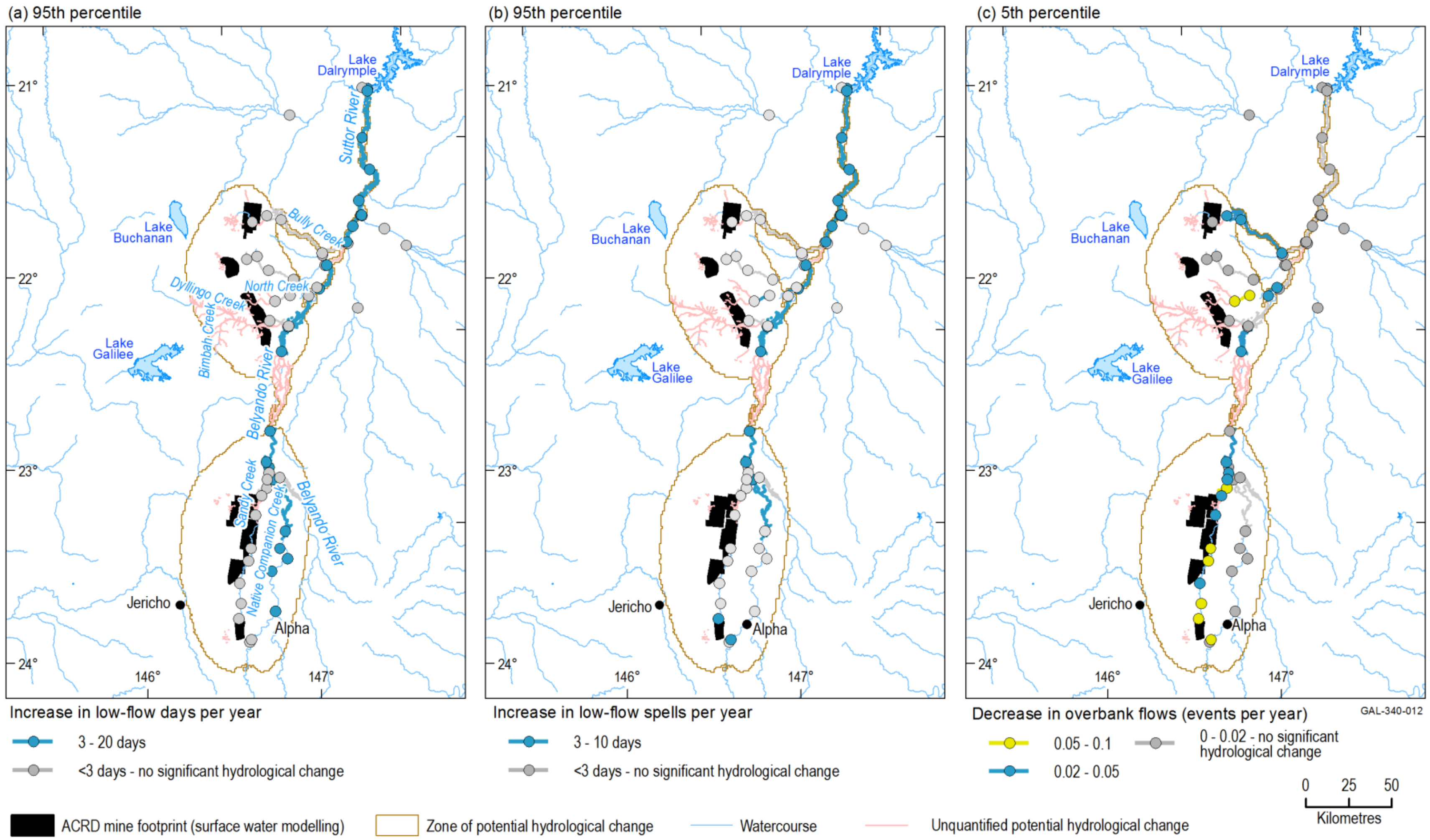

Figure 49 'Streams, GDE' landscape group: modelled (a) increase in low-flow days per year (LQD), (b) increase in low-flow spells per year (LME) and (c) decrease in overbank flows per year (EventsR2.0) in groundwater-dependent streams in 2102 in the zone of potential hydrological change

Maps show 95th percentile estimates of increases in low-flow days per year (averaged over 30 years) (LQD) and low-flow spells per year (LME) and 5th percentile estimates of decreases in overbank flows per year (EventsR2.0) to illustrate where maximum hydrological changes may occur. A reduction of 0.1 events per year means one fewer overbank flow events every 10 years.
ACRD = additional coal resource development; GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 9)

Table 22 'Streams, GDE' landscape group: length (km) of groundwater-dependent streams potentially exposed to varying increases in number of low-flow days per year (LQD) in the years 2042 and 2102 in the zone of potential hydrological change

Landscape class	Length in zone of potential hydrological change	Length potentially impacted but not quantified	Length with increases of ≥3 low-flow days per year			Length with increases of ≥20 low-flow days per year			Length with increases of ≥80 low-flow days per year			Length with increases of ≥200 low-flow days per year		
			5th	50th	95th	5th	50th	95th	5th	50th	95th	5th	50th	95th
2013–2042														
Near-permanent, lowland GDE stream	253	0.6	0	0	251	0	0	0	0	0	0	0	0	0
Near-permanent, upland GDE stream	6.7	0	0	0	6.7	0	0	0	0	0	0	0	0	0
Temporary, lowland GDE stream	2063	693	0	9.7	341	0	0	9.7	0	0	0	0	0	0
Temporary, upland GDE stream	478	59.3	0	0	7.5	0	0	0	0	0	0	0	0	0
Subtotal	**2801**	**753**	**0**	**9.7**	**606**	**0**	**0**	**9.7**	**0**	**0**	**0**	**0**	**0**	**0**
2073–2102														
Near-permanent, lowland GDE stream	253	0.6	0	0	251	0	0	0	0	0	0	0	0	0
Near-permanent, upland GDE stream	6.7	0	0	0	6.7	0	0	0	0	0	0	0	0	0
Temporary, lowland GDE stream	2063	693	0	0	370	0	0	0	0	0	0	0	0	0
Temporary, upland GDE stream	478	59.3	0	0	6.3	0	0	0	0	0	0	0	0	0
Subtotal	**2801**	**753**	**0**	**0**	**634**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Some totals reported here have been rounded. Columns containing zero values are shown to allow consistent comparison between tables.
GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 1)

Table 23 'Streams, GDE' landscape group: length (km) of groundwater-dependent streams potentially exposed to varying increases in duration of low-flow spells per year (LME) in the years 2042 and 2102 in the zone of potential hydrological change

Landscape class	Length in zone of potential hydrological change	Length potentially impacted but not quantified	Length with increases of ≥3 day low-flow spells per year			Length with increases of ≥10 day low-flow spells per year			Length with increases of ≥40 day low-flow spells per year			Length with increases of ≥100 day low-flow spells per year		
			5th	50th	95th	5th	50th	95th	5th	50th	95th	5th	50th	95th
2013–2042														
Near-permanent, lowland GDE stream	253	0.6	0	0	0	0	0	0	0	0	0	0	0	0
Near-permanent, upland GDE stream	6.7	0	0	0	0	0	0	0	0	0	0	0	0	0
Temporary, lowland GDE stream	2063	693	0	0	99.7	0	0	0	0	0	0	0	0	0
Temporary, upland GDE stream	478	59.3	0	0	1.3	0	0	0	0	0	0	0	0	0
Subtotal	**2801**	**753**	**0**	**0**	**101.0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
2073–2102														
Near-permanent, lowland GDE stream	253	0.6	0	0	251	0	0	0	0	0	0	0	0	0
Near-permanent, upland GDE stream	6.7	0	0	0	6.7	0	0	0	0	0	0	0	0	0
Temporary, lowland GDE stream	2063	693	0	0	384	0	0	0	0	0	0	0	0	0
Temporary, upland GDE stream	478	59.3	0	0	6.2	0	0	0	0	0	0	0	0	0
Subtotal	**2801**	**753**	**0**	**0**	**648**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Some totals reported here have been rounded. Columns containing zero values are shown to allow consistent comparison between tables.
GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 1)

Table 24 'Streams, GDE' landscape group: length (km) of groundwater-dependent streams potentially exposed to decreases in recurrence of overbank flows per year (EventsR2.0) due to additional coal resource development in the years 2042 and 2102 in the zone of potential hydrological change

Landscape class	Length in zone of potential hydrological change	Length potentially impacted but not quantified	Length with ≥0.02 decrease of overbank flows (events per year)			Length with ≥0.05 decrease of overbank flows (events per year)			Length with ≥0.1 decrease of overbank flows (events per year)		
			5th	50th	95th	5th	50th	95th	5th	50th	95th
2013–2042											
Near-permanent, lowland GDE stream	253	0.6	252	0	0	0	0	0	0	0	0
Near-permanent, upland GDE stream	6.7	0	6.7	0	0	0	0	0	0	0	0
Temporary, lowland GDE stream	2063	693	488	120	0	152	60.3	0	99.7	9.7	0
Temporary, upland GDE stream	478	59.3	8.2	1.4	0	1.7	0.9	0	1.3	0	0
Subtotal	**2801**	**753**	**754**	**121**	**0**	**154**	**61.2**	**0**	**101**	**9.7**	**0**
2073–2102											
Near-permanent, lowland GDE stream	253	0.6	0	0	0	0	0	0	0	0	0
Near-permanent, upland GDE stream	6.7	0	0	0	0	0	0	0	0	0	0
Temporary, lowland GDE stream	2063	693	250	9.5	0	27.5	0	0	0	0	0
Temporary, upland GDE stream	478	59.3	1.7	0	0	0	0	0	0	0	0
Subtotal	**2801**	**753**	**252**	**9.5**	**0**	**27.5**	**0**	**0**	**0**	**0**	**0**

Some totals reported here have been rounded.
A reduction of 0.02 events per year means one fewer overbank flow events every 50 years, 0.05 is one fewer overbank flow events every 20 years and 0.1 is one fewer overbank flow events every 10 years.
GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 1)

3.4.4.3 Potential ecosystem impacts

During the receptor impact modelling process, the key hydrological determinants of ecosystem function identified by the experts are related to the existence and connectivity of refuge habitats. Here surface water serves a key role, with detritus and algae the principal resources that support populations of aquatic invertebrates and fishes. Surface water also recharges stores of deep groundwater in confined aquifers and in turn, stores of deep groundwater can contribute to shallow groundwater.

One receptor impact model focused on the response of woody riparian vegetation to changes in flow regime and groundwater. For the 'Woody riparian vegetation' receptor impact model, the receptor impact variable is the percent foliage cover of *Eucalyptus camaldulensis* and *Melaleuca* spp. in the streams landscape groups. Percent foliage cover is measured in a 100 m transect along the stream, extending from the stream channel to the top of the bank. The transect is at least 10 m wide, increasing to 15 m where more than a single row of river red gum is present during the reference period. The experts' opinion provides strong evidence that:

- mean percent foliage cover would decrease by approximately 5% if groundwater depth decreases by 5 m and all other model variables are held at their median values
- mean percent foliage cover would decrease by approximately 10% if the number of low-flow days (LQD) increases by 100 days per year from 177 to 277 days per year and all other model variables are held at their median values
- mean percent foliage cover would increase by less than 1% if the number of floods with peak daily flow exceeding the 1983 to 2012 2-year return period (EventsR2.0) doubled and all other model variables are held at their median values.

Uncertainty associated with these predictions increases slightly (i.e. larger credible interval) in the 30-year period preceding 2102. Interestingly, initial percent foliage cover is not a strong predictor of future values in the Galilee subregion. This is at odds with the equivalent receptor impact model in other bioregions where antecedent foliage cover has a strong effect on future foliage cover. However, percent foliage cover in the Galilee subregion is very low – the 90th percentile is approximately 30% with a mean value of about 22%. It is also important to recognise that the relatively modest changes highlighted in the summary above may still be ecologically important given the relatively low baseline condition.

Median estimates of the percent foliage cover under the baseline and CRDP futures ranged from 11% to 44% (Figure 50). Median and 95th percentile estimates of changes in percent foliage cover in the 30-year periods preceding both 2042 and 2102 indicate that there would be a less than 1% change in percent foliage cover compared to the baseline period (Figure 50). There is a 5% chance that percent foliage cover may decrease by 17% to 18% in 2042 and 2102, respectively, due to additional coal resource development.

This is consistent with the modelled changes in groundwater drawdown in excess of 5 m, which are *very unlikely* to affect more than 6% of groundwater-dependent streams in the zone and changes to low-flow days and overbank flows, which are predicted to affect less than 1% of groundwater-dependent streams in the zone. A change in percent foliage cover of 2% represents 10% for the median estimate of projected foliage cover of 0.2. Hence, these changes are small in terms of foliage cover, but are linked to flower production, nectar production and nectar-feeding animals in the associated qualitative mathematical models.

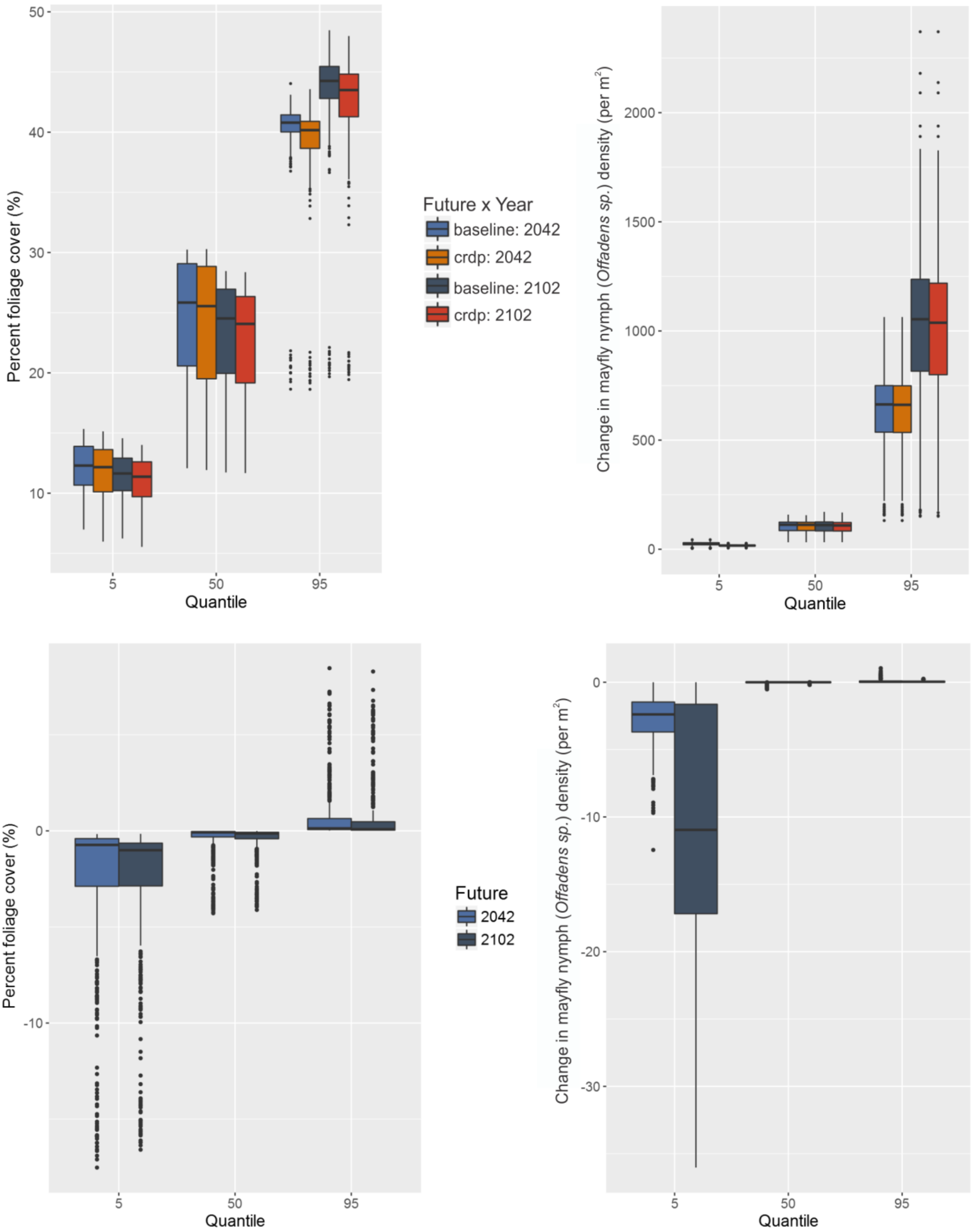

Figure 50 'Streams, GDE' landscape group: 'Woody riparian vegetation' and 'High-flow macroinvertebrate' receptor impact models showing (upper panels) modelled changes in 2042 and 2102 under the baseline and coal resource development pathway (CRDP) futures and (lower panels) difference between futures in 2042 and 2102

GDE = groundwater-dependent ecosystem

Data: Bioregional Assessment Programme (Dataset 11)

The other receptor impact model examined the response of a high-flow macroinvertebrate (mayfly nymphs in the genus *Offadens,* family Baetidae) to changes in the flow regime. For the 'High-flow macroinvertebrate' receptor impact model, the receptor impact variable is the number of mayfly nymphs (order Ephemeroptera) in the genus *Offadens* of the family Baetidae (Webb and Suter, 2011). Mean mayfly nymph density is the number of mayfly nymphs per m^2 measured in a 2 m x 0.5 m quadrat in riffle habitat, 3 months after the end of the wet season. The experts' opinion provides strong evidence that:

- mean mayfly nymph density would decrease by approximately 7% if mean number of low-flow days (LQD) increases by 20 days per year and all other model variables are held at their median values
- mean mayfly nymph density would decrease by approximately 7% if mean annual maximum spell of low-flow days (LME) increases by 20 days per year from 100 to 120 days per year and all other model variables are held at their median values.

The mayfly nymphs in the genus *Offadens* are known to occur in fast-flowing streams in the upper Burdekin river basin (e.g. the Cape and Campaspe rivers) to the north and north-east of the zone of potential hydrological change (Blanchette, 2012). The species can recolonise within 1 to 2 days of flows but is challenged by more than 14 consecutive low-flow days. Water depth in riffles is assumed to be more than 2 cm for this species. There is no legacy effect in terms of how mayflies respond to changing flow conditions and turbidity is not a driver for this species.

Estimates of mayfly nymph density ranged from a median value of 150 mayfly nymphs per m^2 under perennial conditions to a median value slightly less than 50 mayfly nymphs per m^2 under very intermittent conditions (Figure 19 in companion product 2.7 for the Galilee subregion (Ickowicz et al., 2018)). The model also predicts that mayfly nymph density under reference conditions does not influence outcomes under the different low-flow conditions in the future assessment years, which is consistent with receptor impact model predictions for other relatively short-lived species (such as *Hydropyschidae* larvae) in other bioregions.

Median and 95th percentile estimates of the difference in mayfly nymph density due to additional coal resource development in the 30-year periods preceding 2042 and 2102 indicate no change from abundance under the baseline (Figure 50). Results indicate a 5% chance that mayfly nymph density may decrease by up to 12 mayfly nymphs per m^2 in 2042 and up to 36 mayfly nymphs per m^2 in 2102 due to additional coal resource development.

Overall ecosystem risk that combines understanding from the conceptual model of causal pathways, hydrological modelling and expert opinion was estimated based on the distribution of predicted impacts due to additional coal resource development. As explained in Section 3.2.5, risk thresholds were defined for each receptor impact variable to describe areas 'at some risk of ecological and hydrological changes' and 'more at risk of ecological and hydrological changes'. Assessment units where input data exist for the receptor impact modelling, but the risk thresholds are not exceeded, are considered to be 'at minimal risk of ecological and hydrological changes'. Streams where hydrological and/or ecological modelling data were not estimated are classed as 'unquantified risk'. The overall level of risk represents the highest level of risk determined by all relevant receptor impact variables for that assessment unit.

For the ‘Woody riparian vegetation’ receptor impact model, the risk thresholds defined here are:

- ‘at some risk of ecological and hydrological changes’ decreases of greater than 5% foliage cover
- ‘more at risk of ecological and hydrological changes’ decreases of greater than 10% foliage cover.

For the ‘High-flow macroinvertebrate’ receptor impact model, these are:

- ‘at some risk of ecological and hydrological changes’ decreases of greater than 20 mayfly nymphs per m^2
- ‘more at risk of ecological and hydrological changes’ decreases of greater than 30 mayfly nymphs per m^2.

The groundwater-dependent streams where there is some level of risk to woody riparian vegetation and mayfly nymph density mainly occur on parts of Sandy Creek downstream of the four proposed mines in the southern mining cluster, and along parts of the Carmichael, Belyando and lower Suttor rivers between the northern mining cluster and Lake Dalrymple (Figure 51). Receptor impact variables were not calculated for 2088 (67%) assessment units for the ‘Streams, GDE’ landscape group. Of the 1034 assessment units where receptor impact variables were calculated for this landscape group, 194 (or 19%) are considered to be ‘at some risk’ and 42 (or 4%) are considered to be ‘more at risk’. Overall, there is some level of risk to 23% of the assessment units with receptor impact modelling, and 8% of the total number of assessment units in the zone when both the quantified and unquantified changes are considered for this landscape group.

Receptor impact modelling integrates understanding from the conceptual model of causal pathways, hydrological modelling and expert opinion to estimate potential impacts to ecosystems, where receptor impact variables are considered to be useful indicators of ecosystem condition. The strength of this approach is that it provides a measure of the relative risk due to the additional coal resource development and emphasises where further attention using local-scale modelling should focus, and also where it is not needed. Prediction of changes to receptor impact variables is ultimately one line of evidence, and any assessment of risk, particularly at a local scale, needs to be considered in conjunction with the broader hydrological changes that may be experienced and the qualitative mathematical models that can describe potential cumulative impacts to ecosystems. The composite risk map for the ‘Streams, GDE’ landscape group shown in Figure 51, for instance, should thus be considered alongside the evidence provided in Figure 45, Figure 48 and Figure 49.

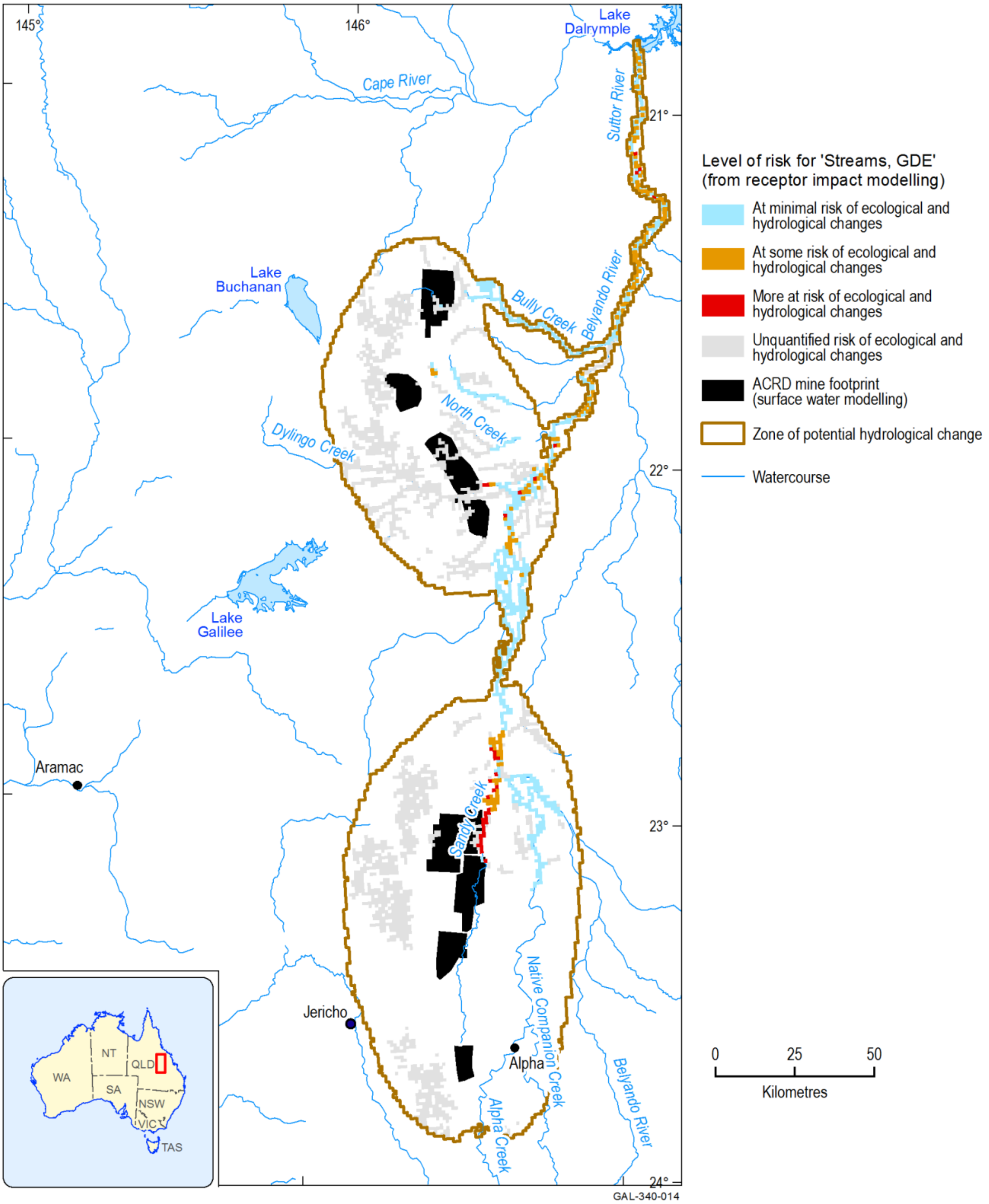

Figure 51 'Streams, GDE' landscape group: level of risk to groundwater-dependent streams due to additional coal resource development

ACRD = additional coal resource development; GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 11)

3.4.5 'Streams, non-GDE' landscape group

3.4.5.1 Description

Most streams in the zone of potential hydrological change are not groundwater dependent (3484 km or 55% of streams in the zone) (Table 19). The 'Streams, non-GDE' landscape group includes four landscape classes that are classified based on water regime (near-permanent or temporary) and landscape position (lowland or upland). Most streams in the zone of potential hydrological change have a temporary water regime. The 'Temporary, lowland stream' landscape class includes 3114 km of streams and 'Temporary, upland stream' landscape class includes 365 km of streams. The zone also includes 5 km of streams with a near-permanent water regime, including 4 km classified as 'Near-permanent, lowland stream' and 1 km classified as 'Near-permanent, upland streams'.

Dry seasonal flows in the Belyando river basin mean that the 'Streams, non-GDE' landscape group is characterised by a 'boom–bust' ecology (Figure 44). Specifically, diversity is maintained by natural cycles of river flow and drying, driven by surface water inputs (Sternberg et al., 2015). While the more arid rivers further west in the Galilee subregion are driven by highly unpredictable rainfall, the 'boom–bust' cycle in the Belyando river basin is relatively predictable and follows an annual hydrological cycle (Blanchette and Pearson, 2012, 2013). Ecological processes within the zone operate in an environmental context where there is seasonally predictable summer rainfall, which produces a resource pulse that is followed by a predictable period of drying. The drying phase is a relatively constant process that is, in an average year, uninterrupted by rainfall falling outside the summer period (Blanchette and Pearson, 2013).

During the months of high rainfall (generally between December and April), the dry rivers begin to flow and seasonally isolated water-dependent habitats (e.g. waterholes) are connected. This annual period of in-channel flow, or flow pulses, may be associated with large floods producing overbank flow (see below) or it may occur independently in response to localised rainfall (Sheldon et al., 2010). Flooding occurs at unpredictable intervals in response to periods of very high rainfall (i.e. it is not an annual occurrence). During these high rainfall periods, there is overbank flow and the environment becomes a large network of interconnected river channel and floodplain habitat. Overbank flooding is used to identify the 'boom' phase in Australia's dryland rivers (e.g. Sheldon et al., 2010).

During the 'boom' phase, aquatic and terrestrial productivity is high. Dispersal of freshwater fauna occurs during this phase and important life-history stages are completed. A significant part of the aquatic fauna in this system is capable of long-distance dispersal, with animals recolonising areas from distant waterholes once movement pathways are opened by flooding. Fish are prime examples of such a group (e.g. Kerezsy et al., 2013). At the end of the wet phase, all of the waterholes are likely to be replenished and be at their most productive.

Thus the 'Streams, non-GDE' landscape group of the zone of potential hydrological change experiences annual in-channel flows each summer and flood events at irregular intervals. The in-channel flows are important for maintaining connectivity and dispersal of aquatic organisms; however, they do not feature the high primary productivity of the flood events (Sheldon et al., 2010).

During the months of low or no rainfall (generally May to November) drying of the drainage system produces a series of waterholes and running reaches that have variable connectivity (Pusey and Arthington, 1996). Where the drying results in cease-to-flow events, shallow waterbodies dry out and a chain of pools, isolated pools or completely dry riverbeds result, depending on riverbed morphology. As conditions continue to dry, evaporation will reduce the depth of each waterhole. Over time, productivity will change and the physico-chemical conditions decline. Changes occur in dissolved oxygen, conductivity and pH (Blanchette and Pearson, 2013).

Waterholes during low-flow or no-flow periods tend to be characterised by high turbidity and limited light penetration. The aquatic food webs of these waterholes are typically driven by energy inputs from filamentous algae that form as a highly productive band in the shallow littoral margins. Phytoplankton blooms and zooplankton may also be important parts of the aquatic food web during the ‘bust’ phase. The algae, phytoplankton and zooplankton support large populations of snails, crustaceans and fish (Bunn et al., 2003).

3.4.5.2 Potential hydrological impacts

Potential ecosystem impacts on streams classified as ‘Streams, non-GDE’ landscape group are assessed using the ‘High-flow macroinvertebrate’ receptor impact model based on predicted mayfly nymph (*Offadens* sp.) densities. Changes to groundwater depth are unlikely to affect these non-groundwater dependent streams.

For the ‘High-flow macroinvertebrate’ receptor impact model, the relevant hydrological response variables are:

- number of days per year with low flow (<10 ML/day), averaged over a 30-year period (LQD)
- maximum length of spells (in days per year) with low flow, averaged over a 30-year period (LME), using a modelled 10 ML/day threshold to represent an ecological flow threshold of 1 ML/day used during the expert elicitation.

3.4.5.2.1 Groundwater

The ‘Streams, non-GDE’ landscape group is not considered to be groundwater dependent.

3.4.5.2.2 Surface water

Most streams in the ‘Streams, non-GDE’ landscape group in the zone of potential hydrological change have a temporary water regime and are not represented in the BA surface water modelling. This includes 1028 km of temporary streams that are classified as ‘Temporary lowland’ (940 km) and ‘Temporary upland’ (89 km) in the surface water zone of potential hydrological change that are potentially impacted but not quantified. This includes upstream parts of the Bully, Lagoon, North, Sandy and Tomahawk creeks and the upstream reaches of the Carmichael River catchment (Figure 20 in Section 3.3).

Hydrological modelling undertaken for this BA indicates that, in 2042, it is *very unlikely* that more than 69 km of streams will be affected by increases in modelled low-flow days in excess of 3 days (Figure 52 and Table 25). This includes Tallarenha Creek and parts of Alpha, Bully and Sandy creeks. It is *very unlikely* that modelled low-flow days will increase by more than 20 days along a 29 km stretch of Tallarenha Creek in this time period. The additional coal resource development is *very unlikely* to increase the number of modelled low-flow days by more than 3 days per year along more than 177 km of streams by 2102. This includes Tallarenha Creek and parts of Alpha, Native Companion and Sandy creeks (Figure 54).

Increases to average annual low-flow spells of more than 3 days are *very unlikely* to affect more than 51 km of modelled streams by 2042. This includes Tallarenha Creek and parts of Alpha and Bully creeks (Figure 53 and Table 26). In 2102, increased average annual low-flow spells of more than 3 days are *very unlikely* to affect more than 90 km of modelled streams in the 'Streams, non-GDE' landscape group, including Tallarenha Creek and parts of Alpha and Bully creeks (Figure 54).

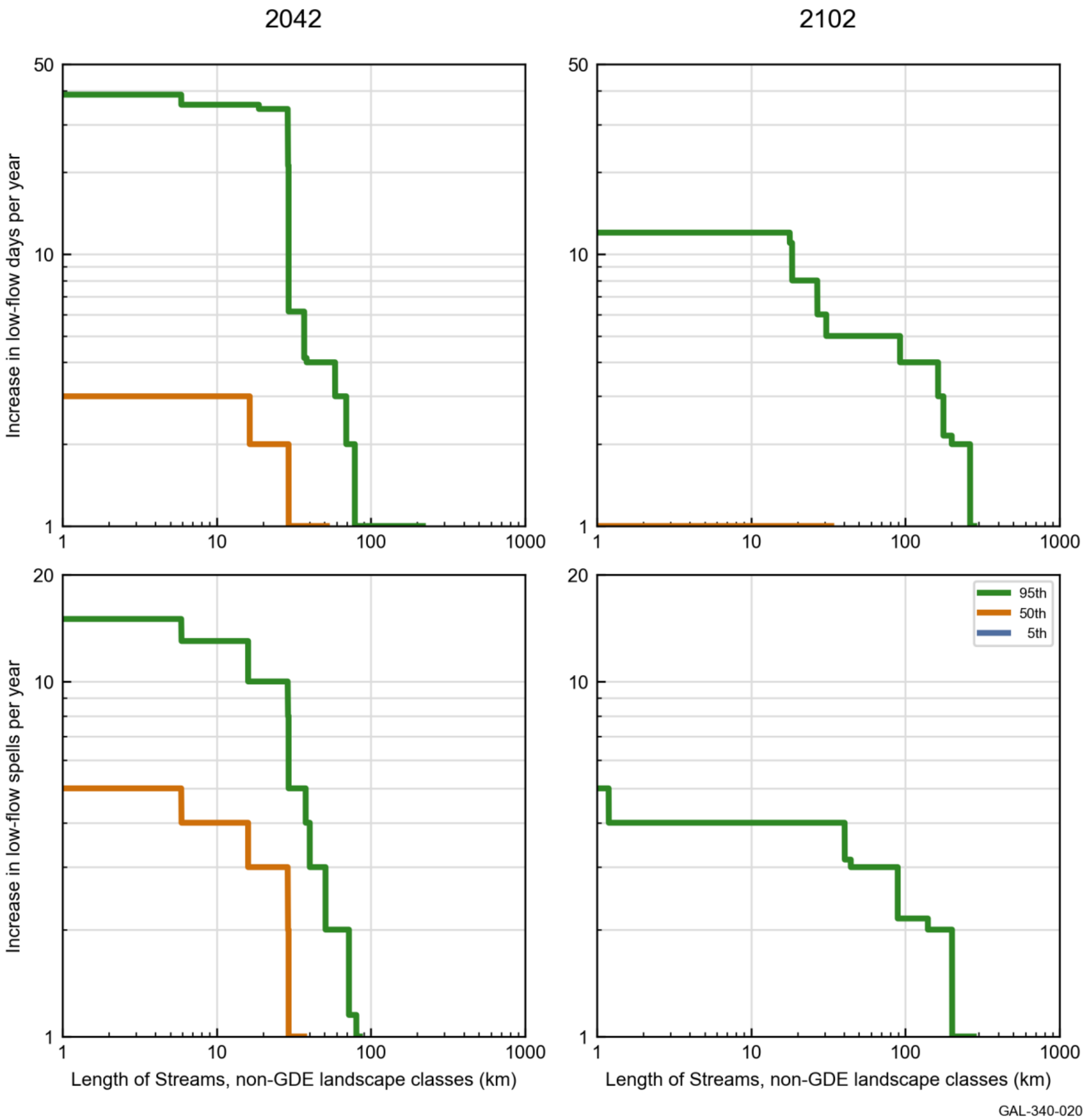

Figure 52 'Streams, non-GDE' landscape group: length (km) of streams potentially exposed to changes to low-flow days per year (LQD) and low-flow spells per year (LME) in 2042 and 2102 in the zone of potential hydrological change

There are no results for the 5th percentile of either of the hydrological response variables in 2042 or 2102 or for the 50th percentile in 2102. This is because, as shown in Table 25 and Table 26, there is zero stream length that exceeds any of the specified thresholds for increases in low-flow days or increases in low-flow spells at the 5th percentile of the hydrological modelling results in both 2042 and 2102 or at the 50th percentile in 2102.
GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 1)

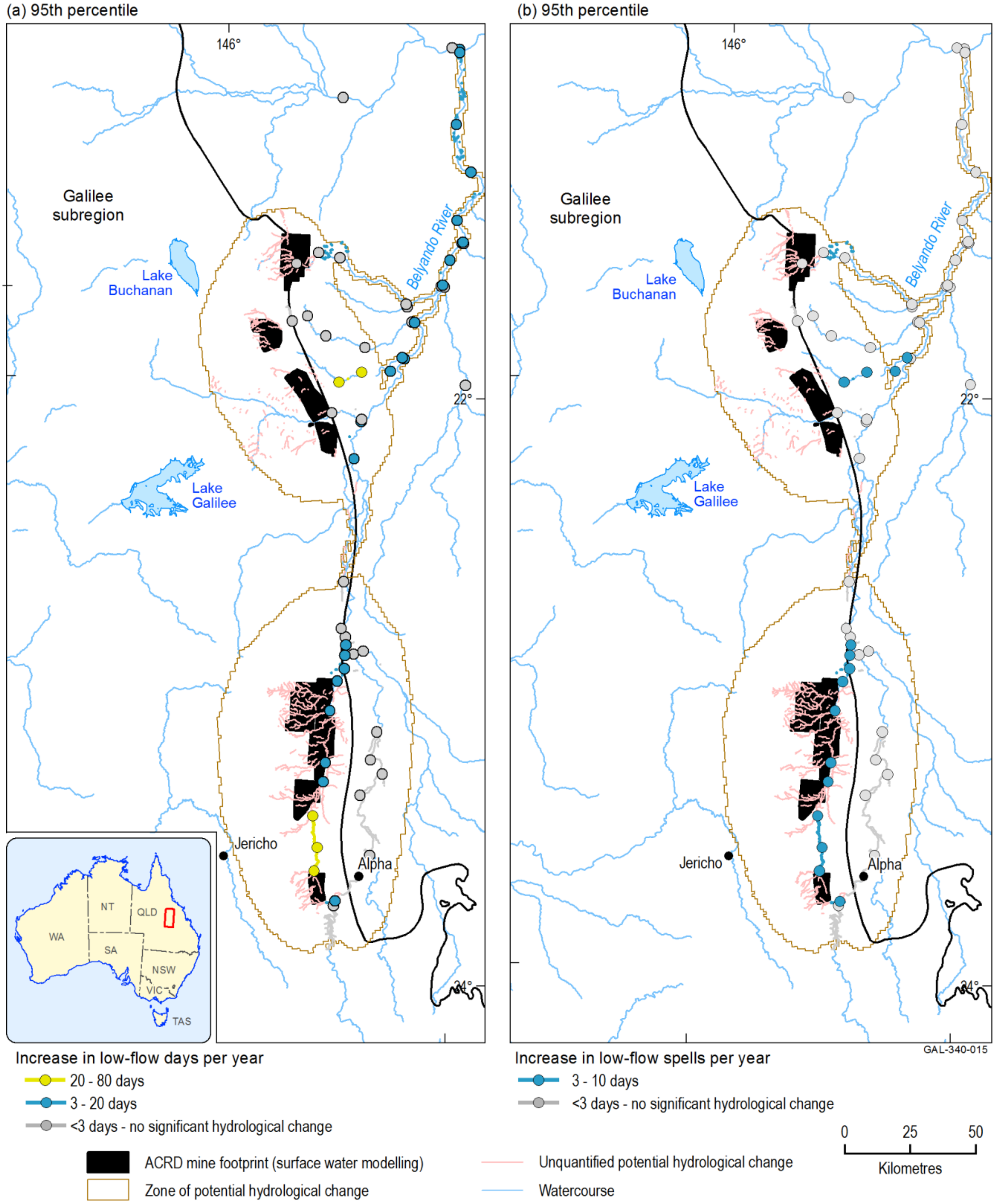

Figure 53 'Streams, non-GDE' landscape group: modelled (a) increases in low-flow days per year (LQD) and (b) increases in low-flow spells per year (LME) in streams in 2042 in the zone of potential hydrological change

ACRD = additional coal resource development; GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 9)

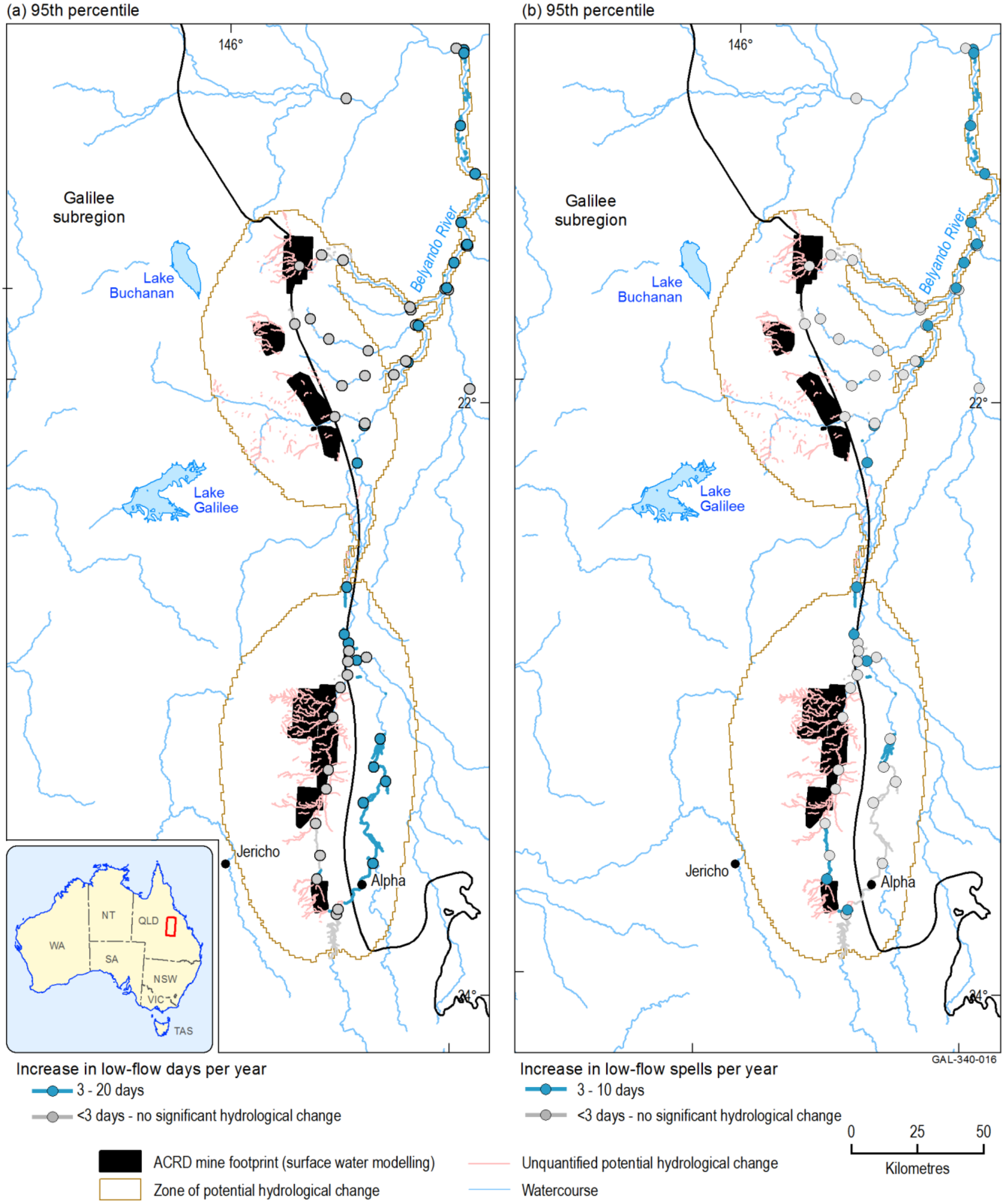

Figure 54 'Streams, non-GDE' landscape group: modelled (a) increases in low-flow days per year (LQD) and (b) increases in low-flow spells per year (LME) in streams in 2102 in the zone of potential hydrological change

ACRD = additional coal resource development; GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 9)

Table 25 'Streams, non-GDE' landscape group: length (km) of streams potentially exposed to varying increases in low-flow days per year (LQD) in 2042 and 2102 in the zone of potential hydrological change

Landscape class	Length in zone of potential hydrological change	Length potentially impacted but not quantified	Length with increases of ≥3 low-flow days per year			Length with increases of ≥20 low-flow days per year			Length with increases of ≥80 low-flow days per year			Length with increases of ≥200 low-flow days per year		
			5th	50th	95th	5th	50th	95th	5th	50th	95th	5th	50th	95th
2013–2042														
Near-permanent, lowland stream	4.0	0	0	0	4.0	0	0	0	0	0	0	0	0	0
Near-permanent, upland stream	1.1	0	0	0	1.1	0	0	0	0	0	0	0	0	0
Temporary, lowland stream	3114	940	0	16.3	56.1	0	0	29.2	0	0	0	0	0	0
Temporary, upland stream	365	88.5	0	0.1	8.0	0	0	0.1	0	0	0	0	0	0
Subtotal	**3484**	**1028**	**0**	**16.4**	**69.2**	**0**	**0**	**29.3**	**0**	**0**	**0**	**0**	**0**	**0**
2073–2102														
Near-permanent, lowland stream	4.0	0	0	0	4.0	0	0	0	0	0	0	0	0	0
Near-permanent, upland stream	1.1	0	0	0	1.1	0	0	0	0	0	0	0	0	0
Temporary, lowland stream	3114	940	0	0	166	0	0	0	0	0	0	0	0	0
Temporary, upland stream	365	88.5	0	0	5.8	0	0	0	0	0	0	0	0	0
Subtotal	**3484**	**1028**	**0**	**0**	**177**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Some totals reported here have been rounded. Columns containing zero values are shown to allow consistent comparison between tables.
GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 1)

Table 26 'Streams, non-GDE' landscape group: length (km) of streams potentially exposed to varying increases in low-flow spells per year (LME) in 2042 and 2102 in the zone of potential hydrological change

Landscape class	Length in zone of potential hydrological change	Length potentially impacted but not quantified	Length with increases of ≥3 day low-flow spells per year			Length with increases of ≥10 day low-flow spells per year			Length with increases of ≥40 day low-flow spells per year			Length with increases of ≥100 day low-flow spells per year		
			5th	50th	95th	5th	50th	95th	5th	50th	95th	5th	50th	95th
2013–2042														
Near-permanent, lowland stream	4.0	0	0	0	0	0	0	0	0	0	0	0	0	0
Near-permanent, upland stream	1.1	0	0	0	0	0	0	0	0	0	0	0	0	0
Temporary, lowland stream	3114	940	0	28.8	45.6	0	0	0	0	0	0	0	0	0
Temporary, upland stream	365	88.5	0	0.1	5.2	0	0	0	0	0	0	0	0	0
Subtotal	**3484**	**1028**	**0**	**28.9**	**50.8**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
2073–2102														
Near-permanent, lowland stream	4.0	0	0	0	4.0	0	0	0	0	0	0	0	0	0
Near-permanent, upland stream	1.1	0	0	0	1.1	0	0	0	0	0	0	0	0	0
Temporary, lowland stream	3114	940	0	0	80.1	0	0	0	0	0	0	0	0	0
Temporary, upland stream	365	88.5	0	0	4.6	0	0	0	0	0	0	0	0	0
Subtotal	**3484**	**1028**	**0**	**0**	**89.8**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Some totals reported here have been rounded. Columns containing zero values are shown to allow consistent comparison between tables.
GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 1)

3.4.5.3 Potential ecosystem impacts

During the receptor impact modelling, the key hydrological determinants of ecosystem function identified by the experts are related to the existence and connectivity of refuge habitats. Surface water serves an important role, with detritus and algae the principal resources that support populations of aquatic invertebrates and fishes. For the 'High-flow macroinvertebrate' receptor impact model, the experts' opinion provides strong evidence that:

- mean mayfly nymph density would decrease by approximately 7% if mean number of low-flow days (LQD) increases by 20 days per year and all other model variables are held at their median values
- mean mayfly nymph density would decrease by approximately 7% if mean annual maximum spell of low-flow days (LME) increases by 20 days per year from 100 to 120 days per year and all other model variables are held at their median values.

The median and 95th percentile estimates of the difference in mayfly nymph density due to additional coal resource development in the 30-year periods preceding 2042 and 2102 indicate no change from densities under the baseline (Figure 55). Results indicate a 5% chance that the hydrological change in some assessment units may translate to a decrease in mayfly nymph density of up to 27 mayfly nymphs per m^2 in 2042 and 2102 due to additional coal resource development (Figure 55).

Overall ecosystem risk that combines understanding from the conceptual model of causal pathways, hydrological modelling and expert opinion was estimated based on the distribution of predicted impacts due to additional coal resource development. The overall level of risk presented here represents the highest level of risk estimated for each assessment unit in the zone. Assessment units where input data exist but the risk thresholds are not exceeded are classed as being 'at minimal risk of ecological and hydrological changes'. Risk thresholds for the 'High-flow macroinvertebrate' receptor impact model are:

- 'at some risk of ecological and hydrological changes' decreases of greater than 20 mayfly nymphs per m^2
- 'more at risk of ecological and hydrological changes' decreases of greater than 30 mayfly nymphs per m^2.

The main non-GDE streams where receptor impact modelling indicated greater than 'at minimal risk' level is the lower part of the Belyando and Suttor rivers, upstream of Lake Dalrymple (Figure 56). Receptor impact variables were not calculated for 3795 (89%) assessment units of this landscape group in the zone of potential hydrological change as surface water hydrological changes were not quantified from the modelling. Of the 475 assessment units (see Section 3.2.4.1.2 for information about assessment units) where receptor impact variables were calculated, 21 (or 4%) are considered to be 'at some risk' and none are considered to be 'more at risk'. Overall, there is some level of risk to less than 0.5% of ecosystems that rely on non-groundwater dependent streams in the zone. A more detailed and local consideration of risk needs to consider location-specific values that the community seeks to protect (e.g. particular assets) as that will help to identify meaningful risk thresholds. It is also necessary to incorporate other lines of evidence, including the magnitude of hydrological change and qualitative models.

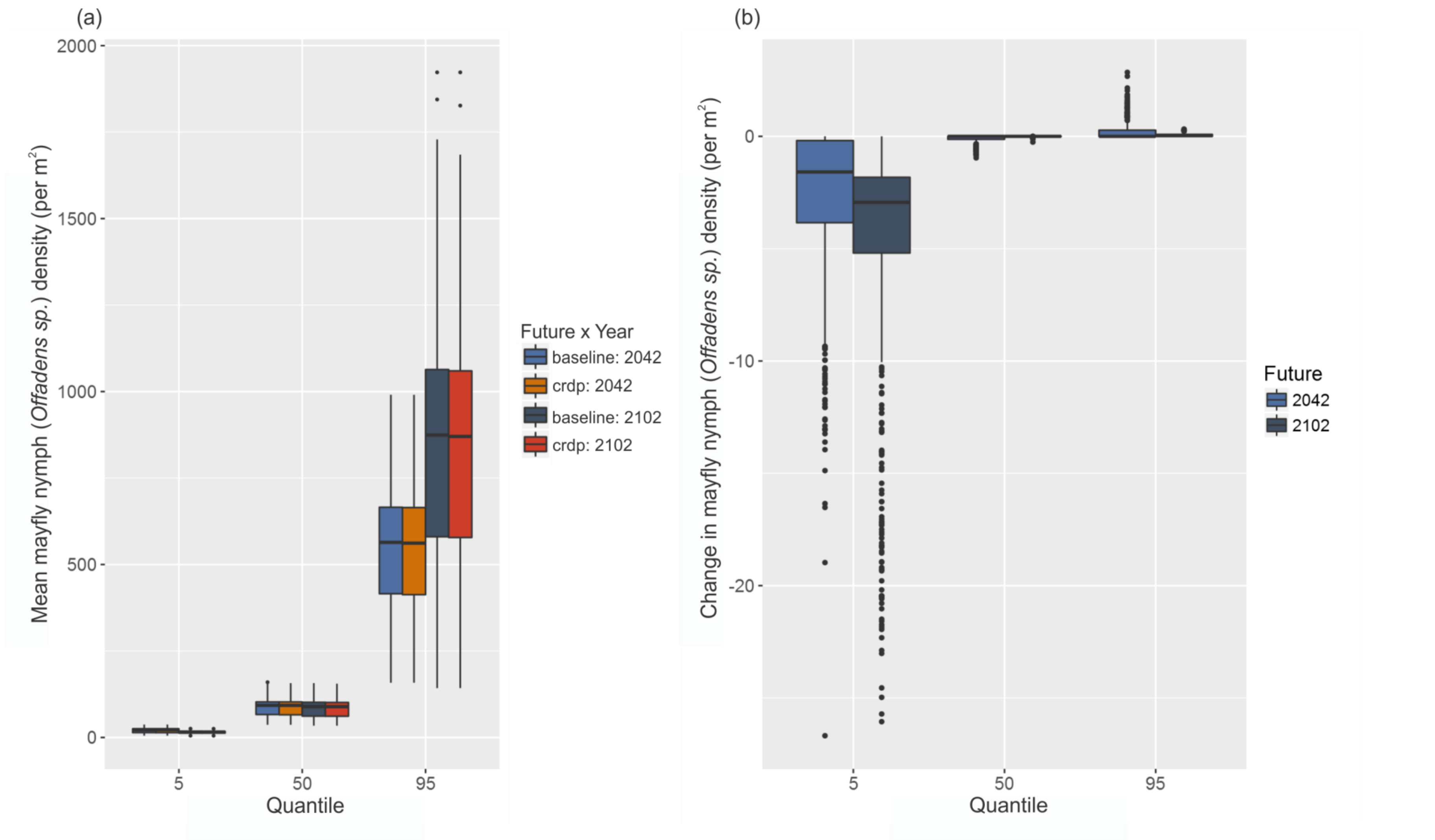

Figure 55 'Streams, non-GDE' landscape group: 'High-flow macroinvertebrate' receptor impact model results showing (a) modelled changes in 2042 and 2102 under the baseline and coal resource development pathway (CRDP) futures and (b) difference between futures in 2042 and 2102

GDE = groundwater-dependent ecosystem

Data: Bioregional Assessment Programme (Dataset 11)

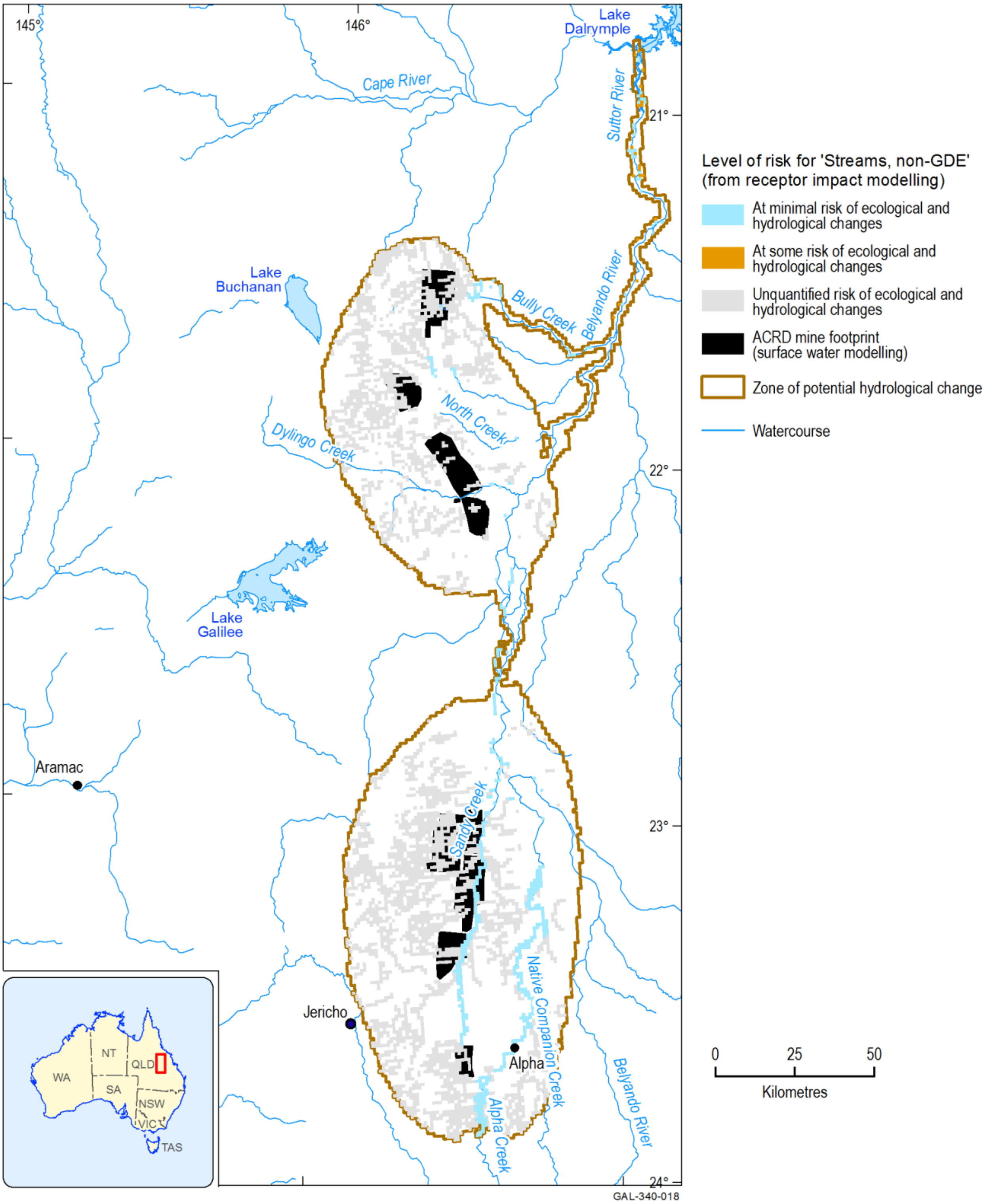

Figure 56 'Streams, non-GDE' landscape group: composite risk to non-groundwater-dependent streams due to additional coal resource development

ACRD = additional coal resource development; GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 11)

3.4.6 'Floodplain, terrestrial GDE' landscape group

3.4.6.1 Description

The 'Floodplain, terrestrial GDE' landscape group includes ecosystems that rely on the subsurface presence of groundwater on a permanent or intermittent basis to maintain growth or to avoid water stress and adverse impacts on condition (Eamus et al., 2006). These landscape classes are broadly defined as groundwater-dependent woodlands or shrublands that occur on floodplains but are not associated with palustrine, lacustrine or riparian wetlands and are classified as Type 3 GDEs (Richardson et al., 2011). The 'Floodplain, terrestrial GDE' landscape group includes two landscape classes: 'Terrestrial GDE', which covers 750 km^2 (or 0.1% of the assessment extent) and 'Terrestrial GDE, remnant vegetation', which covers 78,479 km^2 (or 13% of the assessment extent) (Table 19).

The alluvial aquifers that support these GDEs are formed from particles such as sand, silt and/or clay deposited within channels or on floodplains as a result of highly intermittent flooding processes. Floodplains in the lower parts of catchments tend to be significantly wider and deeper than alluvial floodplains that occur in higher parts of the catchments. These floodplains are commonly underlain by sediments deposited in fluvial (riverine) environments.

The 'Floodplain, terrestrial GDE' landscape group typically occurs in areas that are water limited, with low annual rainfall and high evaporation (companion product 1.1 for the Galilee subregion (Evans et al., 2014)). Low and sporadic rainfall, coupled with high evaporative demand, means that groundwater may be a more reliable source of water for groundwater-dependent vegetation than surface water (Eamus et al., 2006). Several processes acting either individually or in combination control recharge into the alluvial aquifers of this landscape group, including direct infiltration of rainfall, inundation by floodwaters or discharge from surrounding water-bearing geological units.

Shallow groundwater systems in alluvial sediments that underlie the floodplains include perched aquifer systems isolated from the regional watertable and groundwater systems that are connected with deeper aquifers underlying the alluvial sediments (Figure 57). The degree of connection with alluvial sediments is governed by a number of factors, including hydraulic head pressures in the different aquifer systems and whether sedimentary layers in alluvial deposits impede upward groundwater movement from underlying aquifers. If there is sufficient hydraulic head (pressure) in underlying aquifers and a connective pathway, then groundwater may discharge from underlying aquifers into overlying aquifers in alluvial sediments. This may occur if there is not a sufficiently competent aquitard (e.g. thick clay-rich layers) to impede upwards groundwater flow. Deeper aquifers that may discharge to overlying alluvial sediments in the Burdekin river basin include the Clematis Group, Dunda beds (a part of the Rewan Group), upper Permian coal measures and the Joe Joe Group.

Potentiometric mapping of water levels for various aquifers outlined in companion product 2.1-2.2 for the Galilee subregion (Evans et al., 2018a) suggests that there is potential for discharge from deeper aquifers to overlying alluvium where the:

- Clematis Group and Dunda beds aquifers occur near the surface under shallow cover of the Moolayember Formation or where these units directly underlie alluvium in the

Carmichael River valley (in the vicinity and downstream of the Doongmabulla Springs complex)

- Belyando River floodplain is underlain by upper Permian coal measures and Joe Joe Group, in particular, in the vicinity of the confluence of the Carmichael River and Belyando River (including Mellaluka Springs complex and Albro Springs).

Surface water – groundwater interactions in floodplain environments vary depending on local geological conditions (e.g. distribution of sand-rich sediments in the floodplain), hydrogeological conditions and climate. For example, unconfined groundwater levels can rise after heavy rainfall, resulting in temporary discharge to streams. During drier periods, groundwater levels can fall, resulting in surface water recharging the shallow groundwater system.

Regardless of aquifer configuration and connectivity, vegetation can extract groundwater if the watertable, or capillary zone that forms above the watertable, comes within reach of the plant root system (generally at depths of less than 20 m). Most vegetation in the 'Floodplain, terrestrial GDE' landscape group is likely to source groundwater from alluvium and Cenozoic sediments. As a result, GDEs connected to the regional groundwater systems within the zone could be impacted by changes in groundwater (for example, from drawdown or recharge) across a broad area.

The 'Floodplain, terrestrial GDE' landscape group supports over 85 regional ecosystems (REs) in the assessment extent. However, there is considerable uncertainty related to the water regime required to support many of these REs. The nature of the dependency on groundwater is likely to vary among and within vegetation communities as a function of groundwater availability, depth and quality. Additionally, groundwater dependency may be influenced by the age of the vegetation within the REs, for example, younger trees commonly have shorter roots than older trees and thus their groundwater requirements can be met from relatively shallower groundwater systems. The nature of this groundwater dependency may have implications for vegetation recruitment and community persistence, as well as stand structure.

Eucalyptus, *Corymbia* or *Acacia* species are common dominant/co-dominant overstorey species in these REs. Specifically, eucalypt woodlands dominate alluvial river and creek flats of the floodplains. *Eucalyptus brownii* or *E. coolabah* woodlands and open woodlands dominate the alluvial plains. *Acacia* woodlands, including *A. argyrodendron*, *A. cambagei* and *A. harpophylla* are also common on the alluvial plains. Smaller areas of *Corymbia* woodlands are associated with alluvial plains or river terraces. The waxy cabbage palm (*Livistona lanuginosa*) is part of the riparian vegetation along river channels and on floodplains on alluvial duplex soils in a small area of the Burdekin river basin that includes Doongmabulla Springs complex on the Carmichael River. The waxy cabbage palm relies on subsurface availability of groundwater (Pettit and Dowe, 2004; Department of Environment, 2015).

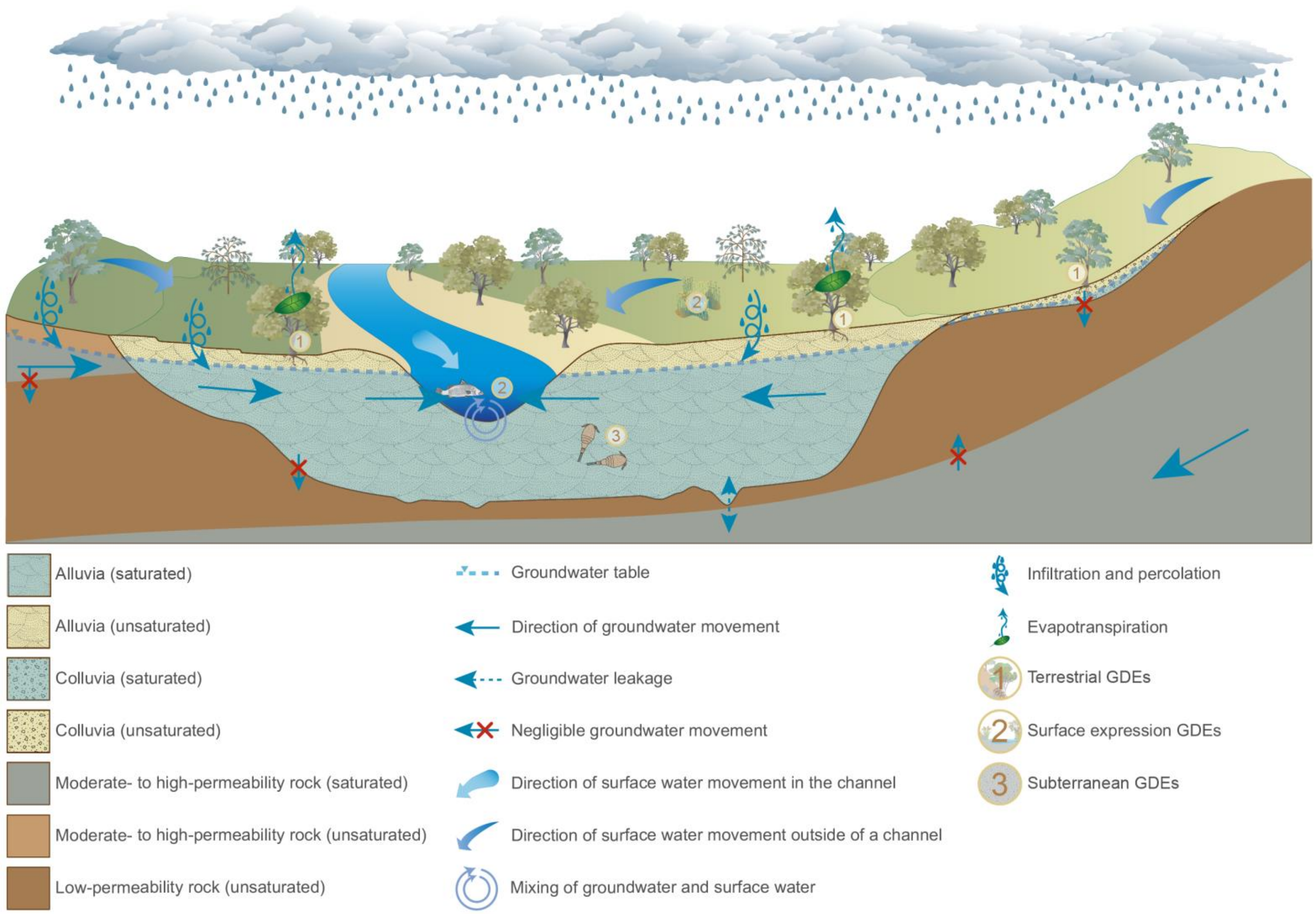

Figure 57 Pictorial conceptual model of the potential interactions between ecosystems and groundwater within alluvial aquifers, such as those of the 'Floodplain, terrestrial GDE' landscape group

GDE = groundwater-dependent ecosystem

Source: adapted from Queensland Department of Science, Information Technology and Innovation (Dataset 4) © The State of Queensland (Department of Science, Information Technology and Innovation) 2015

3.4.6.2 Potential hydrological impacts

The 'Floodplain, terrestrial GDE' receptor impact model focused on the influence that surface water and groundwater hydrology had on trees that support a woodland community, and create local conditions and a microclimate (i.e. shade, leaf litter and soil moisture) that favours mesic vegetation and suppresses xeric vegetation (companion product 2.7 for the Galilee subregion (Ickowicz et al., 2018)).

For the 'Floodplain, terrestrial GDE' receptor impact model, the relevant hydrological response variables are:

- maximum difference in drawdown under the baseline future or under the coal resource development pathway future relative to the reference period (1983 to 2012) (dmaxRef)
- mean annual number of events with a peak daily flow exceeding the threshold (the peak daily flow in flood events with a return period of 2.0 years as defined from modelled baseline flow in the reference period (1983 to 2012)). This metric is designed to be approximately representative of the number of overbank flow events in future 30-year periods (EventsR2.0).

3.4.6.2.1 Groundwater

Vegetation classified as 'Floodplain, terrestrial GDE' in the zone of potential hydrological change is located along the western edge of the zone, upstream of the proposed Hyde Park and China Stone coal mines in the north and upstream of the proposed Kevin's Corner, Alpha and South Galilee coal mines in the south (Figure 58). Vegetation in the Carmichael River valley and Belyando River floodplain in the zone of potential hydrological change are predominantly classified as 'Floodplain, terrestrial GDE'.

Most groundwater-dependent vegetation in the zone of potential hydrological change is classified as 'Floodplain, terrestrial GDE' (2433 km^2 of 3776 km^2, or 64% of groundwater-dependent vegetation in the zone). It is *very unlikely* that additional drawdown in excess of 0.2 m in the uppermost aquifer (i.e. Quaternary alluvium and Cenozoic sediment layer) will affect more than 1967 km^2 of vegetation classified as 'Floodplain, terrestrial GDE' (Table 27 and Figure 59).

The median (50th percentile) estimate of greater than 2 m drawdown due to additional coal resource development is less extensive, potentially affecting 319 km^2 of vegetation classified as 'Floodplain, terrestrial GDE', or 8% of groundwater-dependent vegetation in the zone (Table 27). Additional drawdown in excess of 5 m is *very unlikely* to affect more than 296 km^2 of vegetation classified as 'Floodplain, terrestrial GDE'.

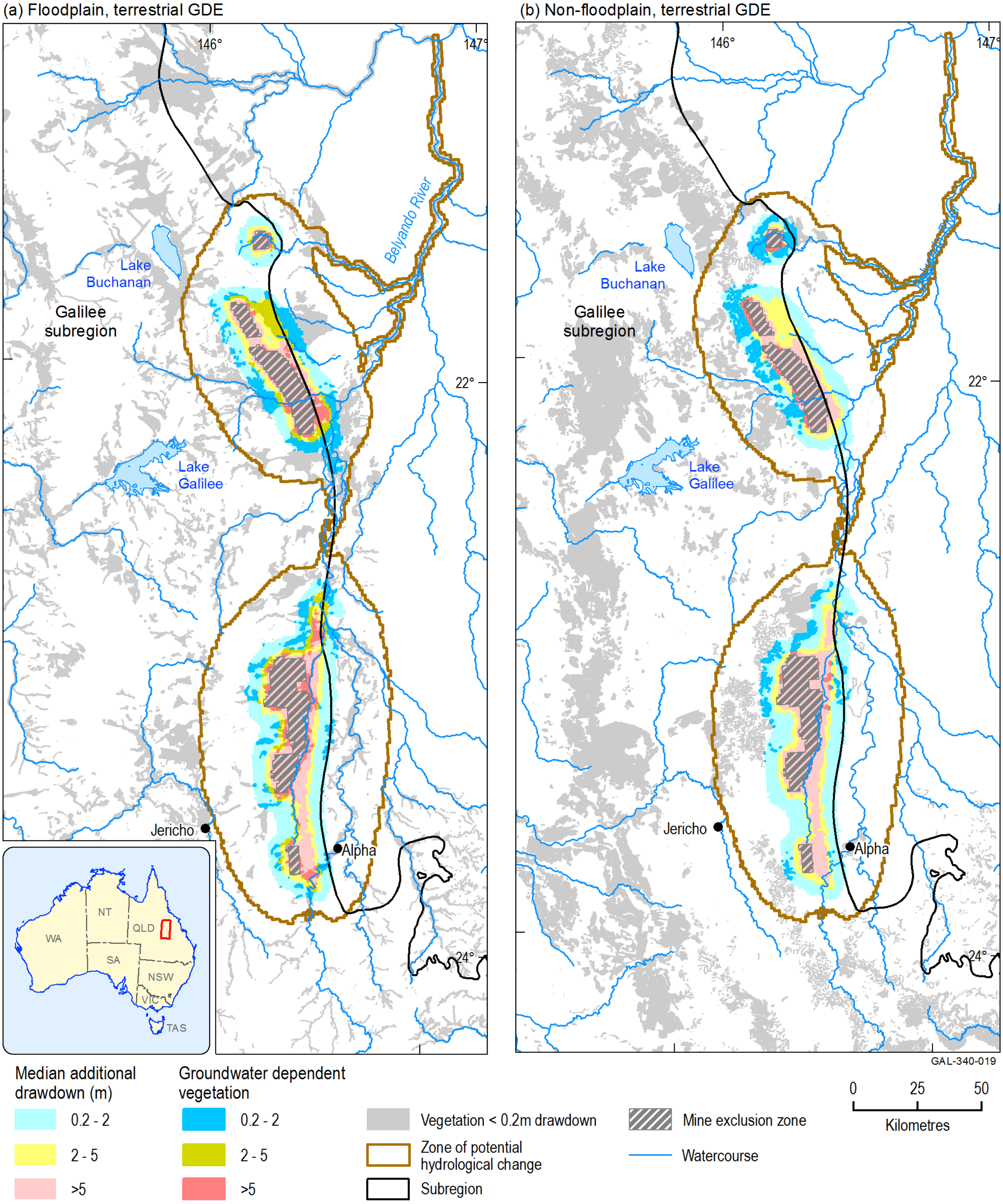

Figure 58 'Floodplain, terrestrial GDE' and 'Non-floodplain, terrestrial GDE' landscape groups: location of groundwater-dependent vegetation in the zone of potential hydrological in the Galilee subregion

GDE = groundwater-dependent ecosystem

Data: Bioregional Assessment Programme (Dataset 1, Dataset 9)

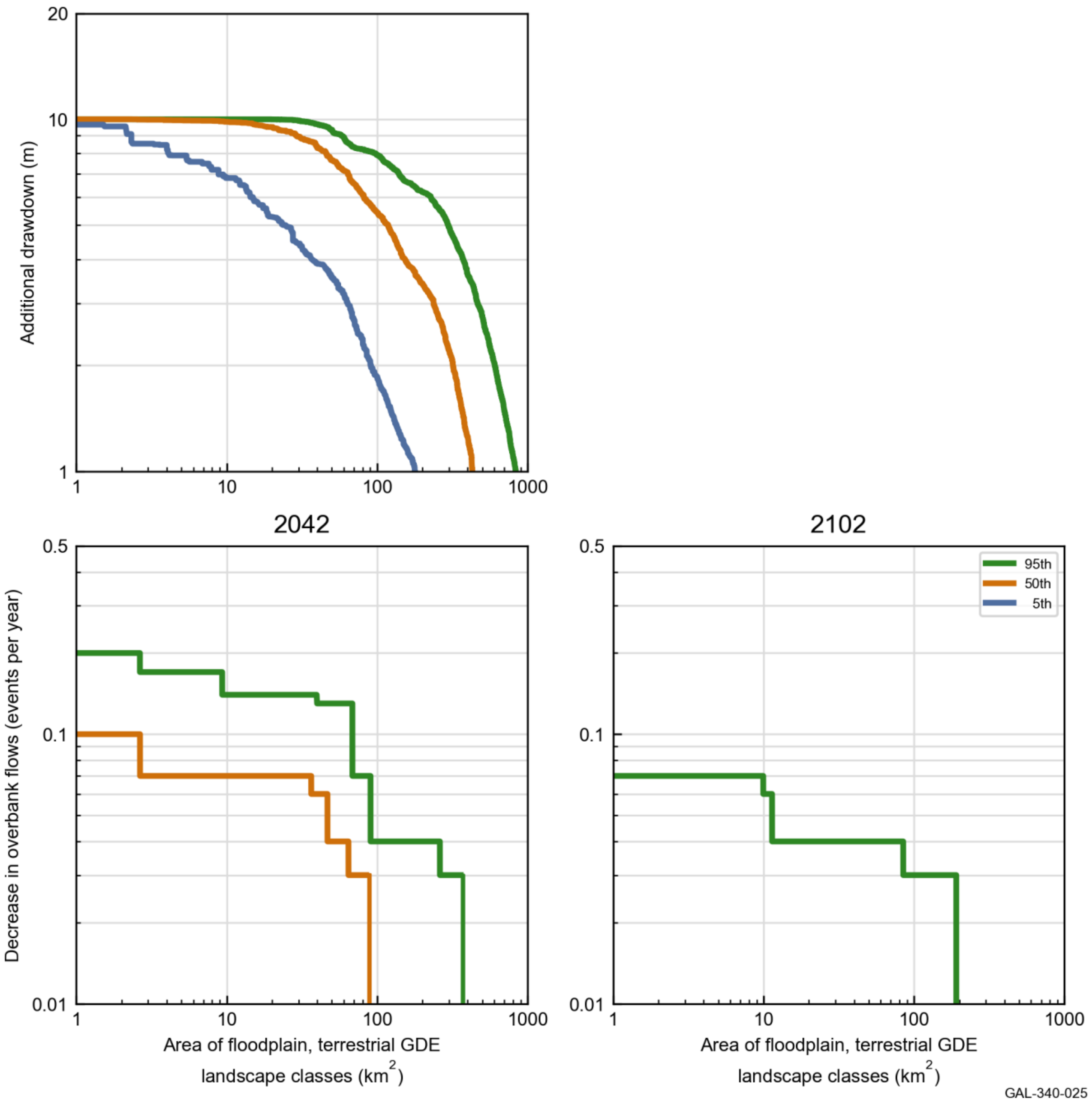

Figure 59 'Floodplain, terrestrial GDE' landscape group: area (km^2) of groundwater-dependent vegetation potentially exposed to varying levels of additional drawdown and changes to recurrence of overbank flows per year (EventsR2.0) in 2042 and 2102 in the zone of potential hydrological change

GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 1)

Table 27 'Floodplain, terrestrial GDE' landscape group: area (km^2) of groundwater-dependent vegetation potentially exposed to varying levels of additional drawdown in the zone of potential hydrological change

Landscape class	Area in assessment extent	Area in zone of potential hydrological change	Area in mine exclusion zone	Area with additional drawdown ≥0.2 m			Area with additional drawdown ≥2 m			Area with additional drawdown ≥5 m		
				5th	50th	95th	5th	50th	95th	5th	50th	95th
Terrestrial GDE	750	75.2	7.4	12.0	20.5	57.2	4.6	11.3	16.9	1.4	5.5	10.8
Terrestrial GDE, remnant vegetation	78,479	2358	189	356	734	1910	86	308	588	23.2	113	286
Subtotal	**79,229**	**2433**	**196**	**368**	**754**	**1967**	**90.6**	**319**	**605**	**24.6**	**118**	**296**

Some totals reported here have been rounded.
GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 1)

3.4.6.2.2 Surface water

Over half of the groundwater-dependent vegetation on floodplains (716 km^2) in the surface water zone of potential hydrological change is potentially impacted but are located on temporary streams that are not modelled. This includes parts of Bimbah, Cattle, Dyllingo and North creeks and the Carmichael and Belyando rivers in the northern zone, and Alpha, Lagoon, Sandy and Tallarenha creeks in the southern zone (Figure 60).

By 2042, it is *very unlikely* that modelled overbank flows will decrease by more than 0.1 events per year, potentially affecting more than 68 km^2 of groundwater-dependent vegetation in the zone of potential hydrological change (Figure 59 and Table 28). This includes vegetation along parts of Alpha, Bully, Sandy and Tallarenha creeks and the Belyando River. A reduction of 0.1 events per year means one fewer overbank flow events every 10 years. Based on the median estimate, the number of modelled overbank flows per year in the 30-year period preceding 2042 is predicted to decrease by more than 0.1 in an area of 3 km^2, 0.05 in an area of 47 km^2 and 0.02 in an area of 85 km^2 of groundwater-dependent vegetation. Predictions in the 30-year period preceding 2102 are less extensive; median estimates of the number of overbank flows per year are predicted to decrease by more than 0.02 in an area of less than 1 km^2 of groundwater-dependent vegetation in the zone of potential hydrological change (Figure 59).

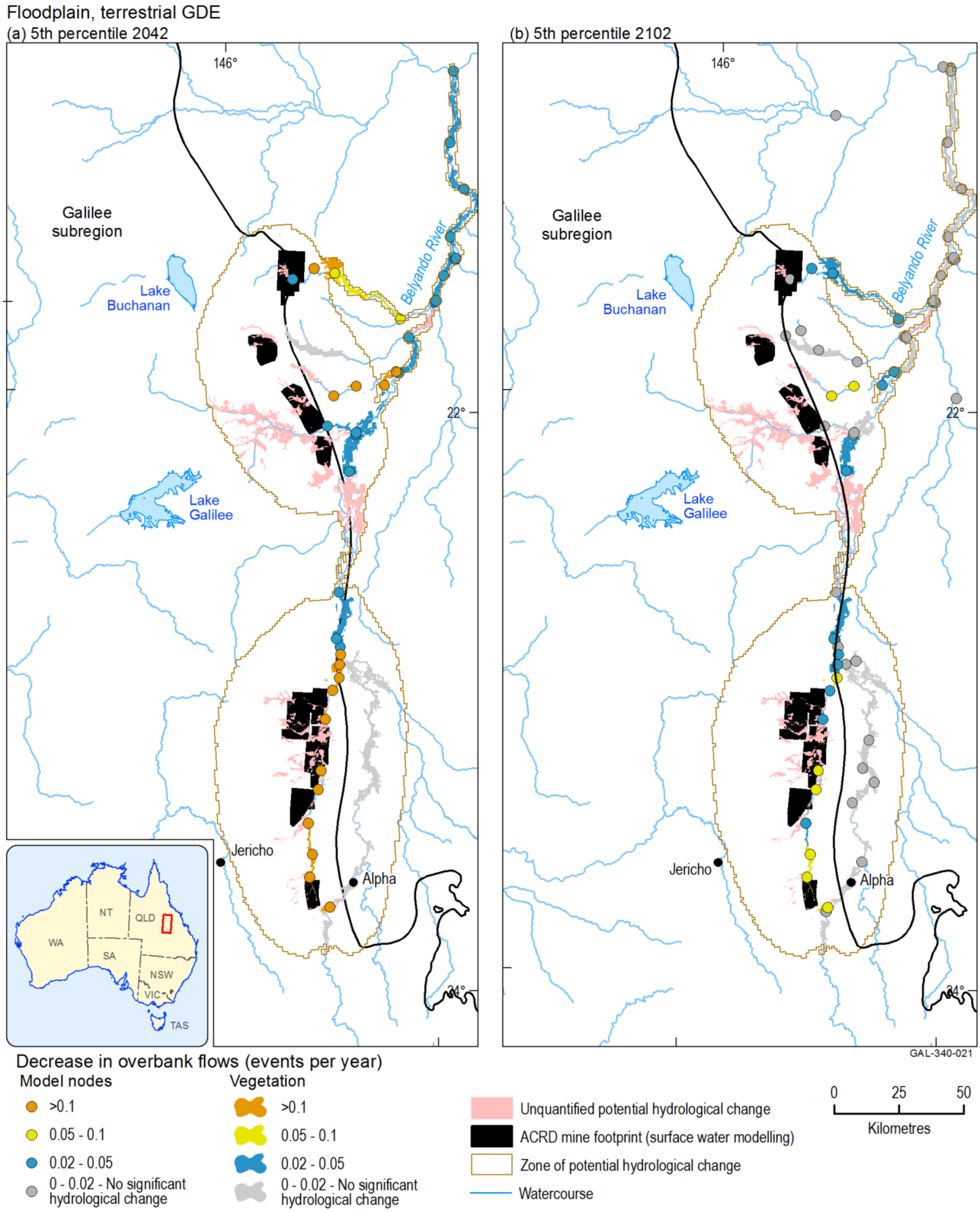

Figure 60 'Floodplain, terrestrial GDE' landscape group: modelled decrease in recurrence of overbank flows per year (EventsR2.0) due to additional coal resource development in 2042 and 2102 in the zone of potential hydrological change

ACRD = additional coal resource development; GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 9)

Table 28 'Floodplain, terrestrial GDE' landscape group: area (km^2) of groundwater-dependent vegetation potentially exposed to changes in recurrence of overbank flows per year (EventsR2.0) due to additional coal resource development in 2042 and 2102 in the zone of potential hydrological change

Landscape class	Area in zone of potential hydrological change	Area potentially impacted but not quantified	Area with ≥0.02 decrease of overbank flows (events per year)			Area with ≥0.05 decrease of overbank flows (events per year)			Area with ≥0.1 decrease of overbank flows (events per year)		
			5th	50th	95th	5th	50th	95th	5th	50th	95th
2013–2042											
Terrestrial GDE	75.2	21.9	14.1	3.1	0	3.5	1.7	0	2.7	0.3	0
Terrestrial GDE, remnant vegetation	2358	694	341	81.6	0	86.8	45.0	0	65.7	2.4	0
Subtotal	**2433**	**716**	**355**	**84.7**	**0**	**90.4**	**46.7**	**0**	**68.4**	**2.7**	**0**
2073–2102											
Terrestrial GDE	75.2	21.9	6.4	0.1	0	1.4	0	0	0	0	0
Terrestrial GDE, remnant vegetation	2358	694	185	0.4	0	10.0	0	0	0	0	0
Subtotal	**2433**	**716**	**191**	**0.5**	**0**	**11.4**	**0**	**0**	**0**	**0**	**0**

Some totals reported here have been rounded.
A reduction of 0.02 events per year means one fewer overbank flow event every 50 years, 0.05 is one fewer overbank flow event every 20 years and 0.1 is one fewer overbank flow event every 10 years.
GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 1)

3.4.6.3 Potential ecosystem impacts

The key hydrological determinants of ecosystem function identified by experts for the 'Floodplain, terrestrial GDE' landscape group are related to overbank flooding and access to relatively shallow alluvial groundwater sources. Tree foliage cover is related to both the rate of groundwater drawdown and its maximum depth, such that tree roots maintain contact with groundwater. Seasonal floods are important contributors to groundwater recharge on floodplains, but could potentially contribute to saturated, anoxic soil conditions that may suppress deep-rooted vegetation.

For the 'Floodplain, terrestrial GDE' receptor impact model, the receptor impact variable is the percent foliage cover of floodplain trees, such as *Eucalyptus*, *Corymbia* or *Acacia* species that dominate the alluvial river and creek flats in the landscape group. Percent foliage cover is the mean annual value measured in a 1 ha plot. The experts' opinion provides strong evidence that:

- antecedent foliage cover has a strong effect on future foliage cover, which reflects the lag in the response of canopy cover to changes in hydrological response variables that would be expected of mature trees with long life spans
- mean percent foliage cover would decrease from approximately 10% by approximately 3% if groundwater depth increases by 6 m and all other model variables are held at their median values
- mean percent foliage cover would increase by less than 1% as the number of flood events with peak daily flows exceeding the 1983 to 2012 2-year return period (EventsR2.0) increases to a maximum value of 1.6 and all other model variables are held at their median values.

There is considerable uncertainty in these predictions, particularly related to the effect of flow regime on percent foliage cover, which means that the large uncertainty in the receptor impact model does not preclude the small possibility of EventsR2.0 having a negligible effect on percent foliage cover.

Median estimates of the difference in percent foliage cover due to additional coal resource development in the 30-year periods preceding 2042 and 2102 indicate no change from that under the baseline (Figure 61). The large uncertainty in the elicited model is reflected by the relatively wide range of model predictions. Results indicate there is a 5% chance that percent foliage cover in some assessment units may decrease by up to 20% in 2042 and up to 11% in 2102, and a 95% chance that it may increase by up to 15% in 2042 and up to 6% in 2102, due to additional coal resource development.

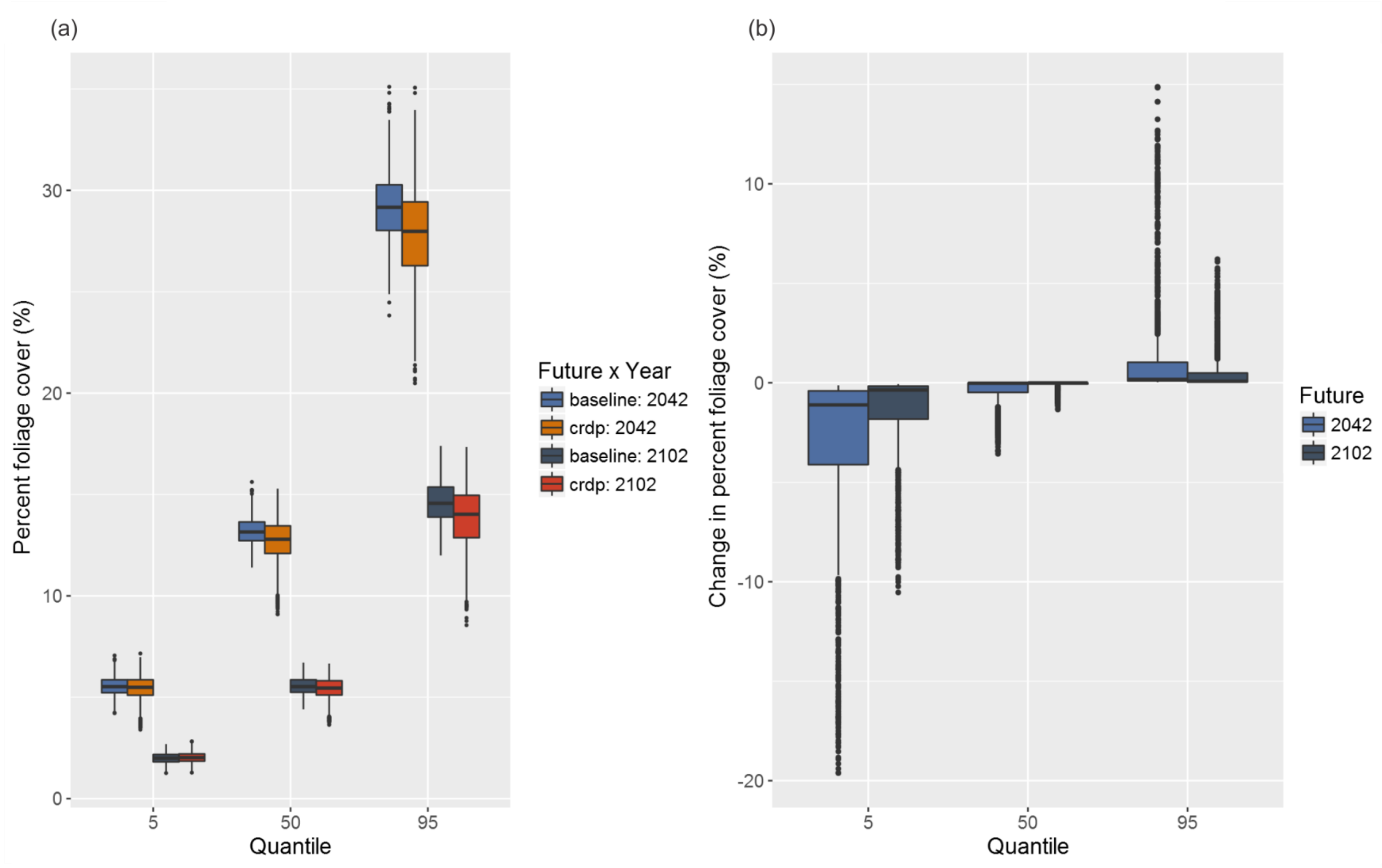

Figure 61 'Floodplain, terrestrial GDE' receptor impact model results showing (a) modelled changes in 2042 and 2102 under the baseline and coal resource development pathway (CRDP) futures and (b) difference between futures in 2042 and 2102

GDE = groundwater-dependent ecosystem

Data: Bioregional Assessment Programme (Dataset 11)

Risk thresholds for the 'Floodplain, terrestrial GDE' receptor impact model are:

- 'at some risk of ecological and hydrological changes' decreases of greater than 5% foliage cover
- 'more at risk of ecological and hydrological changes' decreases of greater than 10% foliage cover.

Groundwater-dependent vegetation where receptor impact modelling indicated greater than 'at minimal risk' level occurs along floodplains associated with Alpha, North, Sandy and Tallarenha creeks and the Belyando and Carmichael rivers (Figure 62). Receptor impact variables were not calculated for 5503 (59%) assessment units for this landscape group in the zone of potential hydrological change (where hydrological changes were not quantified). Of the 1119 assessment units where receptor impact variables were calculated, 105 (or 9%) are considered to be 'at some risk' and 141 (or 13%) are considered to be 'more at risk'. Thus, there is some level of risk to 22% of assessment units with receptor impact modelling, and 3% of the total number of assessment units when both the quantified and unquantified changes are considered for this landscape group. The groundwater-dependent ecosystems on floodplains where there is some level of risk occur along parts of Alpha, North, Sandy and Tallarenha creeks and the Belyando and Carmichael rivers. A more detailed and local consideration of risk needs to consider the specific values at the locations that the community are seeking to protect (e.g. particular assets) because that will help to identify meaningful analysis thresholds. It is also necessary to incorporate other lines of evidence that include the magnitude of the hydrological change and the information from the qualitative mathematical models.

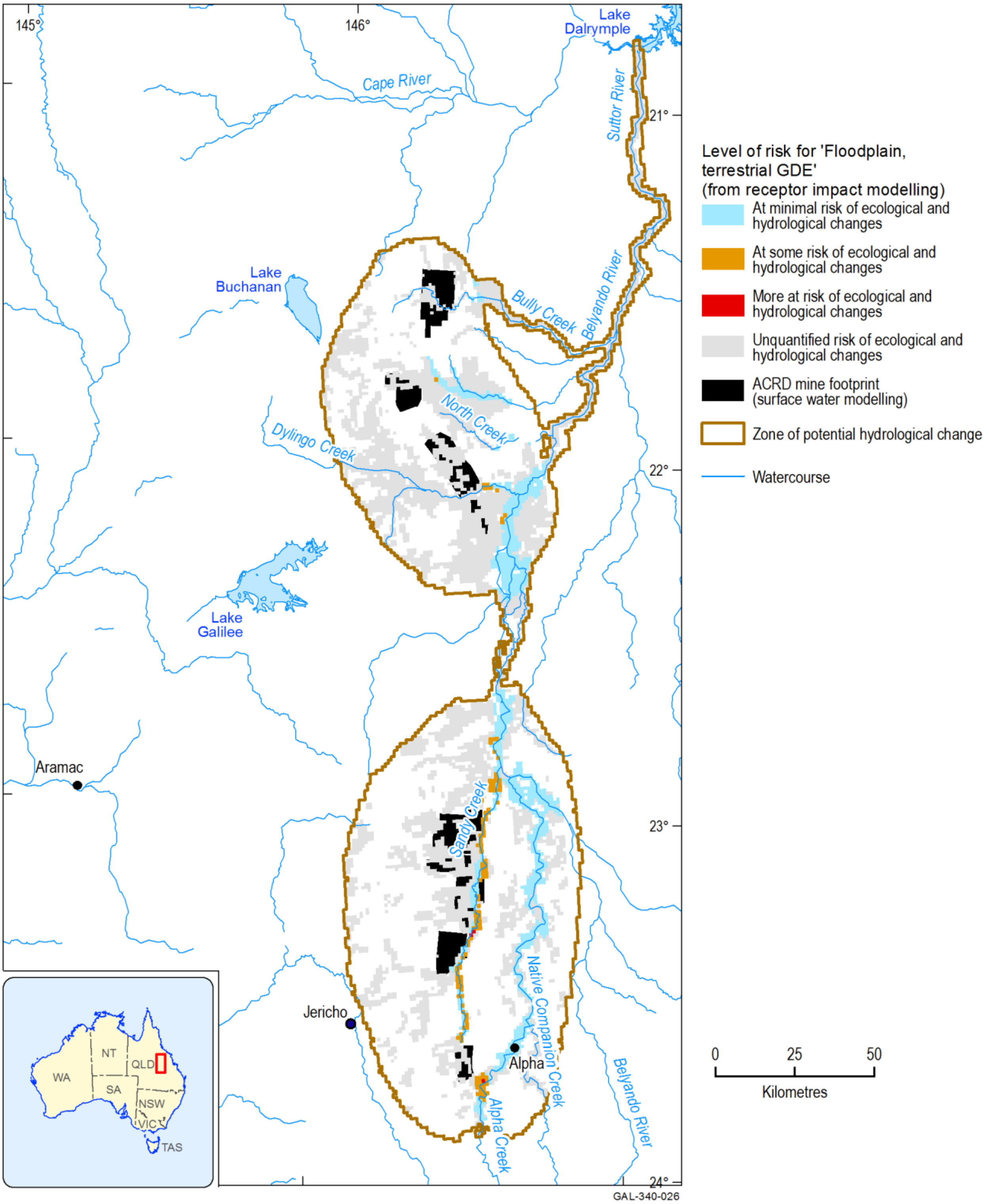

Figure 62 'Floodplain, terrestrial GDE' landscape group: composite risk to groundwater-dependent vegetation due to additional coal resource development

ACRD = additional coal resource development; GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 11)

3.4.7 'Non-floodplain, terrestrial GDE' landscape group

3.4.7.1 Description

The 'Non-floodplain, terrestrial GDE' landscape group includes ecosystems that rely on the subsurface presence of groundwater and are not associated with floodplains or palustrine, lacustrine or riparian wetlands. Non-floodplain landforms include clay plains, loamy and sandy plains, inland dunefields, or areas of fine-grained and coarse-grained sedimentary rocks. The 'Non-floodplain, terrestrial GDE' landscape group includes two landscape classes: 'Non-floodplain, terrestrial GDE' that covers 268 km^2 (or less than 0.1% of the assessment extent) and 'Non-floodplain, terrestrial GDE, remnant vegetation' that covers 20,532 km^2 (or 3% of the assessment extent) (Table 19).

A high-level conceptual model for unconfined, permeable rock aquifers is relevant to this landscape group (Figure 63). Near-surface discharge may occur where there is a change in geology or topography (e.g. at a geological boundary between sandstone and an underlying shale) or at the break of slope at the base of hills or ranges. Here, terrestrial vegetation can access relatively shallow unconfined aquifers via the capillary zone.

Terrestrial vegetation may source groundwater up-gradient of the contact between the plains and elevated areas such as mesas and ironstone jump-ups (Figure 63). Terrestrial GDEs in these areas are likely to support regional ecosystems (REs) dominated by *Corymbia* spp. (DSITI, 2015). Terrestrial vegetation also may source groundwater where it discharges at the break of slope of sandstone ranges. A less common type of permeable rock aquifer occurs in basalts, which stores and transmits groundwater through vesicles, fractures and weathered zones. Terrestrial vegetation may source groundwater at the edge of basalt plains and hills. Connectivity of groundwater in the zone of potential hydrological change is complicated as the Galilee subregion contains a series of stacked groundwater systems, as described in detail in companion product 2.1-2.2 (Evans et al., 2018a) and Section 2.3.2 of companion product 2.3 (Evans et al., 2018b) for the Galilee subregion. The Galilee Basin groundwater system, which includes the Rewan Group and Clematis Group, is the most likely source of groundwater for the 'Non-floodplain, terrestrial GDE' landscape group in the zone of potential hydrological change. In particular:

- shallow perched aquifers in weathered Cenozoic sediments, where groundwater is shallow or discharges at the break of slope, or where percolating groundwater is perched over relatively impermeable layers such as clay or shale
- groundwater flow in unconfined aquifers within the capillary zone of plants or discharging to the surface in weathered sedimentary rock units dominated by sandstone (e.g. Clematis Group, Dunda beds (part of Rewan Group), Colinlea Sandstone, and sandstone beds in the Joe Joe Group).

GDEs that access regional groundwater systems within the zone of potential hydrological change may be impacted by changes in groundwater (for example, from drawdown or recharge) across a broad area. However, some proportion of these GDEs will not be connected to the regional watertable and will be independent of broader-scale changes due to the additional coal resource development.

The water requirements and the degree of groundwater dependency of the vegetation in the 'Non-floodplain, terrestrial GDE' landscape group will depend on a number of factors, including:

- vegetation age and rooting distribution of plants and how this enables access to the watertable
- depth to the watertable and spatial and temporal (seasonal) variation in the watertable level
- groundwater quality.

Vegetation within the 'Non-floodplain, terrestrial GDE' landscape group can typically use deep roots to access groundwater in the capillary zone above the watertable via capillary action or hydraulic lift. Previous research has revealed links between groundwater depth and tree condition, but critical thresholds that lead to rapid and potentially irreversible change have been difficult to quantify. For example, maximum rooting depth in a global study was 5.2±0.8 m for sclerophyllous shrubland and forest, 7.0±1.2 m for trees and 9.5±2.4 m for desert vegetation (Canadell et al., 1996). Further, the mean maximum rooting depth of 11 species of sclerophyllous trees was 12.6±3.4 m (Canadell et al., 1996). This includes tree species such as *Eucalyptus marginata,* where roots have been reported at depths of around 40 m (Dell et al., 1983).

Tree water uptake of groundwater from deeper watertable levels is generally less than where the watertable is shallower (e.g. Zencich et al., 2002; O'Grady et al., 2006a, 2006b). Standing water levels for 98 bores associated with the 'Non-floodplain, terrestrial GDE' landscape group averaged 37.3 m and ranged between 157 m and 0.3 m. The rate of drawdown can also be critical to vegetation survival. Plant roots can only remain in contact with a declining watertable if the rate of decline does not exceed potential root growth rate; 3 to 15 mm/day for arid shrub and grass species (Naumberg et al., 2005). However, there is a critical knowledge gap in the ecohydrology of groundwater-dependent vegetation, particularly relating to the sensitivity of vegetation to changes in the rate of groundwater drawdown across different watertable depths (and whether this response is linear).

The 'Non-floodplain, terrestrial GDE' landscape group supports 90 REs in the assessment extent. There is considerable uncertainty related to the water regime required to support many of these REs. However, the nature of the dependency on groundwater is likely to vary among and within vegetation communities as a function of groundwater availability, depth and quality (companion product 2.1-2.2 for the Galilee subregion (Evans et al., 2018a)).

The majority of REs have *Eucalyptus* and/or *Corymbia* species as dominant/co-dominant in the upper storey. A smaller number of REs have *Acacia* and/or *Melaleuca* species as dominant/co-dominant.

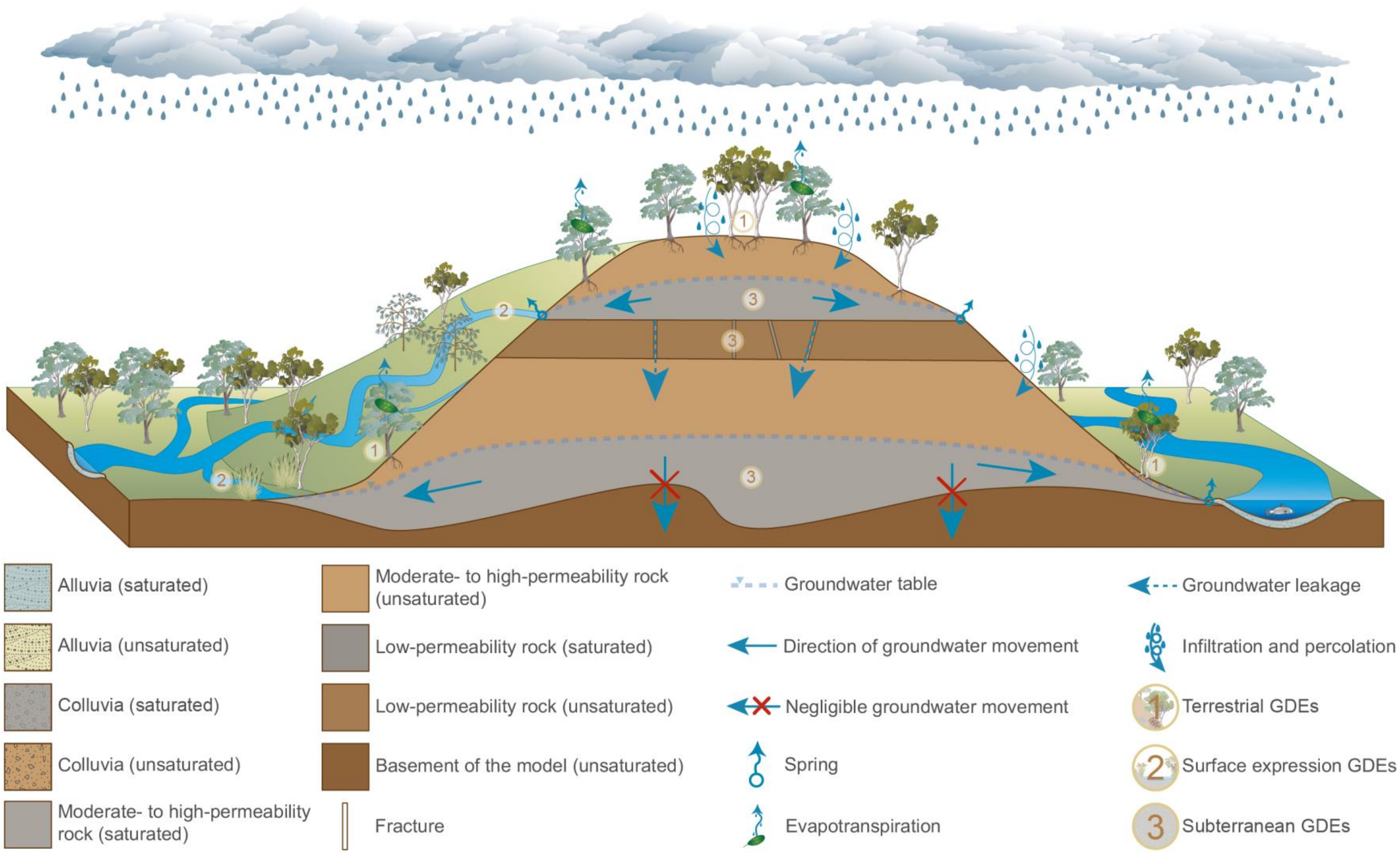

Figure 63 Conceptual model of permeable rock aquifers, many of which are relevant for the 'Non-floodplain, GDE' landscape group

GDE = groundwater-dependent ecosystem

Source: adapted from Queensland Department of Science, Information Technology and Innovation (Dataset 4) © The State of Queensland (Department of Science, Information Technology and Innovation) 2015

3.4.7.2 Potential hydrological impacts

The 'Non-floodplain, terrestrial GDE' receptor impact model focused on recruitment dynamics associated with groundwater-dependent native tree species, with the primary production associated with tree canopies providing a range of (as yet unspecified) ecological functions (companion product 2.7 for the Galilee subregion (Ickowicz et al., 2018)). The qualitative model identified a negative response to groundwater drawdown.

For the 'Non-floodplain, terrestrial GDE' receptor impact model, one hydrological response variable was identified: maximum difference in drawdown under the baseline future or under the coal resource development pathway future relative to the reference period (1983 to 2012) (dmaxRef).

3.4.7.2.1 Groundwater

Most of the remaining groundwater-dependent vegetation in the zone of potential hydrological change is classified as 'Non-floodplain, terrestrial GDE' landscape group (1189 km^2 of 3776 km^2, or 31% of groundwater-dependent vegetation in the zone). It is *very unlikely* that additional drawdown in excess of 0.2 m in the upper aquifer will affect more than 1143 km^2 of vegetation classified as 'Non-floodplain, terrestrial GDE' (Figure 64 and Table 29).

The median (50th percentile) estimate of greater than 2 m drawdown due to additional coal resource development is less extensive, potentially affecting 69 km^2 of vegetation in the 'Non-floodplain, terrestrial GDE' landscape group, or 2% of groundwater-dependent vegetation in the zone (Table 29). Additional drawdown in excess of 5 m is *very unlikely* to affect more than 68 km^2 of vegetation in the 'Non-floodplain, terrestrial GDE' landscape group.

Vegetation in the 'Non-floodplain, terrestrial GDE' landscape group in the zone of potential hydrological change 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).

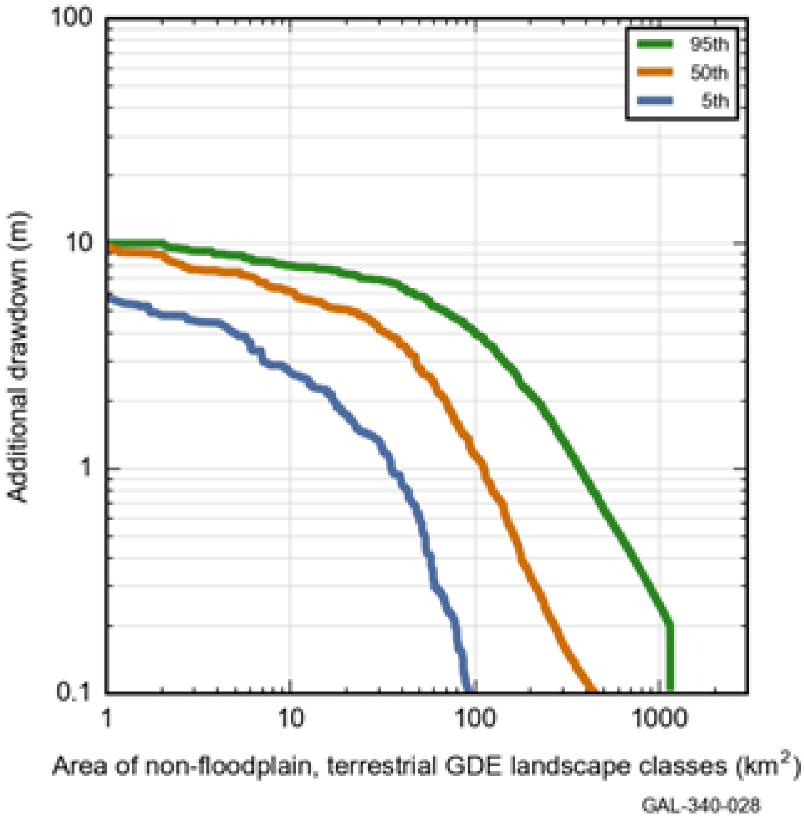

Figure 64 'Non-floodplain, terrestrial GDE' landscape group: area of groundwater-dependent vegetation potentially exposed to varying levels of additional drawdown in the zone of potential hydrological change

GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 1)

Table 29 'Non-floodplain, terrestrial GDE' landscape group: area (km²) of groundwater-dependent vegetation potentially exposed to varying levels of additional drawdown in the zone of potential hydrological change

Landscape class	Area in assessment extent	Area in zone of potential hydrological change	Area in mine exclusion zone	Area with additional drawdown ≥0.2 m			Area with additional drawdown ≥2 m			Area with additional drawdown ≥5 m		
				5th	50th	95th	5th	50th	95th	5th	50th	95th
Non-floodplain, terrestrial GDE	268	5.5	0.1	0.2	0.7	5.4	0.1	0.1	0.5	0	0.1	0.1
Non-floodplain, terrestrial GDE, remnant vegetation	20,532	1184	42.2	78.6	268	1137	16.9	68.5	217	1.7	21.0	67.8
Subtotal	**20,800**	**1189**	**42.3**	**78.8**	**268**	**1143**	**17.0**	**68.7**	**218**	**1.7**	**21.1**	**67.9**

Some totals reported here have been rounded.
GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 1)

3.4.7.2.2 Surface water

Vegetation in the 'Non-floodplain, terrestrial GDE' landscape group is located outside of alluvial river and creek flats and is therefore not affected by changes to surface water flow regimes.

3.4.7.3 Potential ecosystem impacts

The key hydrological determinants of ecosystem function identified by experts for the 'Non-floodplain, terrestrial GDE' landscape group relate to access to relatively shallow groundwater sources. Tree foliage cover is related to both the rate of groundwater drawdown and its maximum depth, such that tree roots maintain contact with groundwater.

For the 'Non-floodplain, terrestrial GDE' receptor impact model, the receptor impact variable is the percent foliage cover of trees, such as *Corymbia* species that overlie shallow local aquifers that typically discharge at the break of slope of sandstone ranges or basalts. Percent foliage cover is the mean annual value measured in a 0.25 ha plot. The experts' opinion provides strong evidence that:

- antecedent foliage cover has a strong effect on future foliage cover, which reflects the lag in the response of foliage cover to changes in hydrological response variables that would be expected of mature trees with long life spans
- mean percent foliage cover would decrease from approximately 48% by approximately 1% if groundwater depth increases by 10 m and all other model variables are held at their median values.

Median estimates of the difference in percent foliage cover due to additional coal resource development in the 30-year periods preceding 2042 and 2102 indicate less than 1% change from under the baseline (Figure 65). The large uncertainty in the elicited model is reflected by the range of model predictions. Results indicate there is a 5% chance that percent foliage cover in some assessment units may decrease by up to 12% in 2042 and 2102, and a 95% chance that it may increase by up to 11% in 2042 and 2102, due to additional coal resource development.

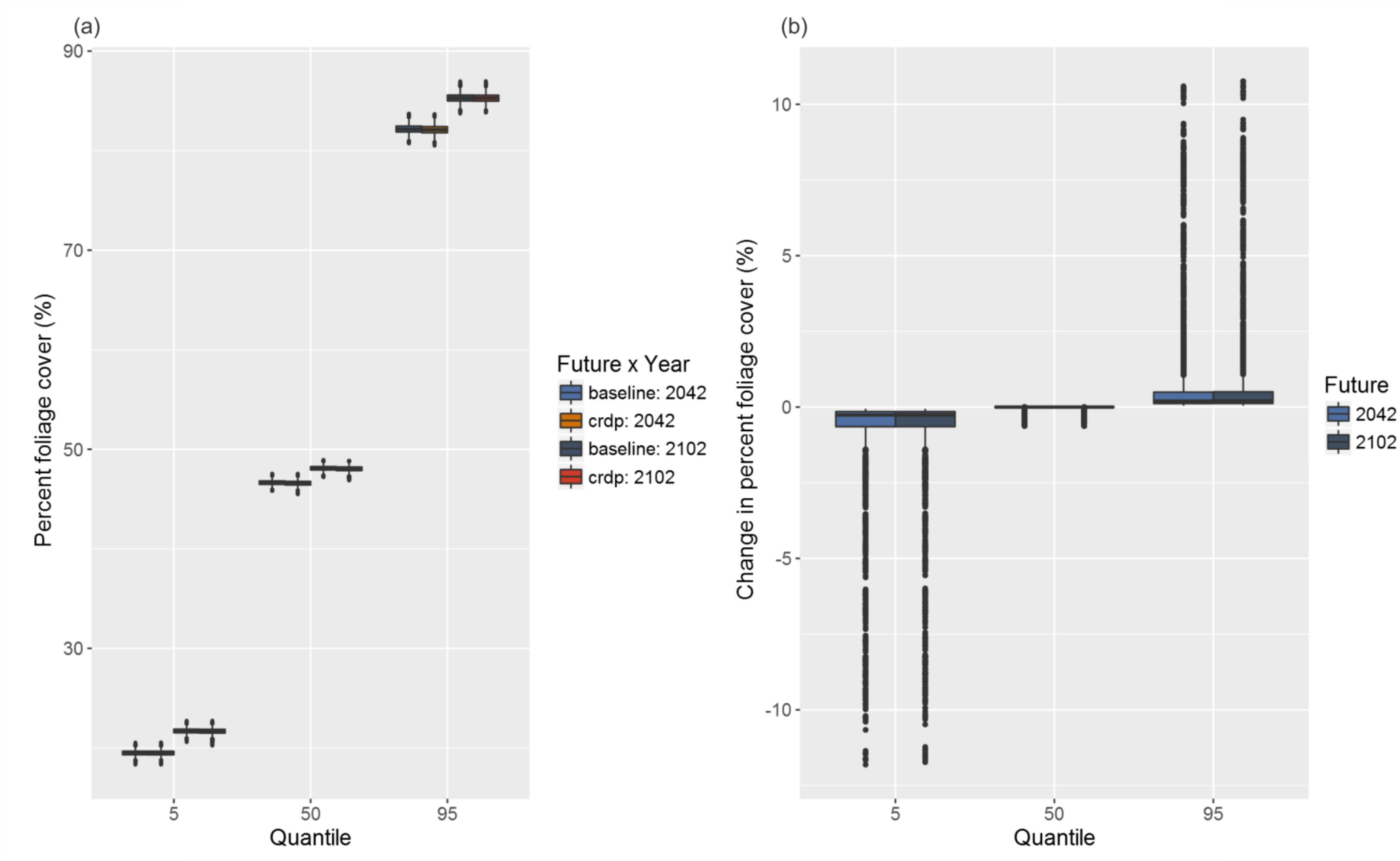

Figure 65 'Non-floodplain, terrestrial GDE' receptor impact model results showing (a) modelled changes in 2042 and 2102 under the baseline and coal resource development pathway (CRDP) futures and (b) difference between futures in 2042 and 2102

GDE = groundwater-dependent ecosystem

Data: Bioregional Assessment Programme (Dataset 11)

Risk thresholds for the 'Non-floodplain, terrestrial GDE' receptor impact model are:

- 'at some risk of ecological and hydrological changes' decreases of greater than 5% foliage cover
- 'more at risk of ecological and hydrological changes' decreases of greater than 10% foliage cover.

Groundwater-dependent ecosystems where receptor impact modelling indicated greater than 'at minimal risk' occur in upland areas near the proposed coal mines in the northern (Carmichael, China Stone, Hyde Park) and southern (South Galilee, Alpha, Kevin's Corner) areas of the zone of potential hydrological change (Figure 66). Receptor impact variables were not calculated for 452 (11%) assessment units for this landscape group in the zone of potential hydrological change. Of the 3792 assessment units where receptor impact variables were calculated, 194 (or 5%) are considered to be 'at some risk' and 21 (less than 1%) are considered to be 'more at risk'. Overall, there is some level of risk to about 5% of groundwater-dependent ecosystems located near the proposed mines, but outside of floodplains where additional drawdown is greatest in the zone of potential hydrological change.

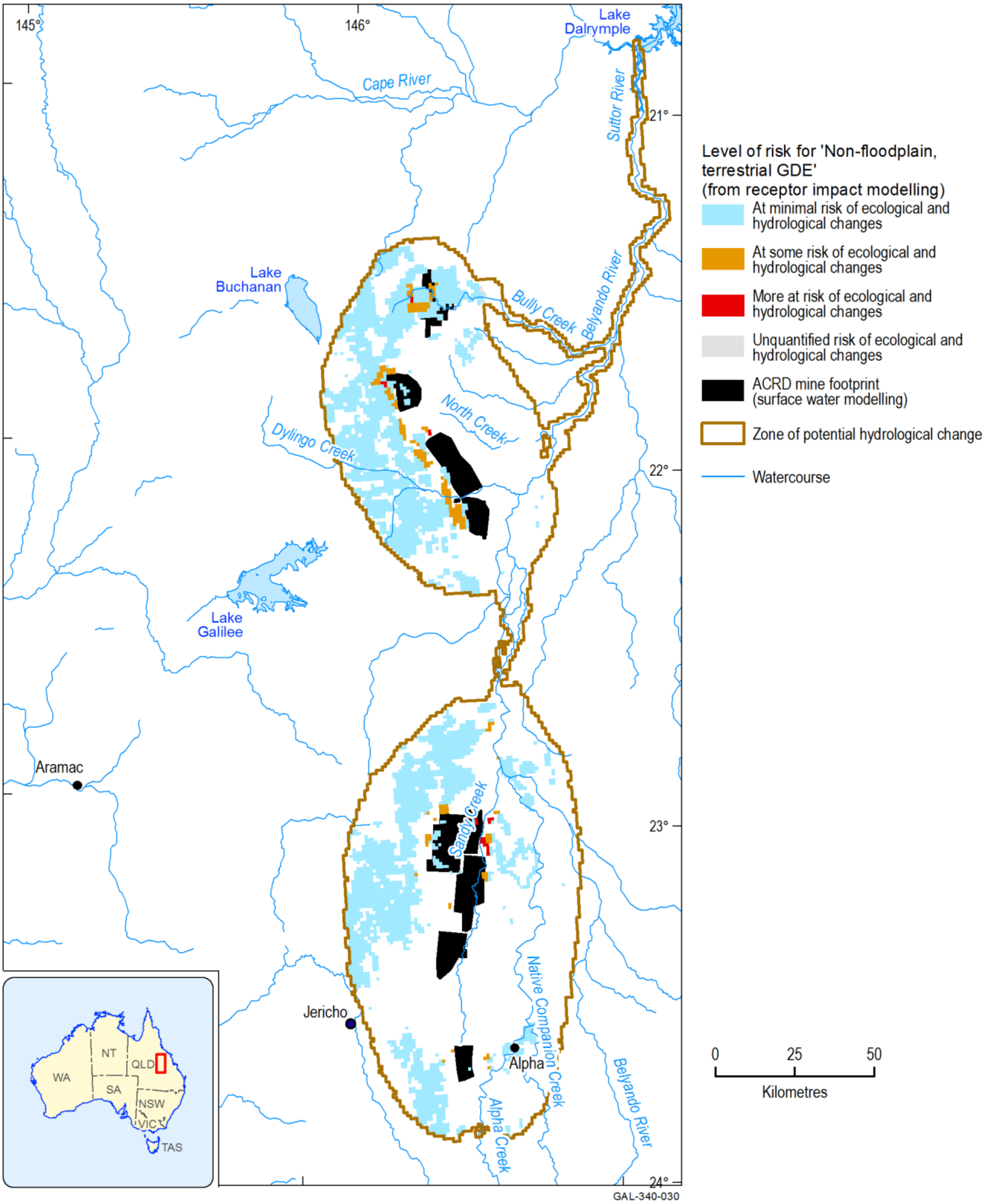

Figure 66 'Non-floodplain, terrestrial GDE' landscape group: composite risk to groundwater-dependent vegetation due to additional coal resource development

GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 11)

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3.5 Impacts on and risks to water-dependent assets

Summary

Ecological water-dependent assets

Of the 3982 ecological assets in the Galilee subregion's register of water-dependent assets, 241 are in the zone of potential hydrological change. The location of assets, including the potential distribution of various species, was determined at a single point-in-time when the asset register was established. Asset locations were not continually updated throughout this bioregional assessment (BA).

All of the 241 assets within the zone intersect with one or more of the potentially impacted landscape groups, and 65 of these assets are confined entirely to the zone. The 3741 ecological assets outside the zone are considered to be *very unlikely* (less than a 5% chance) to be impacted by modelled additional coal resource development in the Galilee subregion.

Of the 241 ecological assets in the zone, 148 meet criteria for potential hydrological impacts that place them 'more at risk of hydrological changes' due to additional coal resource development. That is, all or part of the area of these assets occurs within one or more of the potentially impacted landscape groups and there is a greater than 50% chance of the modelled hydrological change exceeding the defined threshold in one or more of the hydrological response variable(s) relevant to the landscape group(s).

The 'more at risk of hydrological changes' assets include 106 groundwater-dependent ecosystems. Also among the 'more at risk' assets are potential habitat for 12 threatened species listed under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), 2 EPBC Act-listed threatened ecological communities, 7 regional ecosystems listed under Queensland's *Nature Conservation Act 1992* and 4 parks and reserves.

A concentration of ecological assets occurs in the 'Springs' landscape group. Although the 200 springs in this landscape group occupy less than 1% of the area of the zone of potential hydrological change, 48 ecological assets (20% of all ecological assets in the zone) intersect with it, including 16 that are confined entirely to the zone. Doongmabulla Springs complex is the location where most of these assets occur, and they include the springs themselves, the Doongmabulla Mound Springs Nature Refuge, habitat (potential distribution) of an EPBC Act-listed threatened ecological community – 'The community of native species dependent on natural discharge of groundwater from the Great Artesian Basin' – and habitat (potential species distribution) of two EPBC Act-listed threatened plant species.

The majority of available evidence indicates that the groundwater source for the assets associated with the Doongmabulla Springs complex is primarily the Clematis Group aquifer.

Two alternative groundwater model conceptualisations applied in this BA predict that 181 of the 187 springs in the Doongmabulla Springs complex have a 5% chance of experiencing additional groundwater drawdown in excess of 0.2 m. Consideration of multiple lines of evidence – including signed digraphs, qualitative mathematical models, interpretation of various products derived from archived Landsat imagery and expert ecological knowledge of the threatened plant species – indicates that this level of drawdown will impact the ecological functioning of some ecological assets; however, there will be considerable variation in response across springs and spring complexes.

Economic water-dependent assets

There are 129 economic water-dependent assets within the Galilee assessment extent, all of which are classed as either water access rights or basic water rights (stock and domestic). Of these, 96 are associated with groundwater management areas and 33 with surface water management areas. Each asset consists of a variable number of asset 'elements', which are typically individual groundwater bores or surface water extraction points.

The hydrological changes due to the seven coal mines modelled for the BA of the Galilee subregion will potentially impact six of these water-dependent economic assets, comprising five groundwater assets and one surface water asset. The surface water asset is a basic water right under the Burdekin River water resource plan, and has three separate water extraction points (elements) within the zone of potential hydrological change. Two of these asset elements are on the Belyando River, and another is on the headwater tributary of Native Companion Creek. The nearest BA surface water modelling nodes to these three extraction points indicate that it is *very unlikely* (less than 5% chance) that this surface water asset will experience reductions in annual flow volume greater than 1.5%. However, there are a wide range of modelled increases in the number of zero-flow days that may affect this asset, with several locations modelled to exceed increases of 250 zero-flow days per year (at the 95th percentile of all modelling results).

Three of the groundwater economic assets potentially impacted due to additional coal resource development are associated with the Clematis Group aquifer, and are managed as part of the *Water Plan (Great Artesian Basin) 2006* (although this plan was superseded in September 2017). These include a basic water right (stock and domestic) and a water access right in the Barcaldine North 3 Groundwater Management Unit, and a basic water right in the Barcaldine East 4 Groundwater Management Unit. Of the 92 individual groundwater bores in Barcaldine East 4 that are in the Galilee assessment extent, it is *very likely* (greater than 95% chance) that 5 bores will experience between 0.2 and 2 m of drawdown, and *very unlikely* that more than 22 bores will be affected by this level of drawdown. Similarly, for the 162 bores in the assessment extent associated with the basic water right in Barcaldine North 3, the number of bores modelled to experience between 0.2 to 2 m of drawdown varies from 7 bores (5th percentile) to 93 bores (95th percentile). However, it is *very unlikely* that the maximum drawdown that will affect any of the bores associated with these three groundwater economic assets will exceed 1.5 m.

Two other groundwater economic assets in the asset register are likely to be impacted by drawdown associated with the seven coal mines in the modelled coal resource development pathway (CRDP). These are a water access right and a basic water right that are unassigned to a particular management subgroup (for BA purposes). The 15 individual bores associated with the unassigned water access right occur in three main clusters (and may source water from different aquifers), including near the towns of Jericho and Alpha (i.e. their respective town water supply bores). Of the four bores that source water from the Clematis Group aquifer near Jericho, drawdowns of between 0.2 and 2 m are modelled at the 50th and 95th percentiles, although the maximum amount of drawdown is less than 1 m for all results. Potential impacts for many of the bores near Alpha cannot be quantified due to limitations of the groundwater modelling approach, and thus remain a key knowledge gap.

The list of groundwater economic assets compiled for this BA was not exhaustive, and many bores known from the Queensland bore database were not included (for various reasons) in the water-dependent asset register. There are approximately 105 such bores within the zone of potential hydrological change that are interpreted to source water from the near-surface unconfined aquifer (Quaternary alluvium and other Cenozoic sediments). However, 26 of these are company-owned monitoring bores, 6 others are known to be ‘abandoned and destroyed’ and 3 bores occur in the mine exclusion zone. Of the remaining bores analysed here, it is *very likely* that 7 will experience at least 0.2 m of drawdown, and *very unlikely* that more than 52 bores will be affected by this level of drawdown. Drawdowns of greater than 2 m are modelled to affect between 2 and 13 bores (at the 5th and 95th percentiles, respectively), which may trigger the need for ‘make good’ provisions to be negotiated.

A further 31 bores near the central-eastern margin of the Galilee subregion source groundwater from the Clematis Group aquifer but are not in the asset register (this also excludes some company monitoring bores). The maximum modelled drawdown for these bores is about 1 m. Under Queensland’s *Water Act 2000*, 5 m of drawdown may trigger the need for ‘make good’ provisions in consolidated rock aquifers. There are also 34 non-company bores within the zone of potential hydrological change that tap the upper Permian coal measures, the main coal mining (and dewatering) target layer in the Galilee Basin. Based on the results from the analytic element model (AEM) for the Galilee subregion (which uses a simplified conceptualisation of the regional hydrogeology), most of these bores are predicted to experience drawdown in excess of 20 m.

Sociocultural assets

Of the 151 sociocultural assets in the Galilee assessment extent, only four partially intersect with the zone of potential hydrological change. Three of these assets were nominated from the Register of the National Estate, including Doongmabulla Springs (natural indicative place), Lake Buchanan and catchment (natural registered place) and the Old Bowen Downs Road (historic indicative place). Consultation with several local Indigenous groups in the Galilee subregion identified 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 Indigenous assets it was not possible to determine if they occur within the zone of potential hydrological change.

3.5.1 Overview

This section describes the risks to ecological, economic and sociocultural assets that are potentially impacted by hydrological changes arising in response to future pathways of coal mining and coal seam gas (CSG) development in the Galilee subregion. Potential impacts on and risks to water-dependent assets as a consequence of additional coal resource development were assessed using a variety of approaches. These were:

- **overlay analysis**, whereby asset polygons (or lines or points) are intersected with the zone of potential hydrological change to identify whether the asset is potentially subject to changes in groundwater and/or surface water
- **qualitative mathematical models**, derived from expert elicitation, showing the predicted response of ecosystem variables to (cumulative) changes in hydrological response variables
- **receptor impact models**, which are statistical models derived from expert elicitation, showing the predicted response of specified receptor impact variables (ecosystem indicators) to changes in hydrological response variables.

Overlay analysis can identify assets that are unlikely to be impacted by surface water or groundwater changes, based on the lack of intersection with the zone of potential hydrological change.

As described in companion product 2.7 for the Galilee subregion (Ickowicz et al., 2018), receptor impact models were developed for two landscape groups (‘Floodplain, terrestrial GDE’ and ‘Non-floodplain, terrestrial GDE’) and a combination of an additional two landscape groups (i.e. the ‘Streams, GDE’ and ‘Streams, non-GDE’ landscape groups were combined to form the ‘Streams’ supergroup). Each landscape group consists of a number of landscape classes as described in companion product 2.3 for the Galilee subregion (Evans et al., 2018b). Qualitative mathematical models were developed for each of the three landscape groups/supergroups identified above. In addition, a qualitative mathematical model was developed for the ‘Springs’ landscape group (refer to Table 19 in Section 3.4).

Overlay analysis was used to identify assets that are *very unlikely* to be impacted by surface water or groundwater changes due to additional coal resource development, based on lack of intersection of the asset with the zone of potential hydrological change. The zone of potential hydrological change for the Galilee subregion is defined in Section 3.3. The impact and risk analysis uses different probabilities (5th, 50th (median) and 95th percentiles) to indicate the likelihood of hydrological changes to different types of water-dependent assets in the zone of potential hydrological change. The 5th percentile identifies the magnitude of hydrological change that is *very likely* (greater than 95% chance); the 95th percentile defines the magnitude of hydrological change (though not necessarily ecological impact) that is *very unlikely* (less than 5% chance).

The analysis of impacts and risks considers each group of water-dependent assets separately – ecological, economic and sociocultural. Each subgroup of ecological assets is also described separately – ‘Surface water feature’, ‘Groundwater feature (subsurface)’ and ‘Vegetation’. To improve clarity, assets in the ‘Surface water feature’ and ‘Vegetation’ subgroups are further divided into classes. Assets in the 'Surface water feature' subgroup are divided into six classes and those in the 'Vegetation' subgroup are divided into three classes (Table 30).

Economic assets are separated into two classes: 'Groundwater management zone or area (surface area)' and 'Surface water management zone or area (surface area)'. Potential hydrological changes to all groundwater bores (as listed in the Queensland bore database) in the zone of potential hydrological change that are not included as part of the water-dependent asset register are also considered.

The intersection of sociocultural assets with the zone of potential hydrological change is then described, and potential for impact assessed.

The broad spatial extent and considerable number of water-dependent assets mean that not all assets are mapped and assessed in this section. Instead the focus is on a subset of the assets, which are deemed to be 'more at risk of hydrological changes' (i.e. those assets associated with higher probabilities of larger hydrological changes). However, in Section 3.5.2.7 a case study is provided to illustrate the type of detailed analysis that is possible for individual assets, based on the integration of multiple lines of available hydrological and ecological evidence. The specific asset example focuses on the 'potential distribution of Black Ironbox' (BA asset identification number 2126 in the water-dependent asset register), which occurs in the northern part of the surface water zone of potential hydrological change and is associated with reaches of the Suttor River upstream of Lake Dalrymple.

The impact and risk analysis uses a combination of summary tables, maps of modelled hydrological change within assets, plots of cumulative asset extent and degree of modelled hydrological change and narrative. The spatial extent and number of water-dependent assets mean that not all assets can be mapped and assessed in this product. Potential impacts to individual assets can be visually explored at www.bioregionalassessments.gov.au/explorer/GAL/assets.

Importantly, it should be noted that asset information, such as the potential distribution of species and communities, was not updated during the course of this BA. Rather, the potential species distributions were used for BA purposes as they were known (i.e. as mapped) at a particular point in time, which was current at the time when the modelling was started for this BA. However, any subsequent changes in mapped distributions as a result of later field studies or further analysis have not been incorporated into the findings of this Assessment.

Finally, this section describes impacts on and risks to assets due to potential hydrological changes for only that part of the coal resource development pathway (CRDP) that was able to be modelled (i.e. the seven proposed coal mines in the central-eastern Galilee subregion, as described in Section 3.3). Section 3.6 provides commentary for that part of the CRDP that was not modelled.

3.5.2 Ecological assets

3.5.2.1 Description

A total of 3982 water-dependent ecological assets were identified in the assessment extent of the Galilee subregion during the development of the asset register (refer to companion product 1.3 for the Galilee subregion (Sparrow et al., 2015) for details). This list of assets was compiled from 24 different sources that included 8 natural resource management organisations as well as the analysis of data provided by national, state and regional databases. Most assets came from the *National atlas of groundwater dependent ecosystems* (GDE Atlas) (Bureau of Meteorology, 2012). As part of this BA, each asset was assessed to ensure that it was water dependent (refer to companion product 1.3 (Sparrow et al., 2015) for details). Note that a reappraisal of available evidence on the water dependency of the assets was undertaken by the Assessment team after the publication of companion product 1.3 (Sparrow et al., 2015). This process led to the inclusion of ten additional assets in the water-dependent asset register that were not originally included (see Bioregional Assessment Programme, 2017); all of these were assets in the 'Habitat (potential species distribution)' class.

Of the 3982 assets in the assessment extent, a total of 241 ecological assets (about 6%) occur wholly or partly in the zone of potential hydrological change of the Galilee subregion (Table 30). These 241 ecological assets and their exposure to potential hydrological change due to additional coal development are the focus of this section. Of the 241 ecological assets, 9 assets are in the 'Groundwater feature (subsurface)' subgroup, 34 are in the 'Surface water feature' subgroup, and the majority (198) are in the 'Vegetation' subgroup.

The key ecological assets in the zone of potential hydrological change include a large number of groundwater-dependent ecosystems (GDEs) supporting a wide variety of vegetation types ranging from Eucalypt open forest to tussock grassland; surface water features, including riverine wetlands and springs; the potential habitat of various threatened species listed under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act); the distribution of EPBC-Act listed threatened ecological communities; the distribution of endangered regional ecosystems listed under Queensland's *Nature Conservation Act 1992*; and the locations of several national parks, nature refuges and regional reserves. Some notable individual ecological assets include Doongmabulla Springs (and the associated Doongmabulla Mound Springs Nature Refuge), Scartwater Aggregation on Suttor Creek, vegetation associations supported by subsurface groundwater from the Clematis Group aquifer, Carmichael River GDE and the habitat (potential species distribution) of the black-throated finch (southern subspecies) (*Poephila cincta cincta*), blue devil (*Eryngium fontanum*) and salt pipewort (*Eriocaulon carsonii*).

Of the 241 ecological assets in the zone of potential hydrological change, there are 65 (27%) that only occur wholly within the zone (Table 30). Each of these ecological assets is regarded as having increased importance because the additional coal resource development in the Galilee subregion has the potential to globally impact the condition of that asset. Specifically, there are no areas outside the zone where any of these 65 assets occur.

Table 30 Ecological assets within the assessment extent and the zone of potential hydrological change of the Galilee subregion, according to asset subgroup and class

Asset subgroup	Asset class	Number of water-dependent assets in assessment extent	Number of water-dependent assets in the zone	Number of water-dependent assets confined to the zone
Surface water feature	Floodplain	5	2	0
	Lake, reservoir, lagoon or estuary	45	4	2
	Marsh, sedgeland, bog, spring or soak	109	6	5
	River or stream reach, tributary, anabranch or bend	152	3	0
	Waterhole, pool, rock pool or billabong	957	3	2
	Wetland, wetland complex or swamp	171	16	3
	Subtotal	**1439**	**34**	**12**
Groundwater feature (subsurface)	Aquifer, geological feature, alluvium or stratum	151	9	8
	Subtotal	**151**	**9**	**8**
Vegetation	Groundwater-dependent ecosystem	2201	162	39
	Habitat (potential species distribution)	186	36	6
	Riparian vegetation	5	0	0
	Subtotal	**2392**	**198**	**45**
Total		**3982**	**241**	**65**

Data: Bioregional Assessment Programme (Dataset 1)

There are 3741 water-dependent ecological assets that are within the assessment extent but outside the zone of potential hydrological change. Each of these assets is considered to be *very unlikely* (less than 5% chance) to be impacted due to additional coal resource development in the Galilee subregion.

In the following sections, assets that intersect the zone of potential hydrological change and are potentially at risk of impact due to additional coal resource development are identified. The magnitude of risk to an asset is broadly equated to the magnitude of the potential hydrological changes in potentially impacted landscape groups with which the asset is associated. For BA purposes, an asset was deemed to be associated with a landscape group if it shares an assessment unit with one or more of the landscape classes that make up that landscape group.

Assets considered 'more at risk of hydrological changes' as a consequence of additional coal resource development were identified. An asset 'more at risk of hydrological changes' was defined as one where there was at least a 50% chance of the modelled hydrological changes exceeding a defined threshold for the hydrological response variable(s) relevant for the landscape group(s) to which the asset is associated.

The hydrological thresholds chosen to identify ‘more at risk of hydrological changes’ assets within the impacted landscape groups are:

- For ‘Streams, GDE’, ‘Floodplain, terrestrial GDE’ and ‘Non-floodplain, terrestrial GDE’ landscape groups, it is an increase in drawdown due to additional coal resource development exceeding 2.0 m.
- For ‘Streams, non-GDE’ and ‘Streams, GDE’ landscape groups, it is an increase in the frequency of low-flow (10 ML/d) days per year of 20 days or more.

It is important to reiterate that receptor impact modelling was not undertaken for the ‘Springs’ landscape group. This means that it has not been possible for this BA to identify assets associated with the ‘Springs’ landscape group that may be ‘more at risk of hydrological changes’.

The risk to particular assets initially needs to consider these hydrological changes in conjunction with the predicted changes to receptor impact variables and ecosystem dependencies as described by qualitative mathematical modelling (and signed digraphs). A more refined assessment of risk would also need to incorporate specific local information and/or finer-resolution modelling, and a more explicit consideration of the potential pathways to impact for that asset (see Section 3.5.2.7 for an example of a more detailed analysis of risk to an individual asset).

3.5.2.2 ‘Surface water feature’ subgroup

A total of 34 assets are in the ‘Surface water feature’ subgroup in the zone of potential hydrological change. These surface water assets are classified into six classes (Table 30). The asset class within the ‘Surface water feature’ subgroup with the largest number of individual assets is the ‘Wetland, wetland complex or swamp’ class. Individual assets within the class include Lake Dalrymple, Doongmabulla Springs and Scartwater Aggregation. The latter is a riverine wetland in the channels of Suttor Creek. All of these assets are associated with landscape groups that are potentially impacted due to additional coal resource development in the Galilee subregion (Table 31).

Table 31 Number of ecological assets in the six classes of the 'Surface water feature' subgroup within the zone of potential hydrological change that intersect with major water-dependent landscape groups

Landscape group	Floodplain (n=2)	Lake, reservoir, lagoon or estuary (n=4)	Marsh, sedgeland, bog, spring or soak (n=6)	River or stream reach, tributary, anabranch or bend (n=3)	Waterhole, pool, rock pool or billabong (n=3)	Wetland, wetland complex or swamp (n=16)
Floodplain, terrestrial GDE	2	4	5	3	3	16
Non-floodplain, terrestrial GDE	2	0	4	3	1	8
Streams, non-GDE	**2**	3	0	3	0	11
Streams, GDE	2	2	5	2	3	13
Springs	1	0	6	1	0	2

GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 1, Dataset 2)

All but one of the assets intersects the 'Floodplain, terrestrial GDE' landscape group (Table 31). All of the assets in the 'Marsh, sedgeland, bog, spring or soak' class intersect with the 'Springs' landscape group. Twelve assets in this subgroup are confined wholly to the Galilee subregion's zone of potential hydrological change (Table 30). These include five of the six assets in the 'Marsh, sedgeland, bog, spring or soak' class. Individual assets here include Doongmabulla Springs, Scartwater Aggregation, and several unnamed waterholes in the Carmichael River and Belyando River.

3.5.2.3 'Groundwater feature (subsurface)' subgroup

There are nine ecological assets in this subgroup that are in the zone of potential hydrological change; these assets are all within the 'Aquifer, geological feature, alluvium or stratum' class. Each of these assets occurs in landscape classes that will be potentially impacted due to additional coal resource development in the Galilee subregion (Table 32). Most assets intersect with the 'Non-floodplain, terrestrial GDE' and 'Streams, non-GDE' landscape groups.

Eight of the nine assets in this subgroup are confined to the zone of potential hydrological change of the Galilee subregion. These eight assets are various vegetation communities that are GDEs dependent on the subsurface availability of groundwater sourced mainly from the Clematis Group aquifer.

Table 32 Number of ecological assets in the 'Groundwater feature (subsurface)' subgroup within the zone of potential hydrological change that intersect with major water-dependent landscape groups

Landscape group	Number of assets
Floodplain, terrestrial GDE	4
Non-floodplain, terrestrial GDE	7
Streams, non-GDE	7
Streams, GDE	2
Springs	1

Some assets may intersect with more than one landscape group. GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 1, Dataset 2)

3.5.2.4 'Vegetation' subgroup

Most ecological assets in the zone of potential hydrological change are in the 'Vegetation' subgroup. Within this subgroup, assets are divided into two classes: 'Groundwater-dependent ecosystem' and 'Habitat (potential species distribution)'. Each of these classes is covered separately below.

3.5.2.4.1 Groundwater-dependent ecosystem

Most assets (n=162) in the zone of potential hydrological change of the Galilee subregion are within this asset class (Table 30). Among the individual assets in this class are GDEs of varying size distributed along surface water drainages 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.

The landscape group with which the largest number of assets in the 'Groundwater-dependent ecosystem' class intersects is 'Floodplain, terrestrial GDE'. All but six of the individual assets occur wholly or partly in this landscape group (Table 33). The 'Streams, GDE' and 'Streams, non-GDE' landscape groups also have a large number of assets in this class.

Thirty-nine assets within this asset class only occur in the zone of potential hydrological change. These assets are distributed widely across the zone and are commonly associated with riverine systems.

Table 33 Number of ecological assets in the 'Groundwater-dependent ecosystem' class of the 'Vegetation' subgroup within the zone of potential hydrological change that intersect with major water-dependent landscape groups

Landscape group	Number of assets
Floodplain, terrestrial GDE	155
Non-floodplain, terrestrial GDE	102
Streams, non-GDE	133
Streams, GDE	137
Springs	27

GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 1, Dataset 2)

3.5.2.4.2 Habitat (potential species distribution)

A total of 36 individual assets are in the 'Habitat (potential species distribution)' class (Table 30). These divide readily into the following categories: (i) potential distribution of EPBC Act-listed threatened species, (ii) mapped distribution of endangered regional ecosystems under Queensland legislation, (iii) mapped distribution of EPBC Act-listed threatened ecological communities, and (iv) location of national parks, nature refuges and resources reserves.

In relation to category (i), it is important to note that the terms 'habitat' and 'potential species distribution' are synonymous in relation to assets, and that the potential species distribution or habitat does not definitely mean that either the species or its habitat is present within the modelled distribution (see Section 2.3.3 of Evans et al. (2018b)). The Department of the Environment and Energy Environmental Resources Information Network (ERIN) uses maximum entropy (MAXENT) modelling to define the geographic extent of potential species distributions based largely on physical parameters and past observations of the presence and absence of a species (Elith et al., 2011). The habitat itself, in the form of suitable vegetation types or ecosystems, is not necessarily present within the modelled potential species distribution. Furthermore, where suitable habitat does exist within the modelled potential species distribution, the species may not be known or predicted to occur there.

A further point in relation to all the four categories is that the location information (and subsequent modelling of species distribution) is 'point in time' in nature. As previously mentioned, location records were not updated after the water-dependent asset register was finalised for the Galilee subregion (Bioregional Assessment Programme, 2017). Thus, it is possible that some species distributions used in this BA (and possibly shown in this product) may have been subsequently updated or modified on the basis of more recently acquired data.

None of the assets in categories (i), (ii) or (iii) are located entirely within the Galilee subregion's zone of potential hydrological change. The species that is closest to being confined to the zone is the distribution of the wetland plant, the blue devil (*Eryngium fontanum)*. It occurs at Moses Springs in the Doongmabulla Springs complex and also further west outside the zone at Edgbaston Springs (Figure 67).

The potential distribution of 15 EPBC Act-listed threatened species occurs within the zone of potential hydrological change (Table 34). The plants include two endemic spring wetland species, the blue devil and the salt pipewort (*Eriocaulon carsonii)* (Figure 67). There are also two non-wetland plants, the black ironbox (*Eucalyptus raveretiana)*, which is confined to the extreme north of the zone of potential hydrological change, and the hairy-joint grass (*Arthraxon hispidus)*, which occurs in the north-west and south-east parts of the zone (Figure 67).

Habitat (potential species distribution) of six threatened bird species is located within the zone of potential hydrological change. Habitat is potentially available for three species of granivorous birds (Table 34): the black-throated finch (southern), star finch (eastern) and squatter pigeon (southern). Sizeable areas of potential species distribution occur within the zone for each of these species (Figure 68). In comparison, only small areas of potential species distribution occur within the zone for three other EPBC Act-listed threatened bird species: Australian painted snipe, red goshawk and painted honeyeater (Figure 69). The koala is known from a small number of sites across the zone (Figure 69). The assets in this category also include habitat (potential species distribution) of four reptile species listed as threatened under the EPBC Act (Figure 70). Habitat (potential species distribution) of all of these species includes the 'Floodplain, terrestrial GDE' landscape group. The potential distribution of all but one of these species (hairy-joint grass) includes the 'Streams, GDE' landscape group (Table 34).

Table 34 Individual ecological assets in the 'Habitat (potential species distribution)' class of the 'Vegetation' subgroup that are habitat of threatened species found within the zone of potential hydrological change that intersect with major water-dependent landscape groups

Asset name[a]	Floodplain, terrestrial GDE	Non-floodplain, terrestrial GDE	Streams, non-GDE	Streams, GDE	Springs
Australian Painted Snipe (*Rostratula benghalensis*)	Yes	No	Yes	Yes	No
Black Ironbox (*Eucalyptus raveretiana*)	Yes	Yes	Yes	Yes	No
Black-throated Finch (southern) (*Poephila cincta cincta*)	Yes	Yes	Yes	Yes	No
Blue Devil (*Eryngium fontanum*)	Yes	Yes	No	Yes	Yes
Dunmall's Snake (*Furina dunmalli*)	Yes	Yes	Yes	Yes	Yes
Hairy-joint Grass (*Arthraxon hispidus*)	Yes	No	Yes	No	No
Koala (*Phascolarctos cinereus*)	Yes	Yes	Yes	Yes	No
Ornamental Snake (*Denisonia maculata*)	Yes	Yes	Yes	Yes	Yes
Painted Honeyeater (*Grantiella picta*)	Yes	Yes	Yes	Yes	No
Brigalow scaly-foot (*Paradelma orientalis)*	Yes	Yes	Yes	Yes	Yes
Red Goshawk (*Erythrotriorchis radiatus*)	Yes	Yes	Yes	Yes	No
Salt Pipewort (*Eriocaulon carsonii*)	Yes	Yes	No	Yes	Yes
Squatter Pigeon (southern) (*Geophaps scripta scripta*)	Yes	Yes	Yes	Yes	No
Star Finch (eastern) (*Neochmia ruficauda ruficauda*)	Yes	Yes	Yes	Yes	Yes
Yakka Skink (*Egernia rugosa*)	Yes	Yes	Yes	Yes	No

[a]Typology and punctuation are given as they are used in relevant legislation.
GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 1, Dataset 2)

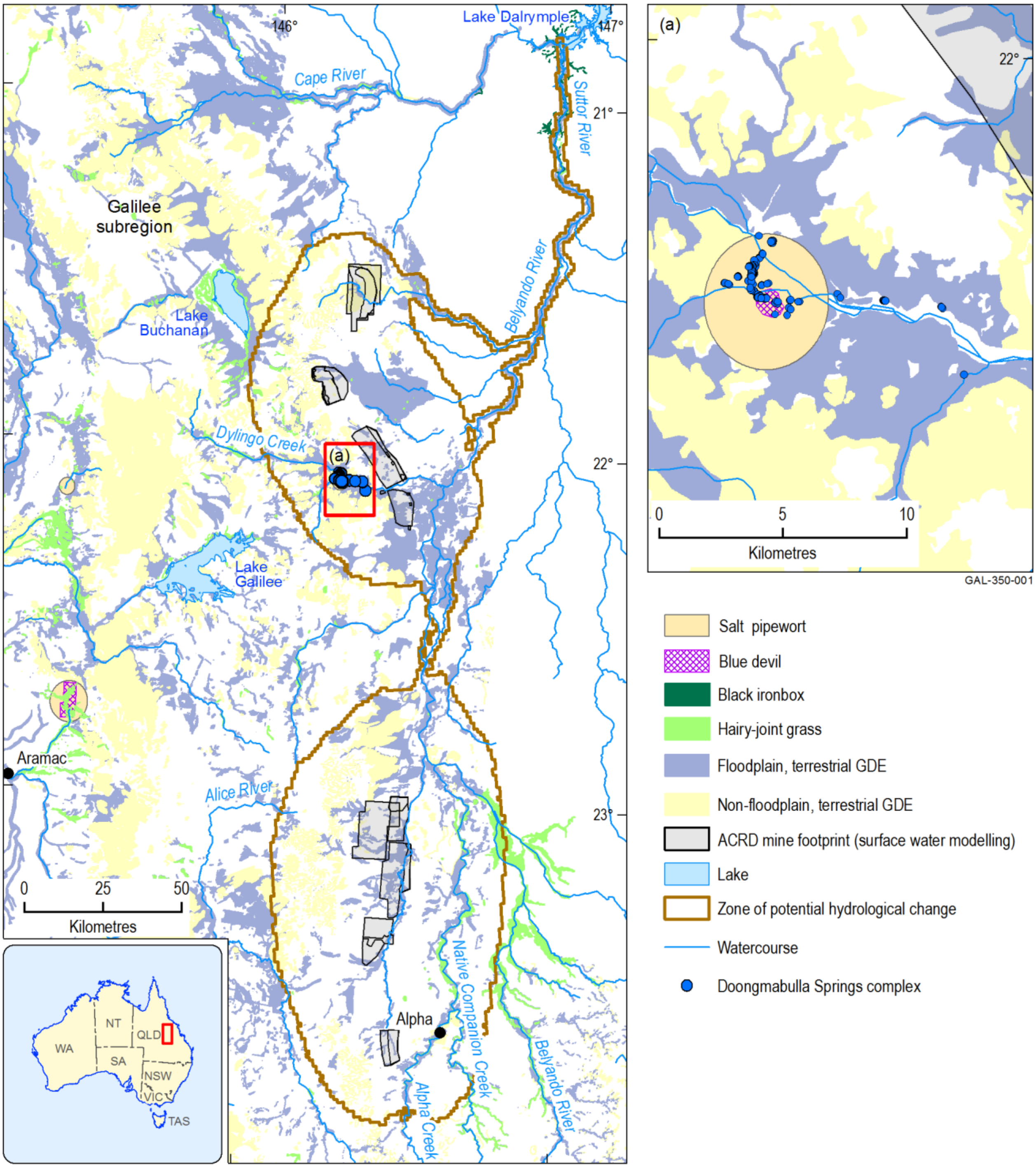

Figure 67 Distribution of threatened plant species in the 'Habitat (potential species distribution)' class in the zone of potential hydrological change, overlain with groundwater-dependent ecosystem (GDE) landscape groups. Inset box (a) zooms into the area around the Doongmabulla Springs complex, highlighting distribution of salt pipewort and blue devil in relation to individual springs

These species are listed nationally under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999*.
ACRD = additional coal resource development
Data: Bioregional Assessment Programme (Dataset 1, Dataset 2, Dataset 3, Dataset 4)

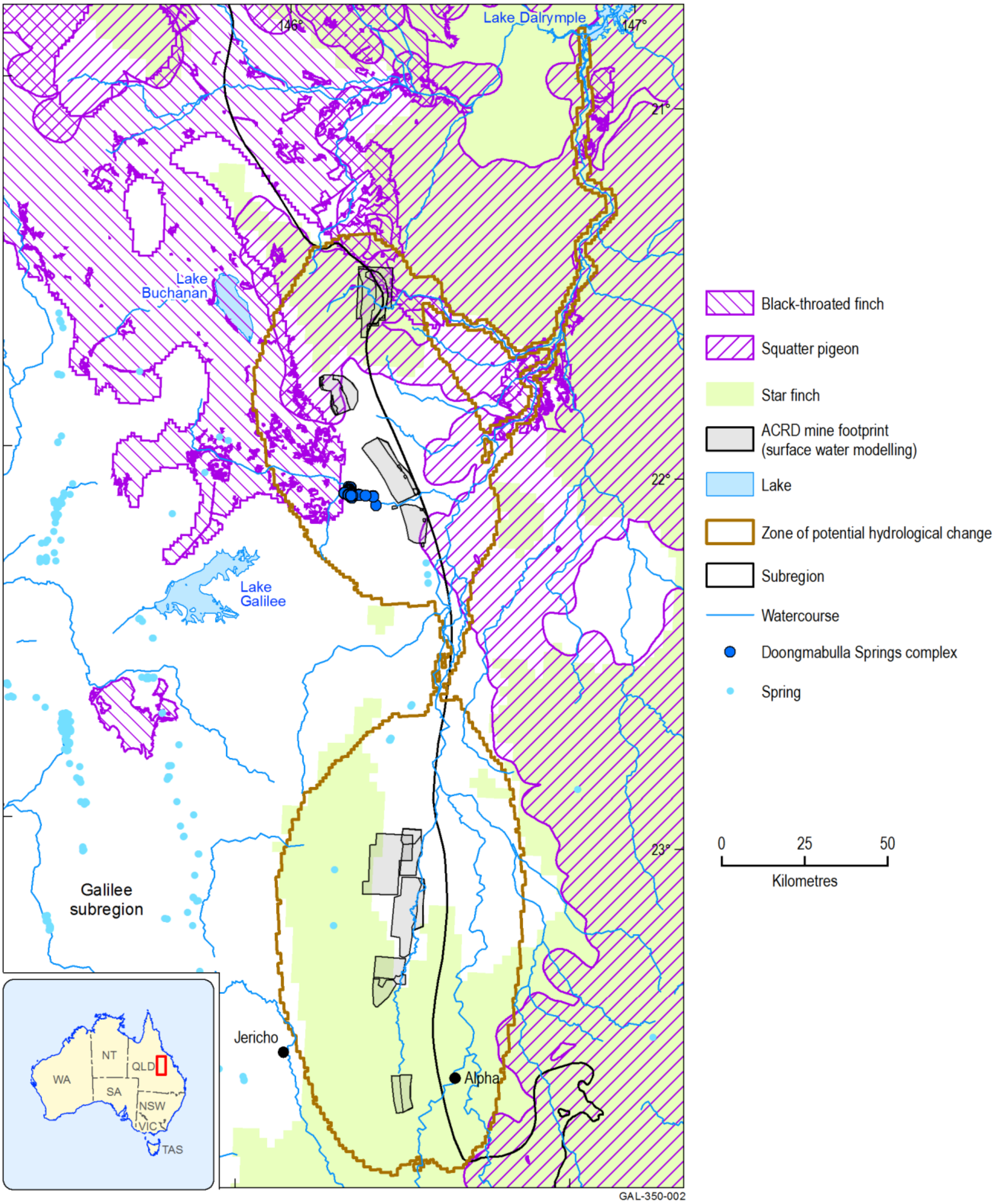

Figure 68 Distribution of species of threatened seed-eating birds in the 'Habitat (potential species distribution)' class in the zone of potential hydrological change

These species are listed nationally under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999*.
ACRD = additional coal resource development
Data: Bioregional Assessment Programme (Dataset 1, Dataset 3, Dataset 4)

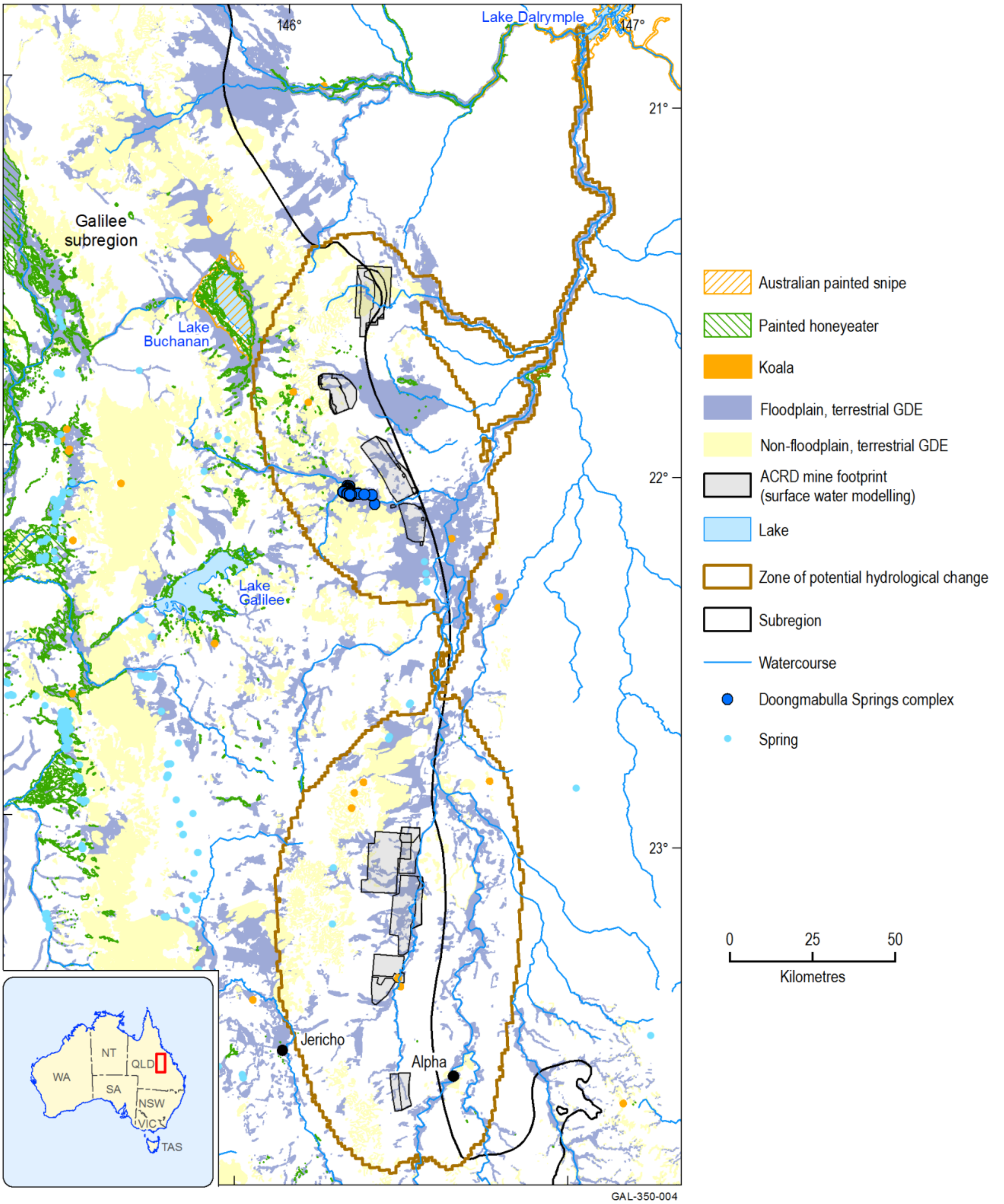

Figure 69 Distribution of the Australian painted snipe, painted honeyeater and the koala in the 'Habitat (potential species distribution)' class in the zone of potential hydrological change, overlaid with groundwater-dependent ecosystem (GDE) landscape groups

These species are listed nationally under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999*.
ACRD = additional coal resource development
Data: Bioregional Assessment Programme (Dataset 1, Dataset 2, Dataset 3, Dataset 4)

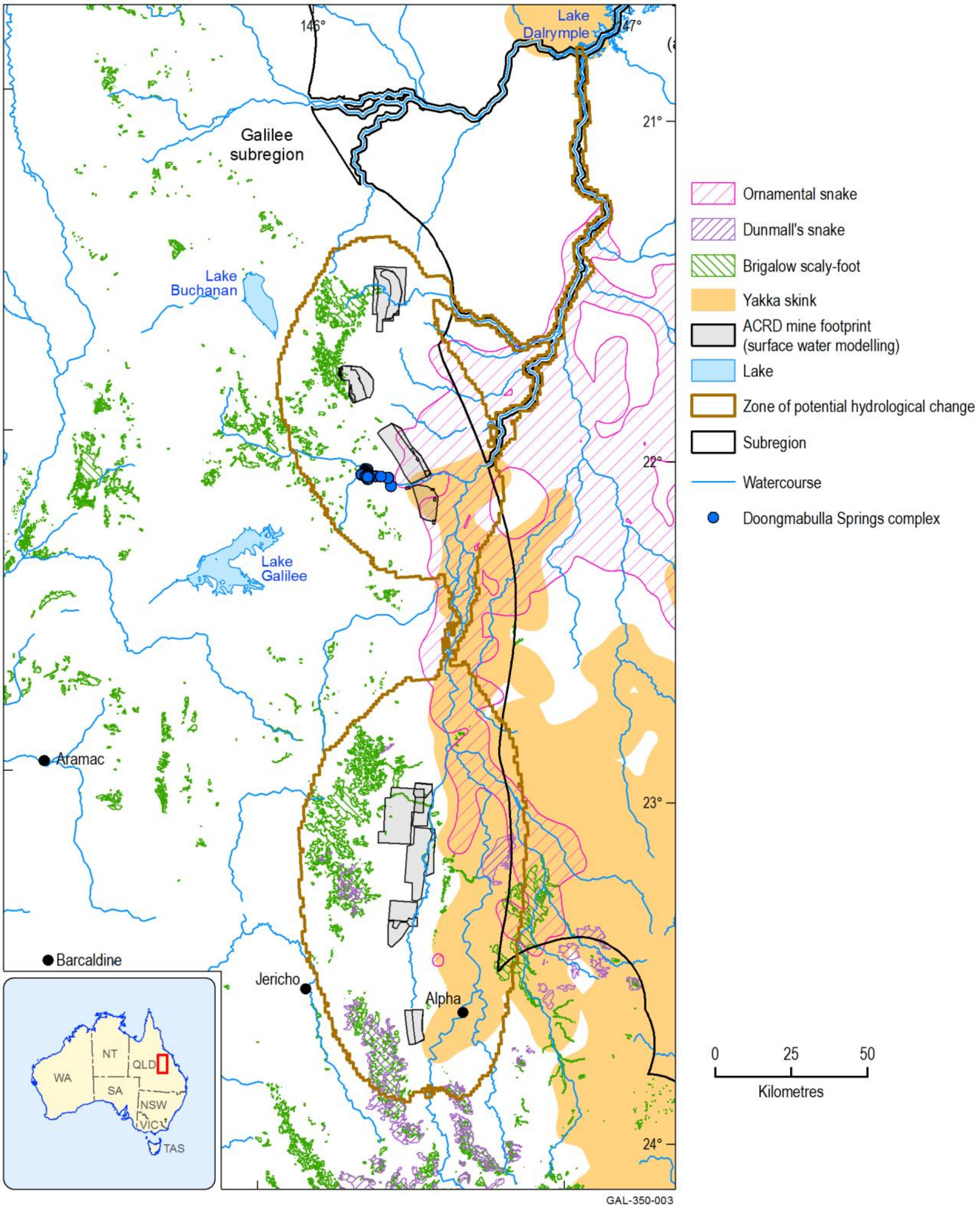

Figure 70 Distribution of species of threatened reptiles in the 'Habitat (potential species distribution)' class in the zone of potential hydrological change

These species are listed nationally under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999.*
ACRD = additional coal resource development
Data: Bioregional Assessment Programme (Dataset 1, Dataset 3, Dataset 4)

The habitat (potential species distribution) of ten endangered regional ecosystems occurs within the zone of potential hydrological change. These regional ecosystems occur patchily throughout the zone (Figure 71). These assets intersect with landscape groups that are potentially impacted due to additional coal resource development (Table 35). All assets intersect with the 'Floodplain, terrestrial GDE' landscape group and the 'Streams, non-GDE' landscape group. Most also intersect with the 'Streams, GDE' and 'Non-floodplain, terrestrial GDE' landscape groups (Table 35).

Table 35 Individual ecological assets in the 'Habitat (potential species distribution)' class of the 'Vegetation' subgroup that are endangered regional ecosystems located within the zone of potential hydrological change and their intersection with the major potentially impacted landscape groups

Asset name[a]	Floodplain, terrestrial GDE	Non-floodplain, terrestrial GDE	Streams, non-GDE	Streams, GDE	Springs
Acacia argyrodendron woodland on Cainozoic clay plains	Yes	Yes	Yes	Yes	No
Acacia cambagei woodland on Cainozoic clay plains	Yes	Yes	Yes	Yes	Yes
Acacia harpophylla and/or Casuarina cristata open forest on alluvial plains	Yes	Yes	Yes	Yes	No
Acacia harpophylla and/or Eucalyptus cambageana open woodland on Cainozoic lake beds	Yes	Yes	Yes	Yes	No
Acacia harpophylla and/or Eucalyptus cambageana open woodland to woodland on Mesozoic sediments	Yes	Yes	Yes	Yes	No
Acacia harpophylla shrubby woodland with Terminalia oblongata on Cainozoic clay plains	Yes	Yes	Yes	Yes	No
Eremophila mitchellii tall open shrubland on alluvial plains	Yes	Yes	Yes	Yes	No
Eucalyptus cambageana woodland to open forest with A. harpophylla or A. argyrodendron on Cainozoic clay plains	Yes	Yes	Yes	Yes	No
Eucalyptus melanophloia open woodland or Lysiphyllum carronii low open woodland on calcareous sandstones	Yes	Yes	Yes	Yes	No
Triodia longiceps hummock grasslands, ephemeral open herblands, and Melaleuca bracteata low open woodland on alluvial plains	Yes	Yes	Yes	Yes	Yes

[a]Typology and punctuation are given as they are used in the asset database.
GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 1, Dataset 2)

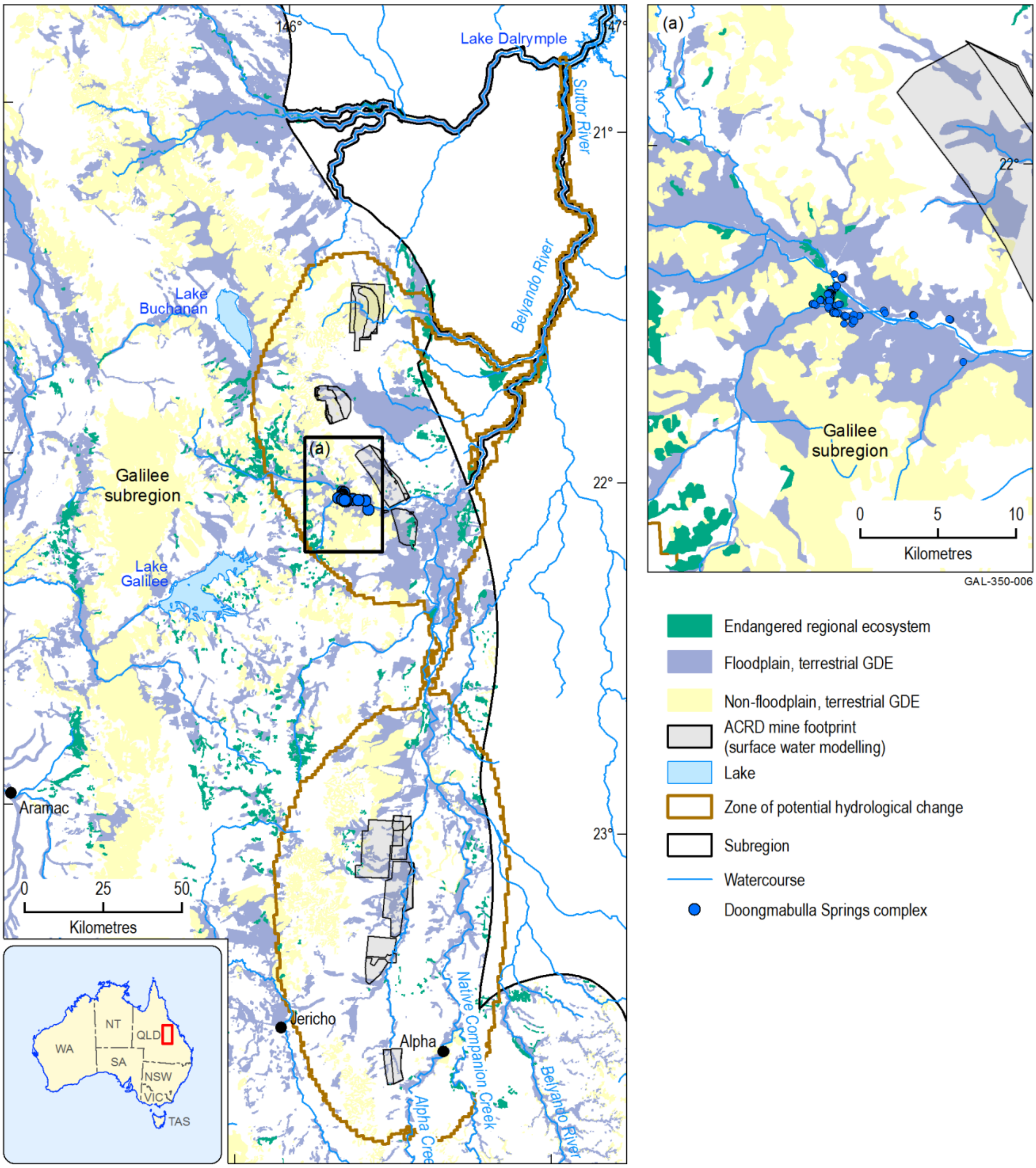

Figure 71 Distribution of endangered regional ecosystems in the 'Habitat (potential species distribution)' class in the zone of potential hydrological change, overlaid with groundwater-dependent ecosystem (GDE) landscape groups. Inset box (a) zooms into the area around the Doongmabulla Springs complex, highlighting the distribution of endangered regional ecosystems, individual springs and landscape groups

These species are listed nationally under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999*.
ACRD = additional coal resource development
Data: Bioregional Assessment Programme (Dataset 1, Dataset 2, Dataset 3, Dataset 4)

Habitat (potential species distribution) of three EPBC Act-listed threatened ecological communities (TECs) occurs within the zone of potential hydrological change. The Brigalow TEC is restricted to the eastern edge of the zone and the weeping myall woodlands to the south-east. 'The community of native species dependent on natural discharge of groundwater from the Great Artesian Basin'

TEC occurs only at Doongmabulla Springs (Figure 72). All of these assets intersect with landscape groups that are potentially impacted due to additional coal resource development (Table 7). All three ecological communities occur within the 'Floodplain, terrestrial GDE' landscape group.

Eight of the ecological assets in the 'Habitat (potential species distribution)' class of the 'Vegetation' subgroup occur within the zone of potential hydrological change and are national parks, nature reserves or resource reserves (regional parks). All of the assets in this category intersect at least one potentially impacted landscape group (Table 37). All eight ecological assets intersect with the 'Floodplain, terrestrial GDE' landscape group. Only one asset intersects with the 'Springs' landscape group: Doongmabulla Mound Springs Nature Refuge.

Six of the eight assets in this category are confined to the zone of potential hydrological change of the Galilee subregion. The two exceptions are East Top Nature Refuge and Nairana National Park.

Table 36 Individual ecological assets in the 'Habitat (potential species distribution)' class of the 'Vegetation' subgroup that are listed threatened ecological communities (TECs) under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* within the zone of potential hydrological change and their intersection with major potentially impacted landscape groups

Asset name[a]	Floodplain, terrestrial GDE	Non-floodplain, terrestrial GDE	Stream, non-GDE	Stream, GDE	Springs
Brigalow (Acacia harpophylla dominant and co-dominant) TEC	Yes	Yes	Yes	Yes	No
Weeping Myall Woodlands TEC	Yes	Yes	Yes	Yes	No
The community of native species dependent on natural discharge of groundwater from the Great Artesian Basin TEC	Yes	Yes	Yes	Yes	Yes

[a]Typology and punctuation are given as they are used in the asset database.
GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 1, Dataset 2)

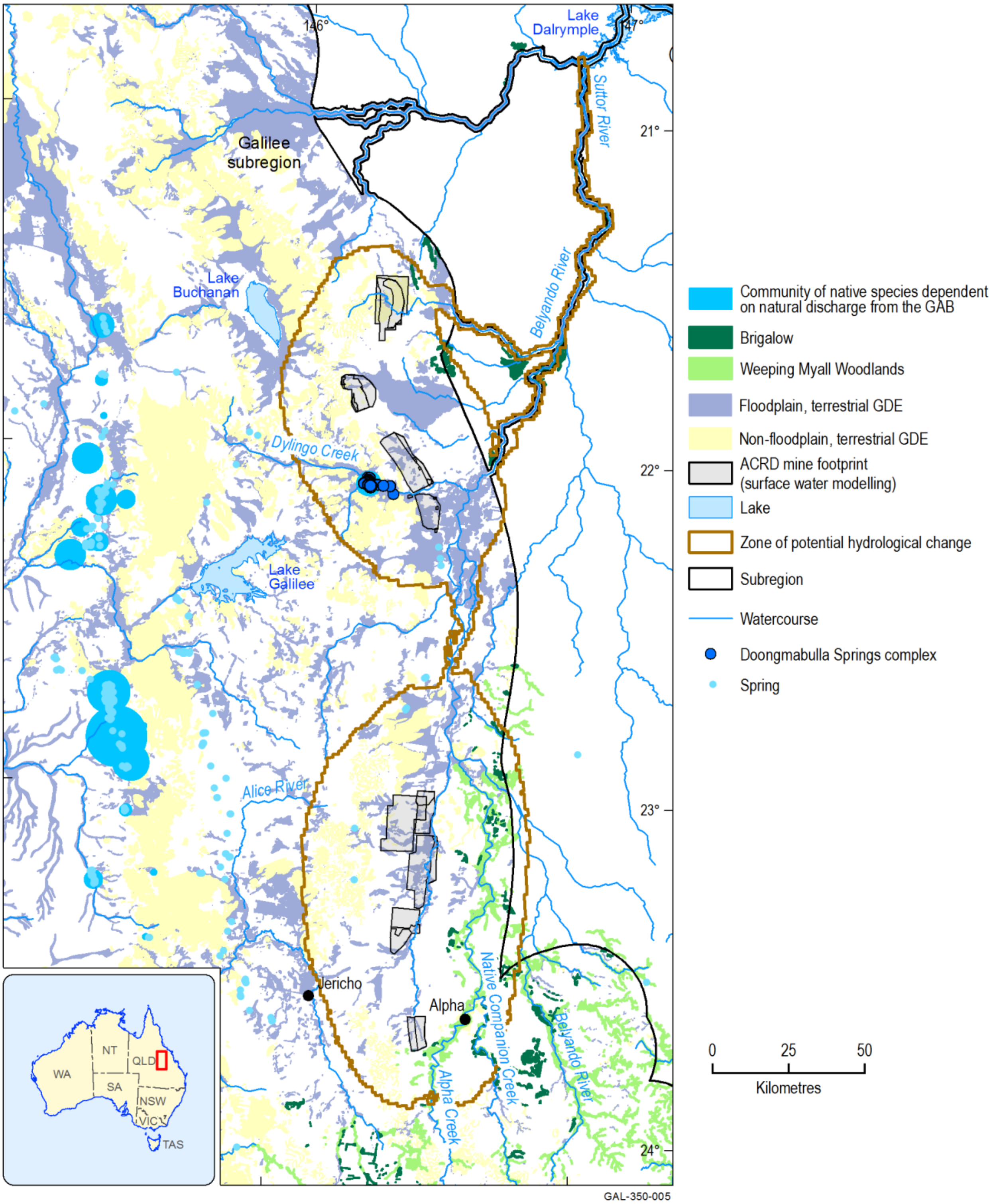

Figure 72 Distribution of threatened ecological communities in the 'Habitat (potential species distribution)' class in the zone of potential hydrological change, overlaid with groundwater-dependent ecosystem (GDE) landscape groups

These species are listed nationally under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999*.
ACRD = additional coal resource development, GAB = Great Artesian Basin
Data: Bioregional Assessment Programme (Dataset 1, Dataset 2, Dataset 3, Dataset 4)

Table 37 Individual ecological assets in the 'Habitat (potential species distribution)' class of the 'Vegetation' subgroup that are nature reserves, national parks or resource reserves within the zone of potential hydrological change and their intersection with major potentially impacted landscape groups

Asset name	Floodplain, terrestrial GDE	Non-floodplain, terrestrial GDE	Streams, non-GDE	Streams, GDE	Springs
Bimblebox Nature Refuge	Yes	No	Yes	No	No
Bygana Nature Refuge	Yes	No	No	Yes	No
Bygana West Nature Refuge	Yes	Yes	Yes	Yes	No
Cudmore National Park	Yes	Yes	Yes	Yes	No
Cudmore Resources Reserve (Regional Park)	Yes	Yes	Yes	Yes	No
Doongmabulla Mound Springs Nature Reserve	Yes	Yes	No	Yes	Yes
East Top Nature Refuge	Yes	No	No	No	No
Nairana National Park	Yes	No	No	Yes	No

GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 1, Dataset 2)

3.5.2.5 Identification of 'more at risk of hydrological changes' assets

Of the 241 ecological assets in the zone of potential hydrological change, 148 are identified as being 'more at risk of hydrological changes' (see Section 3.2.5 for further details about the various risk category terms used in this BA; Table 38). That is, all or part of the area of these assets occurs within one or more of the potentially impacted landscape groups, and there is a greater than 50% chance of the modelled hydrological change exceeding the defined threshold in one or more of the hydrological response variable(s) relevant to the landscape group(s). The defined threshold for assets intersecting the 'Streams, GDE', 'Floodplain, terrestrial GDE' and 'Non-floodplain, terrestrial GDE' landscape groups was an increase in drawdown due to additional coal resource development exceeding 2 m. For the 'Streams, non-GDE' and 'Streams, GDE' landscape groups, the defined threshold was an increase in the frequency of low-flow (10 ML/d) days per year of 20 days or more. These thresholds were developed based on expert ecological input from within the Assessment team.

A number of assets also experienced higher levels of risk than the defined thresholds used to identify 'more at risk of hydrological changes' assets. The response differed depending on the hydrological response variable being considered. Specifically, when considering assets intersecting landscape groups that had groundwater drawdown as the critical hydrological response variable, 69 assets had a greater than 50% chance of the modelled hydrological change exceeding 5 m (Table 39). In contrast, when considering assets intersecting landscape groups that had frequency of low-flow days per year as the main hydrological response variable, only five ecological assets had a greater than 50% chance of the modelled hydrological change exceeding an increase of 200 or more low-flow days per year.

The 'more at risk' assets were mostly in the 'Groundwater-dependent ecosystem' class of the 'Vegetation' subgroup (Table 38). These include a wide range of terrestrial, riverine and wetland GDEs.

A total of 25 of the 'more at risk' assets were in the 'Habitat (potential species distribution)' class of the 'Vegetation' subgroup. Within this list of assets were the potential species distributions of 12 EPBC Act-listed threatened species. These species include all the birds listed as ecological assets except red goshawk (Figure 68 and Figure 69), the koala (Figure 69) and all the reptiles listed as ecological assets (Figure 70), in addition to the plants, black ironbox and hairy-joint grass (Figure 67). The mapped distributions of seven of the ten endangered regional ecosystems that occur within the zone of potential hydrological change (Table 35) are considered 'more at risk of hydrological changes'. The mapped distributions of two of the three TECs listed under the EPBC Act (Table 36, Figure 72) are also considered to be 'more at risk'. Among nature reserves, national parks or resource reserves in the zone, the following are classed as 'more at risk': Bimblebox Nature Refuge, Cudmore National Park, Cudmore Resource Reserve and Nairana National Park.

The risk to the particular water-dependent assets identified here needs to consider these hydrological changes in conjunction with the predicted changes to receptor impact variables (for relevant landscape groups) and ecosystem dependencies as described by qualitative mathematical modelling (and signed digraphs). A more refined assessment of risk would need to also incorporate local information or finer-resolution modelling, and a more explicit consideration of the potential pathways to impact for that asset.

Table 38 Summary of the number of 'more at risk of hydrological changes' ecological assets within the zone of potential hydrological change, according to asset subgroup and class

Asset subgroup	Asset class	More at risk of hydrological changes
Surface water feature	Floodplain	0
	Lake, reservoir, lagoon or estuary	2
	Marsh, sedgeland, bog, spring or soak	0
	River or stream reach, tributary, anabranch or bend	2
	Waterhole, pool, rock pool or billabong	2
	Wetland, wetland complex or swamp	10
	Subtotal	**16**
Groundwater feature (subsurface)	Aquifer, geological feature, alluvium or stratum	1
	Subtotal	**1**
Vegetation	Groundwater-dependent ecosystem	106
	Habitat (potential species distribution)	25
	Riparian vegetation	0
	Subtotal	**131**
Total		**148**

Data: Bioregional Assessment Programme (Dataset 1)

Table 39 Summary of the number of ecological assets exceeding defined categories of modelled hydrological change for those assets that are in landscape groups where the hydrological response variable used for receptor impact modelling is groundwater drawdown within the zone of potential hydrological change

Asset subgroup	Asset class	Number of assets with additional drawdown ≥0.2 m			Number of assets with additional drawdown ≥2 m			Number of assets with additional drawdown ≥5 m		
		5th	50th	95th	5th	50th	95th	5th	50th	95th
Surface water feature	Floodplain	1	1	2	1	1	1	1	1	1
	Lake, reservoir, lagoon or estuary	1	1	4	0	1	1	0	0	1
	Marsh, sedgeland, bog, spring or soak	0	1	6	0	0	1	0	0	0
	River or stream reach, tributary, anabranch or bend	2	2	3	2	2	2	2	2	2
	Waterhole, pool, rock pool or billabong	1	1	3	0	0	1	0	0	0
	Wetland, wetland complex or swamp	6	7	12	4	6	6	2	4	6
Groundwater feature (subsurface)	Aquifer, geological feature, alluvium or stratum	1	1	9	1	1	2	0	1	1
Vegetation	Groundwater-dependent ecosystem	61	85	137	42	57	78	27	43	59
	Habitat (potential species distribution)	20	24	29	17	20	23	9	18	19
Total		**93**	**123**	**205**	**67**	**88**	**115**	**41**	**69**	**89**

The assets potentially exposed to ≥0.2, ≥2 and ≥5 m additional drawdown is shown for the 5th, 50th and 95th percentile estimates of the maximum difference in drawdown (*dmax*) between the coal resource development pathway (CRDP) and baseline, due to additional coal resource development.
Data: Bioregional Assessment Programme (Dataset 1, Dataset 3)

Table 40 Summary of the number of ecological assets exceeding defined categories of modelled hydrological change for those assets that are in landscape groups where the hydrological response variable used for receptor impact modelling is increase in low-flow days per year within the zone of potential hydrological change

Asset subgroup	Asset class	Number of assets for length with increases of ≥3 low-flow days per year			Number of assets for length with increases of ≥20 low-flow days per year			Number of assets for length with increases of ≥80 low-flow days per year			Number of assets for length with increases of ≥200 low-flow days per year		
		5th	50th	95th	5th	50th	95th	5th	50th	95th	5th	50th	95th
Surface water feature	Floodplain	1	1	1	0	1	1	0	1	1	0	0	1
	Lake, reservoir, lagoon or estuary	2	2	2	0	2	2	0	2	2	0	0	2
	Marsh, sedgeland, bog, spring or soak	0	0	0	0	0	0	0	0	0	0	0	0
	River or stream reach, tributary, anabranch or bend	2	2	2	0	2	2	0	2	2	0	0	2
	Waterhole, pool, rock pool or billabong	2	2	2	0	2	2	0	2	2	0	0	2
	Wetland, wetland complex or swamp	8	9	9	0	9	9	0	7	9	0	0	7
Groundwater feature (subsurface)	Aquifer, geological feature, alluvium or stratum	0	0	0	0	0	0	0	0	0	0	0	0
Vegetation	Groundwater-dependent ecosystem	84	95	95	0	93	95	0	74	95	0	4	77
	Habitat (potential species distribution)	21	21	21	0	21	21	0	17	21	0	1	19
Total		**120**	**132**	**132**	**0**	**130**	**132**	**0**	**105**	**132**	**0**	**5**	**110**

'Low-flow days' is the number of low-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 low-flow days is the 10th percentile from the simulated 90-year period.
Data: Bioregional Assessment Programme (Dataset 1, Dataset 3)

3.5.2.6 Assets and the 'Springs' landscape group

The 'Springs' landscape group is potentially impacted due to modelled additional coal resource development. The potential impacts and risks for the 'Springs' landscape group due to groundwater drawdown in the zone of potential hydrological change are detailed in Section 3.4.3. Section 3.4.3 also outlines the two interpretations of the hydrogeology for the source aquifer of the Doongmabulla Springs complex. Section 3.3.2 presents the two modelling conceptualisations that were used in the groundwater analytic element model (AEM), which are also relevant to understanding the potential impacts of coal resource development on these important ecological assets. In particular, the modelling results from the alternative AEM conceptualisation (Section 3.3.2) are considered to be more appropriate for assessing impacts to some specific points in the landscape (such as springs) that occur in areas where the uppermost Quaternary alluvium and Cenozoic sediment aquifer (the uppermost aquifer layer modelled in the AEM) is absent or not in direct (unimpeded) connection with the mining areas. Further information on the hydrological regimes and connectivity of the Doongmabulla Springs complex is also provided in Section 2.7.3 of companion product 2.7 for the Galilee subregion (Ickowicz et al., 2018).

The focus of this current section is on ecological assets that intersect with the 'Springs' landscape group and, in lieu of receptor impact modelling, on using the available lines of information to assess potential impacts on and risks to these assets. A large number of high-profile assets in the water-dependent asset register intersect with the 'Springs' landscape group. Although the 200 springs in this landscape group occupy less than 1% of the area of the zone of potential hydrological change, a total of 48 individual ecological assets (20% of all ecological assets in the zone) intersect with the 'Springs' landscape group (Table 39). Of these assets, 16 are confined entirely to the zone (i.e. do not occur anywhere outside the zone).

Most ecological assets associated with the 'Springs' landscape group are predominantly located in and around the Doongmabulla Springs complex. However, the Mellaluka Springs GDE is also an ecological asset listed in the asset register. Individual ecological assets located within the Doongmabulla Springs complex include the springs themselves (listed as a wetland complex in the 'Surface water feature' subgroup); the Doongmabulla Mound Springs Nature Refuge; habitat (potential species distribution) of an EPBC Act-listed TEC, 'The community of native species dependent on natural discharge of groundwater from the Great Artesian Basin'; and habitat (potential species distribution) of two EPBC Act-listed threatened plant species: blue devil and salt pipewort (Figure 67 and Figure 72). Blue devil is an erect perennial herb, whereas salt pipewort is a small aquatic herb that grows in shallow water (in depths as low as 10 cm). In addition, a sociocultural asset, Doongmabulla Spring Natural Indicative Place, is located within the Doongmabulla Springs complex (see Section 3.5.4 for information about potential impacts to sociocultural assets).

Table 41 Ecological assets that intersect with the 'Springs' landscape group

Asset ID	Asset name (shortened)[a]
2677	Aquifer boundary – Birkhead Formation
2694	Floodplain in Burdekin River region
2550	Clematis Formation_Eucalyptus low open woodlands with tussock grass
2560	Clematis Formation_Eucalyptus open forests with a grassy understorey
2570	Clematis Formation_Mulga woodlands and shrublands
2588	Clematis Formation_Tropical mixed species forests and woodlands
2644	Tasman_*Acacia* (+/- low) open woodlands and sparse shrublands with a shrubby understorey
2651	Tasman_Mallee with hummock grassland
2738	Rivers in the Burdekin River region
408	Doongmabulla Springs
2826	Wetland/s of *Eucalyptus* woodlands with a tussock grass understorey
27452	Cattle Creek GDE
27454	Cattle Creek GDE Moderate potential for GW interaction
28432	Dyllingo Creek GDE
28433	Dyllingo Creek GDE Low potential for GW interaction
28434	Dyllingo Creek GDE Moderate potential for GW interaction
28666	*Eucalyptus* low open woodlands with hummock grass Broken River Burdekin River Spring GDE
29326	*Eucalyptus* low open woodlands with hummock grass Broken River Burdekin River Spring GDE
29334	*Eucalyptus* low open woodlands with hummock grass Broken River Burdekin River Wetland GDE
24673	*Eucalyptus* open woodlands with a grassy understorey GDE Low potential for GDE interaction
24674	*Eucalyptus* open woodlands with a grassy understorey GDE Moderate potential for GDE interaction
24684	*Eucalyptus* open woodlands with shrubby understorey GDE Moderate potential for GDE interaction
24691	*Eucalyptus populnea* or *E. melanophloia* (or *E. whitei*) dry woodlands to open-woodlands on sandplains or depositional plains GDE High potential for GW interaction
24693	*Eucalyptus populnea* or *E. melanophloia* (or *E. whitei*) dry woodlands to open-woodlands on sandplains or depositional plains GDE Low potential for GW interaction
24694	*Eucalyptus populnea* or *E. melanophloia* (or *E. whitei*) dry woodlands to open-woodlands on sandplains or depositional plains GDE Moderate potential for GW interaction
24711	*Eucalyptus* spp. dominated open-forest and woodlands drainage lines and alluvial plains GDE
24704	*Eucalyptus* spp. low open-woodland often with *Triodia* spp. dominated ground layer GDE
30316	*Eucalyptus* woodlands with a tussock grass understorey Broken River Burdekin River Spring GDE
30321	*Eucalyptus* woodlands with a tussock grass understorey Broken River Burdekin River wetland GDE
30324	*Eucalyptus* woodlands with a tussock grass understorey Broken River Burdekin River wetland GDE
31762	Hector GDE
31876	Hummock grasslands Broken River Burdekin River Spring GDE

Asset ID	Asset name (shortened)[a]
33462	Mellaluka Springs GDE
24921	Other *Acacia* forests and woodlands GDE High potential for GW interaction
24924	Other *Acacia* forests and woodlands GDE Moderate potential for GW interaction
36056	Other tussock grasslands Broken River Burdekin River Spring GDE
36061	Other tussock grasslands Broken River Burdekin River Wetland GDE
25031	Wetlands associated with permanent lakes and swamps, as well as ephemeral lakes, claypans and swamps. Includes fringing woodlands and shrublands GDE High potential for GW interaction
23461	*Acacia cambagei* woodland on Cainozoic clay plains Endangered Regional Ecosystem
216	Doongmabulla Mound Springs Nature Refuge
2085	Potential distribution of Blue Devil (*Eryngium fontanum*)
2147	Potential distribution of Dunmall's Snake (*Furina dunmalli*)
2102	Potential distribution of Ornamental Snake (*Denisonia maculata*)
2186	Potential distribution of *Paradelma orientalis*
2107	Potential distribution of Salt pipewort (*Eriocaulon carsonii*)
2111	Potential distribution of Star Finch (eastern) (*Neochima ruficauda ruficauda*)
2210	The community of native species dependent on natural discharge of groundwater from the Great Artesian Basin threatened ecological community
23502	*Triodia longiceps* hummock grassland, ephemeral open herblands, and *Melaleuca bracteata* low woodland on alluvial plains Endangered Regional Ecosystem (as dominant component)

[a]Typology and punctuation are given as they are used in the asset database.
GDE = groundwater-dependent ecosystem; GW = groundwater
Data: Bioregional Assessment Programme (Dataset 1, Dataset 2)

Fensham et al. (2016) described the morphology and distribution of the various spring groups that comprise the Doongmabulla Springs complex. In general, springs underlain by the Moolayember Formation are termed 'discharge springs' (see Figure 41 in Section 3.4), and some of these have a distinctive mounded morphological structure. At some locations though, the original morphology of the springs is uncertain due to various types of anthropogenic modification (e.g. Joshua Spring has been extensively modified through construction of a turkey's nest dam for use on the local pastoral lease). Springs to the east of the discharge springs (Figure 41 in Section 3.4) are situated near the base of topographic slopes within or near areas of outcropping Triassic bedrock (i.e. Clematis Group or Dunda beds). These are termed 'outcrop springs' by Fensham et al. (2016). The Little Moses and Yukunna Kumoo spring groups are underlain by the Clematis Group, whereas Dusk and Surprise spring groups occur on the Dunda beds outcrop. Groundwater discharges from some springs and contributes baseflow to Dyllingo Creek and the Carmichael River, and into alluvium associated within these stream valleys.

The signed digraph models for the 'Springs' landscape group identify the rate of groundwater flow as a critical factor in maintaining the aquatic community of springs (see companion product 2.7 for the Galilee subregion (Ickowicz et al., 2018)). Groundwater flow from the source aquifer needs to be at a rate that maintains a damp or submerged state in the spring such that the surface does not dry. An increase in groundwater flow above this threshold supports a wetted-area regime around the perimeter and downstream of the spring. Qualitative mathematical modelling indicated a zero or ambiguous response for most of the biological variables in the system to depletion of groundwater and available subsurface water. The models predicted a positive response for macrophytes (submerged and floating) but only for the cumulative impact scenario where subsurface water decreased and groundwater drawdown did not occur (see companion product 2.7 for the Galilee subregion (Ickowicz et al., 2018)).

The use of the Landsat archive of Digital Earth Australia enables the qualitative modelling predictions for the 'Springs' landscape group to be examined through time (i.e. over the past 30 years) within the zone of potential hydrological change (see Section 3.2.3.3 for further information about Digital Earth Australia and its application to the BA). The distribution of surface water and wet vegetation (Figure 73) as identified by the tasselled cap wetness (TCW) index derived from the Landsat archive shows that wet areas in surface drainages persist along Dyllingo Creek and the Carmichael River (even in dry years). These occur in the vicinity of the Doongmabulla Springs complex as well as downstream along the Carmichael River towards its confluence with the Belyando River. Surface water and areas of wetted vegetation are not temporally persistent in most tributary streams, except for isolated ponds (e.g. the previously unmapped water features located along some streamlines in Figure 73). The different discharge spring groups also show wide variation in persistence of water and wetted vegetation at surface (Figure 73). For instance, spring pools at the Moses-Keelback and Wobbly springs have remained persistent over the last 30 years, whereas only a relatively minor response is evident in the wetness index for the Mouldy Crumpet springs. The difference in response may have some bearing on localised differences in the water budgets and local geomorphology for individual spring groups. For example, springs with more persistent occurrence of water at surface may have a discharge rate that generally exceeds the evaporation rate, with the local geomorphology allowing for water to be ponded at surface. In general, outcrop springs associated with the Clematis Group aquifer (e.g. Yukunna Kumoo spring group) appear to be temporally persistent and have a relatively high wetness index, whereas outcrop springs that occur on areas of outcropping Dunda beds (e.g. Surprise and Dusk spring groups) have a lower wetness index. Visual inspection of the TCW index mapping for this area indicates that there may be more spring vents in the vicinity of Surprise and Dusk springs than have previously been mapped (Figure 73).

Hovmöller time-series plots (see Section 3.2) provide a useful tool to evaluate how the Landsat response for different spring groups varies over a 30-year period (1987 to 2016). The time-series response for two transects (Transect 1 and Transect 2, as shown in Figure 73) is depicted for various springs in the Doongmabulla Springs complex, using the TCW index and normalised difference vegetation index (NVDI). Analysis of these plots provides clear indications that there are significant variations in the distribution and availability of water in the vicinity of different springs groups within the Doongmabulla Springs complex. Such internal complexity may complicate the downscaling of impacts and risks from the scale of a spring complex to that of a spring group, as well as for their ongoing monitoring and management.

Stepping Stone and Mouldy Crumpet spring groups are not readily apparent on the TCW Hovmöller plot (Figure 74). It could be that discharge at these springs is too low to support wetted vegetation or spring pools that are extensive enough to be detected by the Landsat sensors (at least for the past 30-year period of the Landsat record). The highest TCW response in Figure 74 occurs around the channel of Dyllingo Creek. On the northern bank of the creek, it appears the Joshua Springs turkey's nest dam was empty prior to 1992 but has been relatively full since. The NDVI (Figure 74) plot shows that narrow bands of permanent and stable vegetation occur around the Cattle Creek and Dyllingo Creek channels. Vegetation around Stepping Stone and Mouldy Crumpet spring groups is patchy and varies on an annual basis with the greatest extent occurring during the wet season, which suggests that long-term groundwater supply may be less reliable. In the vicinity of Mouldy Crumpet springs, vegetation was most extensive during relatively wetter seasons that occurred in 1992, 1998 to 2001, and 2010 to 2011. Some changes in land cover or land use may have occurred up slope of the Joshua Spring turkey's nest dam around 1990.

The Hovmöller time-series plot for Transect 2 (Figure 75, location shown in Figure 73) intersects the Moses, Keelback and Wobbly spring groups. From the TCW response, landscape wetness around the Moses spring group is generally only detectable during the wet season. However, a pool fed by outflows from the Keelback and Moses springs is apparent. The TCW response suggests that since 1994 this pool has been a significant feature, remaining fairly constant in extent (approximately 200 m long) year round (although this pool appears to have diminished between 1988 and 1994). Another spring-fed pool, downstream of Moses and Keelback springs at the confluence of Cattle and Dyllingo creeks, shows more seasonal variation with a lower wetness index than the pool upstream. However, it is still largely present year round. While minimal variation in greenness is evident in the NDVI response here (Figure 75), it appears that vegetation cover has been relatively stable since 1988 (when data acquisition commenced).

Combining these remotely sensed observations with the signed-digraph models and qualitative mathematical modelling for the 'Springs' landscape group indicates that there is likely to be considerable variability in response to groundwater depletion among the many individual springs and spring groups that comprise the Doongmabulla Springs complex. Further, this inherent variability will likely mean that different levels of groundwater drawdown may potentially impact the ecological functioning of different springs and spring groups. This is a noteworthy set of conclusions given that all 187 springs in the Doongmabulla Springs complex are considered for this BA as a single ecological asset.

As has been emphasised previously the potential impact of groundwater drawdown due to additional coal resource development on these assets depends on the interpretation of the source aquifer(s) for Doongmabulla Springs (Section 3.4 and companion product 2.6.2 (Peeters et al., 2018)). The identity of the source aquifer for the Doongmabulla Springs complex has been contentious and the subject of previous scientific and legal dispute. Further information on the competing arguments for the source aquifer of these springs is provided in Section 3.4. Other references include: JBT Consulting (2015), Webb (2015), Currell (2016), Currell et al. (2017), Evans et al. (2018b) and Fensham et al. (2016).

As detailed in Section 3.4, the Clematis Group aquifer is considered the most plausible primary source aquifer for the Doongmabulla Springs complex, with the Dunda beds contributing minor volumes of groundwater to the easternmost spring groups in the complex (Dusk and Surprise, Figure 73). Leakage through the Moolayember Formation aquitard from the regional groundwater system in confined portions of the Clematis Group aquifer is the likely source for the discharge springs in the western part of the complex (Figure 73). In contrast, more localised groundwater flow in unconfined parts of the Clematis Group aquifer is considered the main source for springs near areas of Clematis Group outcrop (Little Moses and Yukunna Kumoo, Figure 73). Overall, it is inferred from the available evidence that the Doongmabulla Springs complex may represent a regional groundwater discharge feature sourced from the Clematis Group aquifer.

The identity of the source aquifer determines the nature of the impact from additional coal resource development, specifically aquifer depressurisation, on the assets related to the Doongmabulla Springs complex. If the source aquifer is primarily the Clematis Group aquifer then the potential exists for hydrological and ecological impact. Results for cumulative drawdown for both conceptual models used for the Galilee subregion's AEM are presented in Section 3.4. Probabilistic modelling results based on both groundwater model conceptualisations show that 181 of the 187 springs in the Doongmabulla Springs complex have a 5% chance of experiencing additional groundwater drawdown in excess of 0.2 m. The original conceptualisation also predicts that there is also a 50% chance of these 181 springs experiencing this level of drawdown. In comparison, the alternative conceptualisation predicts that none of the springs in the Doongmabulla Springs complex would experience greater than 0.2 m of drawdown at the 50th percentile (median) of all model runs. Further, the original conceptualisation predicts that 120 springs in the Doongmabulla Springs complex have a less than 5% chance (*very unlikely*) of experiencing additional groundwater drawdown in excess of 2 m (there are no model results that exceed 2 m of drawdown at either the 5th, 50th or 95th percentile using the alternative conceptualisation). Section 3.4 suggests that results for the alternative groundwater modelling conceptualisation are more applicable for assessing drawdown at the Doongmabulla Springs complex (the rationale for this assessment is detailed in Section 3.3.2). In addition, and although not directly comparable due to major differences in modelling approach and development scenario, the peak drawdown at the springs from the proposed Carmichael Coal mine development (the mine nearest to these springs) will be about 0.1 to 0.3 m (Currell et al., 2017; GHD, 2013a).

In summary, the following statements can be made about the group of ecological assets that intersects the Doongmabulla Springs complex. First, the weight of available scientific evidence presented in this product, and in companion products 2.1-2.2 (Evans et al., 2018a) and 2.7 (Ickowicz et al., 2018), indicates that the source aquifer for these assets is primarily the Clematis Group aquifer. Second, both groundwater model conceptualisations used in this BA predict that 181 of the 187 springs in the Doongmabulla Springs complex have a 5% chance of experiencing additional groundwater drawdown in excess of 0.2 m. Last, consideration of multiple lines of evidence – including signed digraph models, qualitative mathematical modelling, archived Landsat imagery and ecological knowledge of the threatened vegetation species – indicates that this predicted level of drawdown will impact the ecological functioning of some ecological assets; however, there will be considerable variation in response across different springs and spring complexes. This final point underscores the need for additional local-scale analysis using more detailed geological, hydrological and ecological data to better understand the potential impact responses for individual springs and spring complexes.

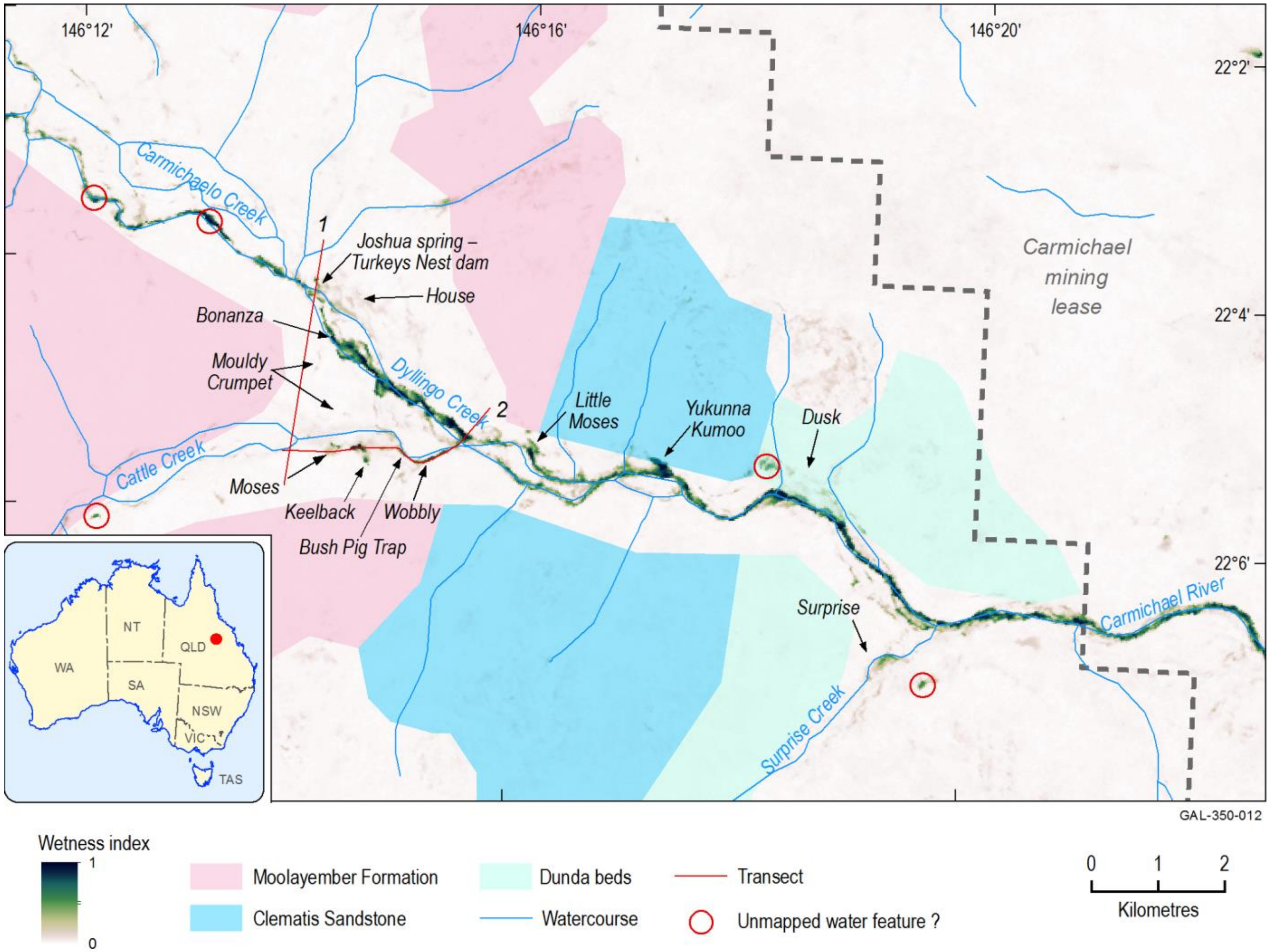

Figure 73 Tasselled cap wetness index map – Doongmabulla Springs complex

The 'wetness index' represents the percentage of time observed as 'wet', based on the tasselled cap wetness (TCW) index. In the period 1987 to 2016, it is the proportion of times a pixel in the Landsat image archive exceeds a TCW index threshold. Each pixel represents a 25 x 25 m square area. A value of '1' represents permanent water, whereas '0' represents dry land and vegetation. Cenozoic sediment cover occurs in areas of this map where outcropping Triassic rocks of the Moolayember Formation, Clematis Sandstone and Dunda beds are not shown.
Data: Queensland Department of Natural Resources and Mines (Dataset 5); Bioregional Assessment Programme (Dataset 6); Queensland Department of State Development Infrastructure and Planning (Dataset 7)

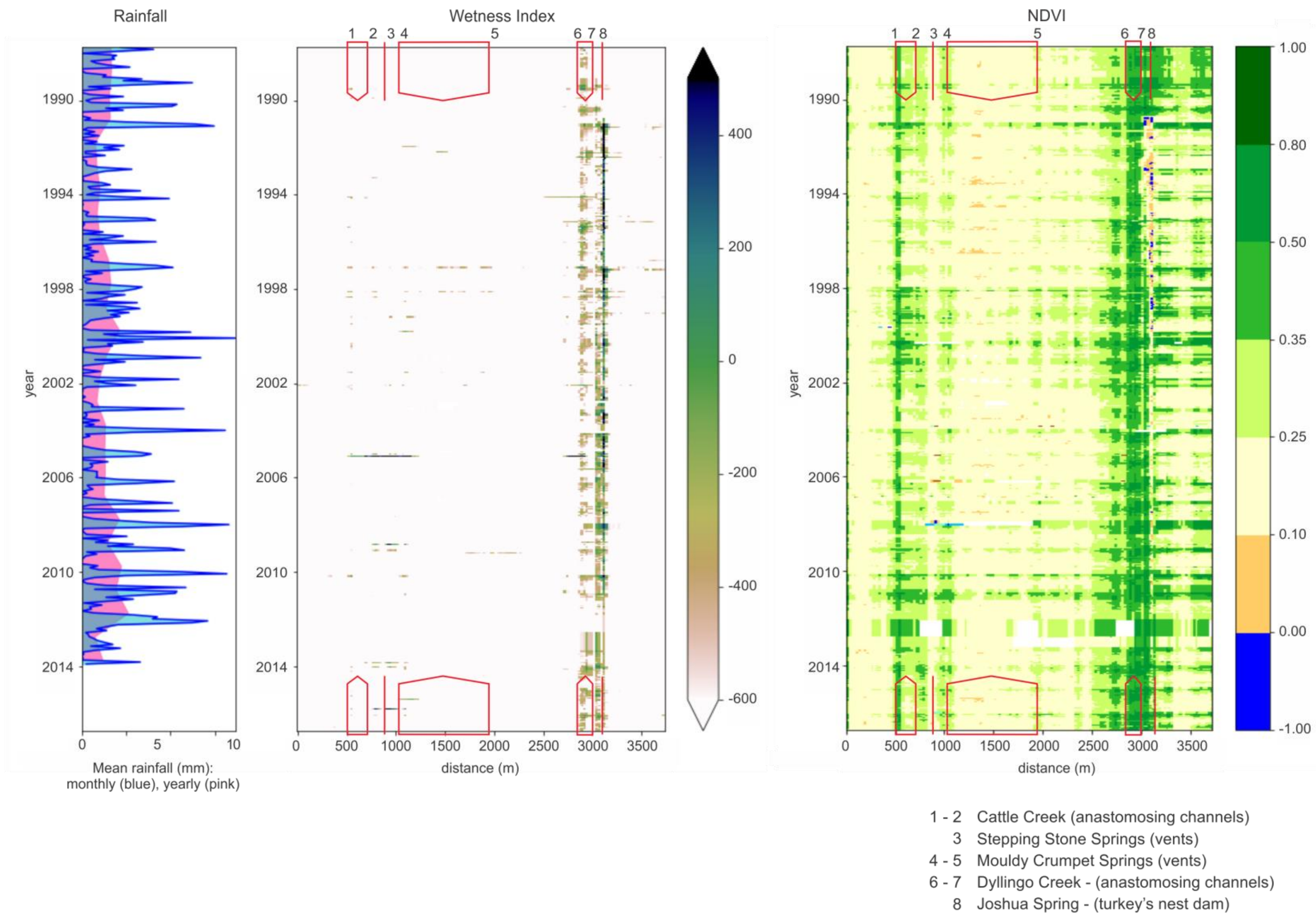

Figure 74 Time – Landsat transect (Transect 1) through the Stepping Stone, Mouldy Crumpet and Joshua spring groups – Doongmabulla Springs complex

Middle panel shows wetness index response above a threshold of –400. Right-hand panel shows normalised vegetation difference index (NVDI) response. Location of Transect 1 on Figure 73.
Data: Bioregional Assessment Programme (Dataset 6)

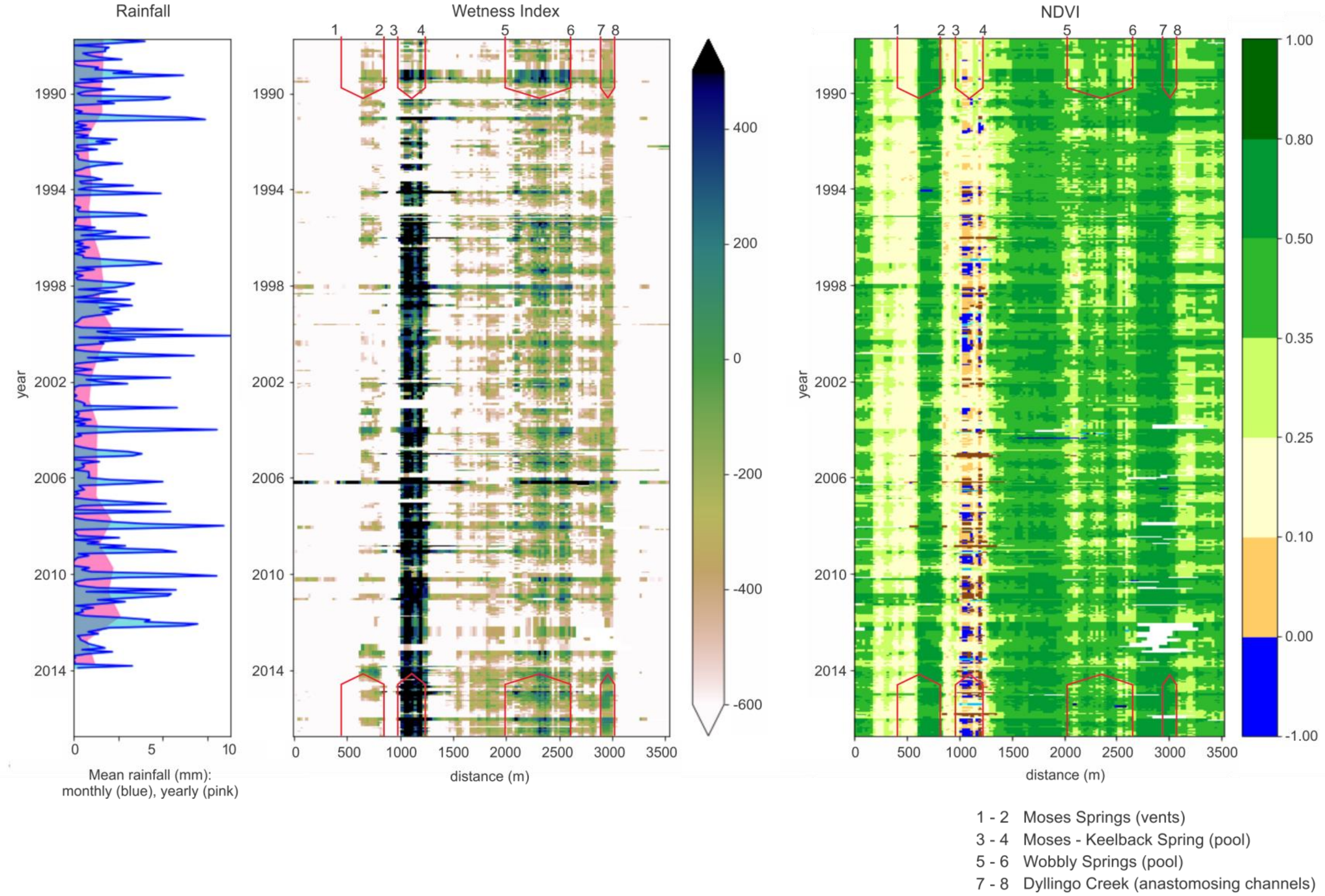

Figure 75 Time – Landsat transect (Transect 2) through the Moses, Keelback and Wobbly spring groups – Doongmabulla Springs complex

Middle panel shows wetness index response above a threshold of –400. Right-hand panel shows normalised vegetation difference index (NVDI) response. Location of Transect 1 on Figure 73.
Data: Bioregional Assessment Programme (Dataset 6)

3.5.2.7 *Assessing potential impacts on individual ecological water-dependent assets: a case study focused on the potential distribution of black ironbox*

Within the operational constraints of the BAs it is not possible to assess potential impacts on each of the 241 ecological water-dependent assets within the zone of potential hydrological change. Instead, this section provides a case study to illustrate how multiple lines of available hydrological and ecological evidence may be used to assess potential impacts on individual assets. The detailed asset analysis presented here may assist future users of this BA to undertake a similar type of assessment, in order to develop a better understanding of potential impacts on, and risks to, a particular asset of interest.

The ecological asset selected for the detailed assessment presented here is the 'potential distribution of Black Ironbox (*Eucalyptus raveretiana*)'. This is asset identification number 2126 in the water-dependent asset register for the Galilee subregion (Bioregional Assessment Programme, 2017). Black ironbox is listed as vulnerable nationally under the EPBC Act. Black ironbox grows to 25 m in height and mostly occurs along watercourses and on floodplains (Figure 76), although it may also occur (less commonly) in open woodland away from watercourses.

Black ironbox does not grow in pure stands, but rather is co-dominant with other tree species, including river red gum (*E. camaldulensis*), Moreton Bay ash (*Corymbia tessellaris*), river oak (*Casuarina cunninghamiana*) and weeping paperbark (*Melaleuca fluviatilis*). Black ironbox occurs mostly in coastal and sub-coastal parts of central Queensland, but is also recorded along the Suttor River (and its upper tributaries) in the Galilee assessment extent. It grows on soils that include sands, loams, light clays and cracking clays at up to 300 m above sea level.

The 'potential distribution of Black Ironbox (*Eucalyptus raveretiana*)' intersects with about 87 km^2 of vegetation ecosystems and 145 km of stream network in the northern part of the zone of potential hydrological change for the Galilee subregion (Figure 76). As noted previously, the potential geographic extent of this and other species within the zone is based on maximum entropy (MAXENT) modelling that relies largely on physical parameters and past observations of the presence and absence of the species. This means that the modelled extent of this asset within the zone has not been validated by field-based studies undertaken for this BA. Further work, which is beyond the scope of this assessment, would be needed to confirm the actual presence and distribution of black ironbox in the areas of the zone where it is modelled to occur.

The 'potential distribution of Black Ironbox (*Eucalyptus raveretiana*)' overlies parts of the northernmost area of the surface water zone of potential hydrological change, along sections of the Suttor River just upstream of Lake Dalrymple (Figure 21). However, this asset extent does not intersect with the groundwater zone of potential hydrological change (Figure 20). The asset extent within the surface water zone intersects areas that may experience hydrological changes due to additional coal resource development, in particular an increase in the number of zero-flow days per year (Figure 28). This includes the area within the zone of potential hydrological change where surface water modelling predicts the largest increases in the number of zero-flow days (Section 3.3.3). These modelled hydrological changes occur in the main channel of the Belyando River, and the Suttor River downstream of its junction with the Belyando, in particular, the approximately

250 km stretch of this river network from downstream of the junction with Native Companion Creek to Lake Dalrymple (Burdekin Falls Dam).

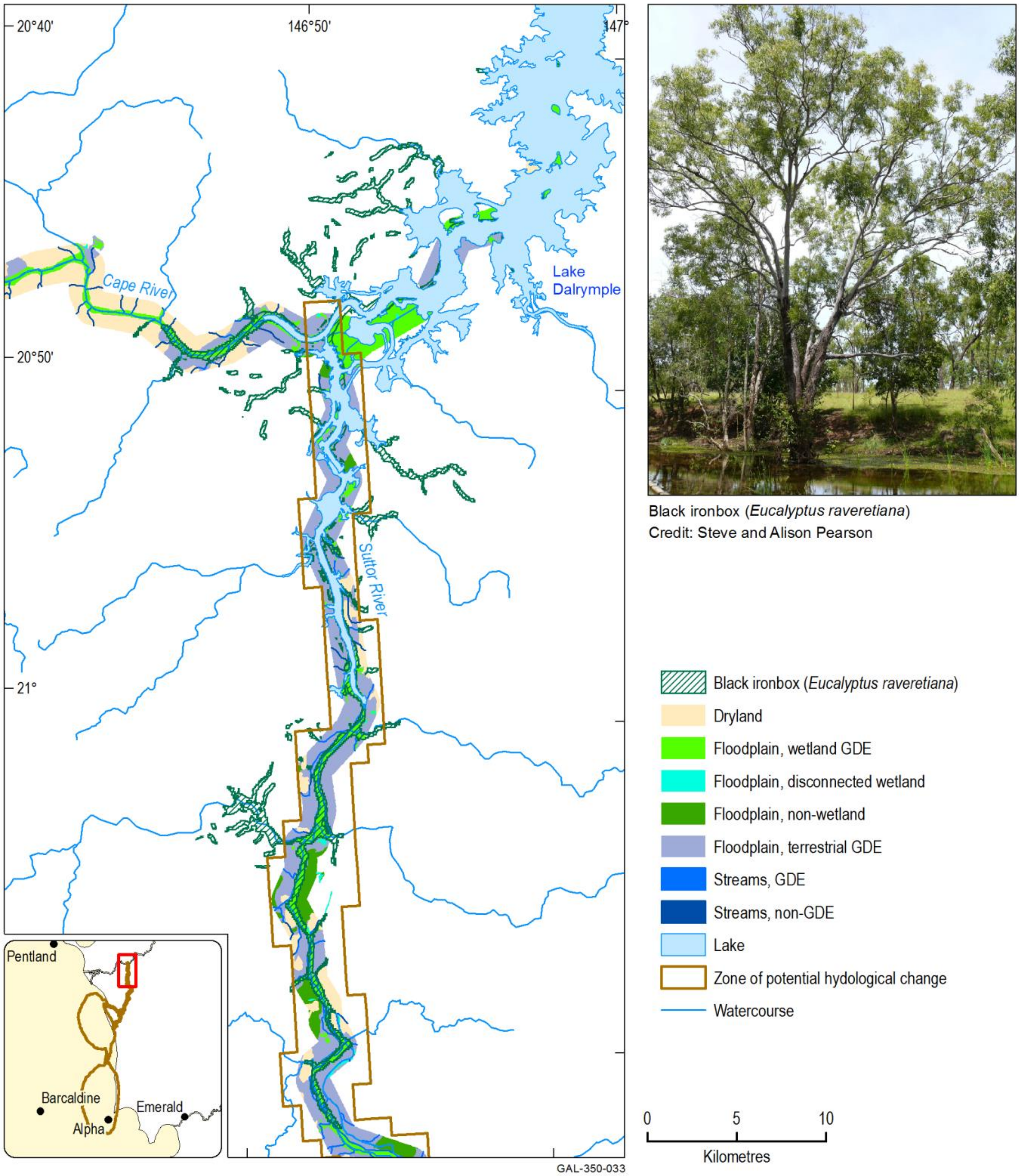

Figure 76 Intersection of 'potential distribution of Black Ironbox (*Eucalyptus raveretiana*)' and landscape groups in the northern part of the zone of potential hydrological change for the Galilee subregion

The 'potential distribution of Black Ironbox (Eucalyptus raveretiana)' is asset identification number 2126 in the water-dependent asset register for the Galilee subregion
Data: Bioregional Assessment Programme (Dataset 1, Dataset 2)

Along the northernmost part of the Suttor River (above the junction with Lake Dalrymple), there is a 5% chance that low-flow days will increase by 3 to 20 days per year in both the short-term period (2013 to 2042) and the long-term period (2073 to 2102). In addition, the modelling indicates that there is a 5% chance that low-flow spells will increase by 3 to 10 days per year in the long-term period (2073 to 2102) and that overbank flows will decrease by 0.02 to 0.05 events per year over the short-term period (2013 to 2042) (meaning one fewer overbank flow every 20 to 50 years on average) (Figure 48 and Figure 49). Hydrological changes (groundwater or surface water) are not predicted along the Cape River upstream of the junction with the Suttor River. As mentioned, changes to the groundwater system in areas where the black ironbox occurs in the zone are *very unlikely* as the asset extent does not intersect with the groundwater zone of potential hydrological change for the Galilee subregion (Figure 20).

In this case study, the intersection of landscape groups with the extent of individual assets is used to assess potential impacts to the natural and human-modified ecosystems represented by each landscape group. Seven landscape groups are contained within the asset extent of the 'potential distribution of Black Ironbox (*Eucalyptus raveretiana*)' within the zone of potential hydrological change (Table 42). This includes a relatively small area of vegetation (14.3 km^2) that is not considered to be water-dependent as it overlaps with the 'Dryland' and 'Floodplain, non-wetland' landscape groups. This small area of non-water dependent vegetation within the asset extent likely reflects the challenges of integrating datasets and assessment methods at different scales to estimate the geographic distribution of the asset and the overlapping landscape groups.

Most of the remaining asset extent within the zone is classified as groundwater-dependent vegetation (65.2 km^2) (the 'Floodplain, terrestrial GDE' and the 'Floodplain, wetland GDE' landscape groups) or groundwater-dependent streams (145 km) ('Streams, GDE'). Two of the four receptor impact models developed for this assessment ('Floodplain, terrestrial GDE' and 'Woody riparian vegetation') are relevant when assessing potential impacts on the 'potential distribution of Black Ironbox (*Eucalyptus raveretiana*)' within the zone. Further details about the development of these receptor impact models is in companion product 2.7 for the Galilee subregion (Ickowicz et al., 2018), with the application of these models discussed in Section 3.4.

The 'Floodplain, terrestrial GDE' receptor impact model predicts changes to percent foliage cover of floodplain trees, such as *Eucalyptus*, *Corymbia* or *Acacia* species that dominate the alluvial river and creek flats in the 'Floodplain, terrestrial GDE' landscape group. These species co-occur with *Eucalyptus raveretiana* (as described above). The asset occurs in areas of the 'Floodplain, terrestrial GDE' landscape group that are considered to be 'at minimal risk' due to additional coal resource development (Figure 62).

Within the zone of potential hydrological change, most streams within the asset extent are classified in the 'Streams, GDE' (129 km or 89% of streams) landscape group. The 'Woody riparian vegetation' receptor impact model predicts changes to the percent foliage cover of *Eucalyptus camaldulensis* and *Melaleuca* spp. in the 'Streams, GDE' landscape group. The 'High-flow macroinvertebrate' receptor impact model is relevant to both the 'Streams, GDE' and 'Streams, non-GDE' landscape groups. However, this receptor impact model is not relevant to assessing potential impacts to the black ironbox asset as it predicts changes to the density of mayfly nymphs (order Ephemeroptera in the family Baetidae of the genus *Offadens*) in riffle habitat, 3 months after the end of the wet season.

Considering the multiple lines of evidence generated through this BA, as well as the existing knowledge base about the hydrological dependence and ecological characteristics of the black ironbox, allows for an assessment of potential impacts on this asset due to additional coal resource development. Integrating this information with the experts' opinions developed through the receptor impact modelling process provides strong evidence that potential impacts to the 'potential distribution of Black Ironbox (*Eucalyptus raveretiana*)' are *very unlikely* within the zone of potential hydrological change as:

- The asset extent does not intersect with the groundwater zone of potential hydrological change, meaning that groundwater drawdown due to modelled coal resource development is *very unlikely* to impact this asset.
- The 'Floodplain, terrestrial GDE' receptor impact model relevant to the 'Floodplain, terrestrial GDE' landscape group predicts 'minimal risk' within the asset extent (i.e. decreases of less than 5% foliage cover of floodplain trees (see Section 3.4.6)).
- The 'Woody riparian vegetation' receptor impact model relevant to the 'Streams, GDE' landscape group predicts 'minimal risk' within the asset extent (i.e. decreases of less than 5% foliage cover of floodplain trees (see Section 3.4.4)).

Table 42 Landscape groups within the zone of potential hydrological change for the Galilee subregion and the extent of their overlap with the 'potential distribution of Black Ironbox (*Eucalyptus raveretiana*)'

Landscape group	Area or length	Extent in zone of potential hydrological change	Extent overlapping with 'potential distribution of Black Ironbox (*Eucalyptus raveretiana*)'
Dryland	Area (km^2)	8,134	9.1
Floodplain, disconnected wetland	Area (km^2)	19	7.2
Floodplain, non-wetland	Area (km^2)	2,098	5.2
Floodplain, terrestrial GDE	Area (km^2)	2,433	40.7
Floodplain, wetland GDE	Area (km^2)	153	24.5
Total area	Area (km^2)	**12,837**	**86.7**
Streams, GDE	Length (km)	2,801	129
Streams, non-GDE	Length (km)	3,484	16
Total length	Length (km)	**6,285**	**145**

The 'potential distribution of Black Ironbox (Eucalyptus raveretiana)' is an ecological water-dependent asset of the 'Vegetation' subgroup, and is listed as asset identification number 2126 in the water-dependent asset register for the Galilee subregion. The three non-floodplain landscape groups that occur in the Galilee assessment extent are not included in this table as they do not intersect with the black ironbox asset extent in the zone of potential hydrological change.
GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 1)

3.5.3 Economic assets

The groundwater and surface water resources in the central-eastern part of the Galilee subregion are utilised by the local population for a variety of purposes. These include town water supplies (e.g. the townships of Jericho and Alpha), stock and domestic supplies, and some minor irrigation usage (see companion product 1.5 for further information on water use in the Galilee subregion (Evans et al., 2015)). Consequently, the region's water resources have an intrinsic economic value, and this may potentially be impacted by the proposed coal resource developments planned for the Galilee Basin. For example, groundwater drawdown caused by dewatering coal mines may reduce water levels within a bore, potentially increasing pumping costs or, at worst, causing an existing bore to run permanently dry. The management arrangements and/or infrastructure that control the access and supply of water resources in the Galilee subregion provide the foundation for defining the register of economic water-dependent assets (Bioregional Assessment Programme, 2017).

Most of the economic water-dependent assets within and around the Galilee subregion's zone of potential hydrological change are associated with the Great Artesian Basin (GAB). During the time that the various stages of the BA for the Galilee subregion were being undertaken, the management of the Queensland part of the GAB was provided for by the *Water Plan (Great Artesian Basin) 2006*, which was implemented through the *Great Artesian Basin Resource Operations Plan* (DNRM, 2012). Consequently, all of the analysis of impacts to economic assets in the GAB reported in this product is based upon the framework of groundwater management areas and groundwater management units that are defined in the *Water Plan (Great Artesian Basin) 2006*.

Preliminary spatial analysis of bores within and nearby to the zone of potential hydrological change in the Galilee subregion (Figure 77) indicated that there are two groundwater management areas of the GAB that are potentially most affected by drawdown due to additional coal resource development:

- Barcaldine East Groundwater Management Area
- Barcaldine North Groundwater Management Area.

Within the vicinity of the zone of potential hydrological change, one of the main groundwater systems managed under the auspices of both of these groundwater management areas is the Clematis Group aquifer. This is also one of the three aquifers specifically modelled and assessed for this BA. For the Barcaldine East Groundwater Management Area, the Clematis Group is managed as part of the Barcaldine East 4 Groundwater Management Unit, along with the aquifers of the Moolayember Formation, Warang Sandstone and Rewan Group. For the Barcaldine North Groundwater Management Area, the Clematis Group is managed under the Barcaldine North 3 Groundwater Management Unit, along with the Moolayember Formation.

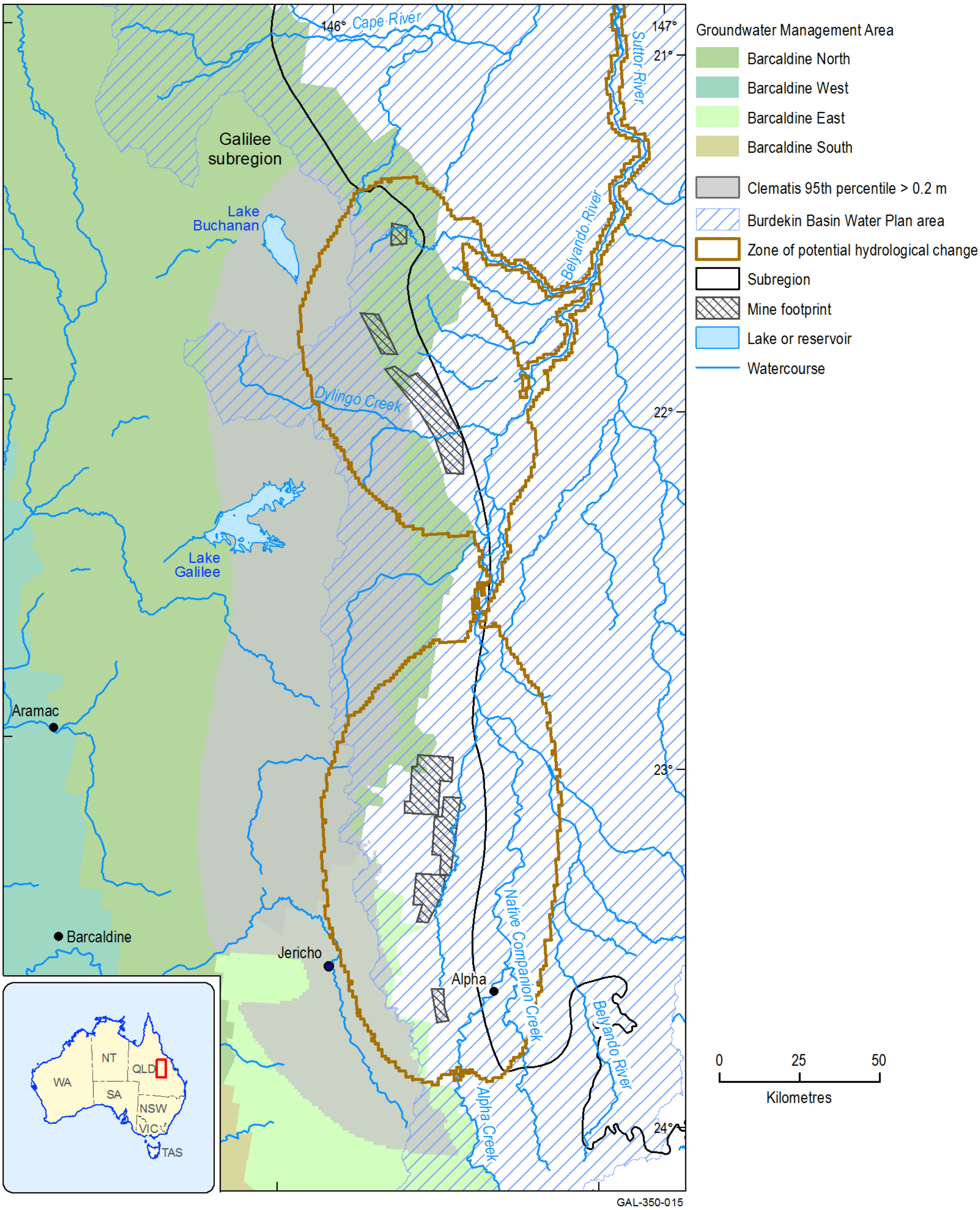

Figure 77 Water management areas in the vicinity of the central-eastern Galilee subregion

The grey shaded zone depicted on this map indicates the spatial extent of drawdown >0.2 m at the 95th percentile of modelling results for the Clematis Group aquifer, based on the probabilistic outputs of the analytic element model for the Galilee subregion. This aquifer is the main Great Artesian Basin hydrostratigraphic unit managed under the *Water Plan (Great Artesian Basin) 2006* for which drawdown predictions have been modelled for this bioregional assessment. Modelled drawdown in the Clematis Group aquifer may potentially impact water-dependent economic assets in both the Barcaldine North and Barcaldine East groundwater management areas.

Data: Bioregional Assessment Programme (Dataset 3, Dataset 8, Dataset 9); Queensland Department of Natural Resources and Mines (Dataset 10); Bureau of Meteorology (Dataset 11)

As probabilistic drawdown predictions are available for the Clematis Group aquifer from the groundwater modelling undertaken for this BA, it is possible to evaluate potential mining impacts on the various bores that occur within the Barcaldine East 4 and Barcaldine North 3 groundwater management units. There are also some groundwater economic assets within the zone of potential hydrological change that rely on the near-surface (watertable) aquifer hosted in Quaternary alluvium or other Cenozoic sediments. As BA modelling results are also available for this aquifer, it is possible to assess any potential impacts to groundwater assets that rely on these Cenozoic aquifers. The groundwater modelling also produced probabilistic drawdown estimates for the upper Permian coal measures, although this hydrostratigraphic unit is not specifically managed under the 2006 GAB water plan.

The Assessment team recognises, however, that the 2006 GAB water plan expired in September 2017, and has been replaced by a new water-planning document, namely the *Water Plan (Great Artesian Basin and Other Regional Aquifers) 2017*. This new water plan for the GAB will be implemented through a water management protocol (replacing the former resource operations plan), known as the Great Artesian Basin and Other Regional Aquifers Water Management Protocol. The new GAB water plan will alter the previous framework of management areas and units against which impacts to economic assets are reported for this BA. Importantly, the GAB and other regional aquifers (GABORA) plan is divided into a new system of groundwater units, which comprises the water from specified geological units that cover parts of the broader plan area. For example, the new Clematis groundwater unit specifies six geological formations, including the Clematis Group, Dunda beds, Moolayember Formation and Rewan Group. The various groundwater units may also be further subdivided into groundwater sub-areas, reflecting specific geographic variations that may exist for a particular geographic unit (e.g. Galilee Clematis and Bowen Clematis sub-areas). Further information about how the new GABORA plans were developed, as well as their intent and variations from the former management arrangements are documented in a Statement of Intent (DNRM, 2017).

In the context of the BA for the Galilee subregion, an important change proposed as part of the new GABORA water plan is the inclusion of the Betts Creek beds in the water-planning framework. This new addition to the management of GAB water resources reflects the anticipated development of the large-scale coal mining operations that will extract coal from (and also dewater) the Betts Creek beds (and associated Permian stratigraphic units). Even though the aquifers of the Betts Creek beds are generally not directly connected to the main aquifers of the GAB, there may be potential for hydraulic connectivity to develop between the Betts Creek beds and the Clematis Group aquifer, due to large-scale mine dewatering or other mining impacts (e.g. subsurface fracturing above underground longwall mining panels). Hence, the GABORA water plan recognises that existing groundwater users in this region would be better served if both of these aquifers are managed under arrangements of a single plan. The Clematis Group aquifer (which was previously included in the 2006 GAB water plan) will continue to be managed under the GABORA water plan.

In addition to the water resources of the GAB, the central and eastern areas of the zone of potential hydrological change for the Galilee subregion occur within the Burdekin Basin Water Plan area (Figure 77). This area is managed under the *Water Plan (Burdekin Basin) 2007*. The Burdekin Basin Water Plan area is defined on the basis of the surface water catchment of the

Burdekin River, and the management strategies incorporated into this plan are generally not concerned with groundwater resources. As shown in Figure 77, there is considerable overlap between the water plan areas of the GAB and the Burdekin Basin, given their differing focus on groundwater resources (GAB) and surface water resources (Burdekin). Most of the area covered by the zone of potential hydrological change in the Galilee assessment extent is part of the Belyando-Suttor Subcatchment of the Burdekin Basin Water Plan (Figure 77).

3.5.3.1 Water-dependent economic assets in the Galilee assessment extent

There are 129 economic water-dependent assets in the water-dependent asset register for the Galilee assessment extent, consisting of 96 groundwater economic assets and 33 surface water economic assets. Both groundwater and surface water economic assets are subdivided into two classes, either ‘water access rights’ or ‘basic water rights’, with most of the latter class being for water supply for stock and domestic purposes. Within the asset register, the individual ‘water access rights’ and ‘basic water rights’ are grouped by their type and spatial location according to the relevant groundwater or surface water management zones or areas to create the assets. As shown in Table 43, each asset comprises a variable number of individual elements, which can range from one element per asset up to many hundreds of elements per asset. Further information about the economic assets evaluated in the BA for the Galilee subregion is provided in companion product 1.3 (Sparrow et al., 2015), with the updated water-dependent asset register available at Bioregional Assessment Programme (2017).

Table 43 Summary of economic assets in the Galilee assessment extent

	Asset class	Number of assets	Number of elements	Mean number of elements per asset	Maximum number of elements per asset
Groundwater management zone	Water access right	39	350	9	77
	Basic water right (stock and domestic)	57	4513	79.2	509
Surface water management zone	Water access right	25	123	4.9	21
	Basic water right (stock and domestic)	8	26	3.3	8
Total		**129**	**5012**	**na**	**na**

na = not applicable
Data: Bioregional Assessment Programme (Dataset 1)

Elements associated with surface water assets are mainly water extraction points located on part of a stream network. In the Galilee assessment extent, most surface water assets only occur on the major river channels, such as the Thomson, Barcoo and Flinders rivers. As shown in companion product 1.5 (Evans et al., 2015), the only surface water assets near the central-eastern boundary of the Galilee subregion occur at specific points along the Belyando River and some headwater tributaries. All of the surface water assets in this area are classified as basic water rights that are managed under the Burdekin Basin Water Plan.

Most elements associated with groundwater economic assets are individual bores that have been drilled to extract groundwater from a target aquifer. Many bores in the GAB extract groundwater from deeper confined aquifers (i.e. not the near-surface watertable). Consequently, it is important that the source aquifer of the bore is known when evaluating potential impacts due to additional coal resource development for this BA. Without information relating to the source aquifer of an individual bore, it may not be possible to evaluate drawdown impacts from the BA's groundwater modelling outputs.

For BA purposes, assessing impacts to groundwater bores in the Galilee assessment extent relies on having reliable information to assess the source aquifer for each bore. The probabilistic groundwater modelling outputs for specific aquifer layers (outlined in companion product 2.6.2 for the Galilee subregion (Peeters et al., 2018)) are then used to evaluate the range of potential drawdown values that may occur for any bore that extracts groundwater from the target aquifer. This analysis method differs from the approach taken for assessing impacts to groundwater-dependent ecological (Section 3.5.2) and sociocultural (Section 3.5.4) assets, as most of these are considered to access the shallow, near-surface aquifer, which is commonly hosted in Quaternary alluvium and other Cenozoic sediments. The important exception to this rule is for some springs (ecological assets) that source their water from deeper confined aquifers (and hence impacts to springs are evaluated in a similar way to the groundwater-dependent economic assets).

The groundwater modelling undertaken for the BA for the Galilee subregion provided probabilistic estimates for groundwater drawdown due to additional coal resource development for three separate aquifer layers, namely:

- Quaternary alluvium and Cenozoic sediments (AEM layer 1) – the geologically young, uppermost aquifer that mainly hosts the regional watertable within the zone of potential hydrological change for the Galilee subregion
- Clematis Group aquifer (AEM layer 3) – a Triassic hydrostratigraphic unit, it occurs in limited areas of outcrop to the west of the seven proposed coal mines of the CRDP for the Galilee subregion, and mostly forms a deeper confined aquifer system that provides water resources to many stock and domestic bores in the Barcaldine North 3 and Barcaldine East 4 groundwater management units
- upper Permian coal measures (AEM layer 5) – the geological unit that contains the coal resources targeted for mining at the seven coal mines in the CRDP for the Galilee subregion. This is the main geological unit that needs to be dewatered at each mine site to allow open-cut and underground mining to occur. However, as previously noted, under the 2006 GAB water plan, the upper Permian coal measures are not specifically managed as part of any groundwater management area.

The focus of much of this section is on evaluating potential impacts to water-dependent economic assets that source water from these hydrostratigraphic layers. Additionally, any other bores registered in the Queensland groundwater bore database that are not included as part of a water-dependent economic asset in the BA are also assessed, providing the source aquifer for the bore is known.

3.5.3.2 Surface water economic assets

There is a single surface water economic asset within the zone of potential hydrological change for the Galilee subregion (BA water-dependent asset number 2311, Bioregional Assessment

Programme (2017)). This is a basic water right under the Burdekin River water resource plan, specifically part of the Belyando-Suttor River Subcatchment Area. This single surface water asset has three different basic water right extraction locations that occur within the zone of potential hydrological change, two of which are on the Belyando River and one on its headwater tributary of Native Companion Creek (Figure 78). Using the BA's modelled surface water predictions (outlined in companion product 2.6.1 for the Galilee subregion (Karim et al., 2018)) for the Belyando River and its main tributaries, an estimate of potential surface water changes at the model nodes nearest these three extraction points is provided in Table 44. This tabulated summary is focused on the predicted reductions in the annual flow volume, as well as the increase in zero-flow days, as these two hydrological response variables are considered most suited to evaluate the potential impacts to these surface water assets.

Table 44 Modelled surface water changes to annual flow and zero-flow days at nodes proximal to basic surface water rights under the *Water Plan (Burdekin Basin) 2007* area, within the zone of potential hydrological change for the Galilee subregion

Surface water model node	Location details	Percent reduction in annual flow volume (%)			Increase in zero-flow days per year		
		5th	50th	95th	5th	50th	95th
40	Situated on Native Companion Creek, this is the nearest model node to the southern-most element of the basic surface water right in the Burdekin Water Resource Plan area, within the zone of potential hydrological change (Figure 78).	<1	<1	<1	2	14	152
44	Situated on the Belyando River downstream of the southern cluster of modelled coal mines, this model node occurs very close to the central element of the basic surface water right in the Burdekin Water Resource Plan area, within the zone of potential hydrological change (Figure 78).	<1	1.1	1.4	8	51	261
53	Situated on the Belyando River downstream of all inflow tributaries directly affected by coal mining, and just upstream of the junction with the Suttor River, this model node occurs very close to the location of the northern-most element of the basic surface water right in the Burdekin Water Resource Plan area, within the zone of potential hydrological change (Figure 78).	<1	<1	1.2	19	77	260

Data: Bioregional Assessment Programme (Dataset 12)

Based on the results presented in Table 44, some salient observations of the modelled changes to the basic surface water right asset include:

- The surface water element on Native Companion Creek (near node 40) is not expected to experience any significant changes in annual flow volume, as all predictions at the 5th, 50th and 95th percentile are below the 1% threshold. However, the modelled increase in zero-flow days is more variable across the range of predictions. At the 5th and 50th percentiles the modelled increase in number of zero-flow days is less than 15 days. However, an increase of over 150 zero-flow days is modelled at node 40 for the 95th percentile.

- The hydrological changes are greater for the other two element locations (near nodes 44 and 53 on the Belyando River) that comprise this surface water asset. Overall, the reductions in annual flow remain relatively low, only just exceeding 1% at the median result for node 44 (and up to 1.4% at the 95th percentile). Zero-flow days are also expected to increase at both sites, with similar median results suggesting an increase of greater than 50 days per year of zero-flow conditions. Very large increases of similar magnitude (around 260 days) occur at the 95th percentile in both cases.

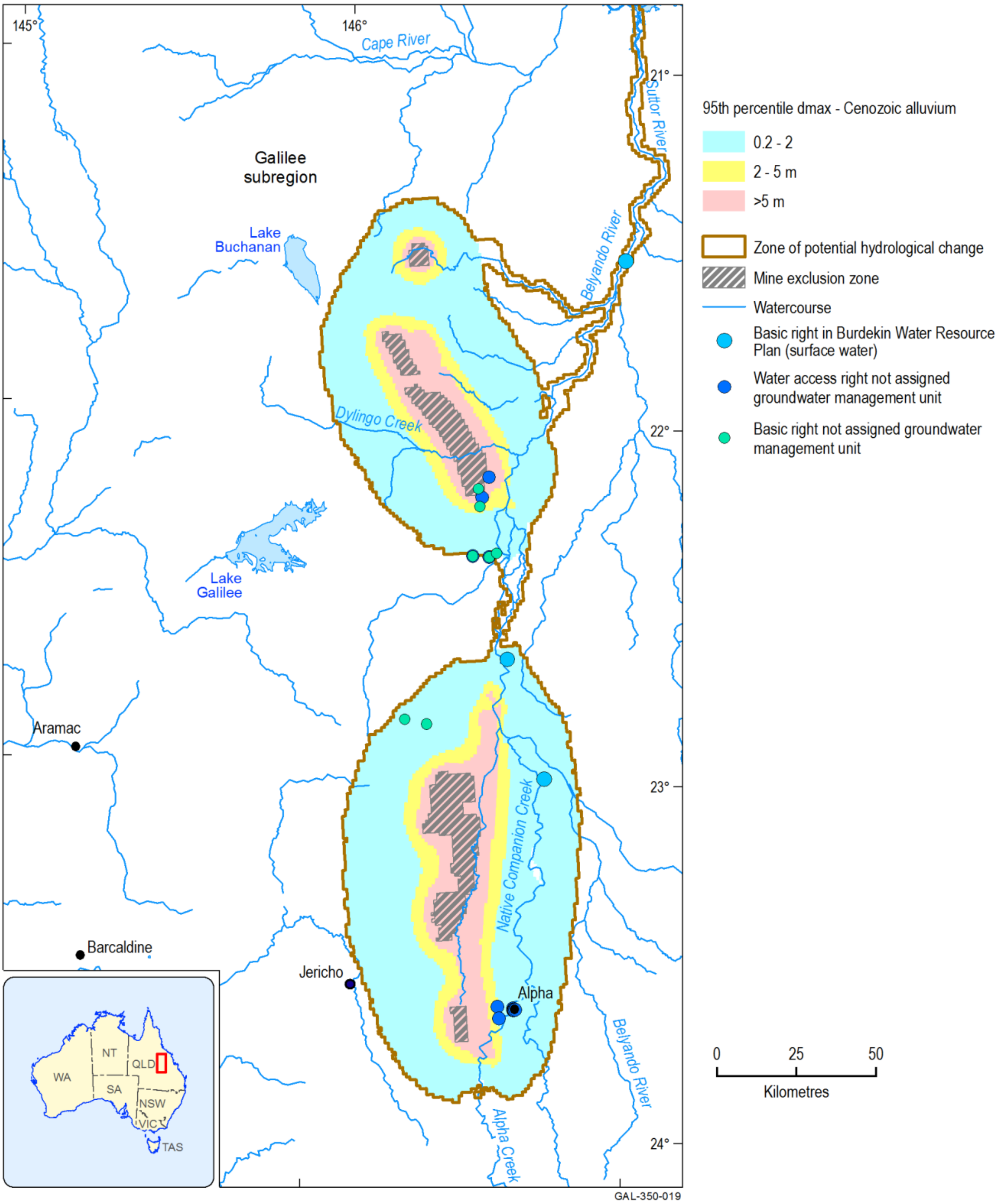

Figure 78 Element locations associated with surface water economic assets managed under the Burdekin Basin Water Plan and groundwater economic assets that are not part of a specified groundwater management unit, within the zone of potential hydrological change in the Galilee subregion

Data: Bioregional Assessment Programme (Dataset 1, Dataset 3, Dataset 8)

3.5.3.3 Groundwater economic assets

3.5.3.3.1 Potentially impacted groundwater economic assets

The Clematis Group aquifer is the main hydrogeological unit managed under the 2006 GAB water plan that occurs near the central-eastern margin of the Galilee subregion, in the area of the proposed coal mining developments modelled for this BA. Using a similar approach to that which was used to create the groundwater component of the zone of potential hydrological change (Section 3.3), the area of the Clematis Group with greater than 0.2 m of drawdown at the 95th percentile of all modelled predictions was used to identify relevant water-dependent assets that may potentially be impacted due to additional coal resource development. The results of this analysis are presented in Figure 79, showing the area of predicted drawdown >0.2 m in the Clematis Group aquifer at the 5th, 50th and 95th percentile of all modelling results. Notably, the areal extent of the Clematis Group aquifer that is potentially impacted by drawdown is greatest at the 95th percentile. Additionally, it is only at the 95th percentile that any areas are predicted to experience more than 2 m of drawdown in the Clematis Group, and this occurs only in a relatively isolated area near to the two nearest mines in the northern cluster (China Stone and Carmichael).

As shown in Figure 79, the Clematis Group aquifer occurs only to the west of all the modelled coal mines in the CRDP (i.e. it does not exist directly in the areas targeted for mining), although it occurs much nearer to the cluster of northern mines than to those mines in the south. There is also some degree of overlap between this Clematis drawdown zone and the zone of potential hydrological change, even though the latter zone is not directly relevant to assessing impacts within the confined Clematis groundwater system.

Spatial overlay analysis using a geographic information system (GIS) approach indicates that there are three groundwater economic assets associated with the Clematis Group aquifer that are potentially affected by drawdown due to additional coal resource development in the Galilee subregion (Bioregional Assessment Programme, 2017). These are the:

- basic water right in Barcaldine East 4 Groundwater Management Unit (BA asset identification number 2217)
- basic water right in Barcaldine North 3 Groundwater Management Unit (BA asset identification number 2220)
- water access right in Barcaldine North 3 Groundwater Management Unit (BA asset identification number 2276).

The numbers of individual elements (i.e. different bores) that will potentially experience drawdown within the range of 0.2 to 2 m at the 5th, 50th and 95th percentile for each of these three economic assets are shown in Table 45. In all cases, the total number of bores potentially affected by drawdown in the Clematis Group aquifer is less than the entire total number of bores in the assessment extent for each groundwater management unit. In addition, there are no asset-related bores (elements) that are expected to experience greater than 2 m of drawdown, even at the 95th percentile of all model results.

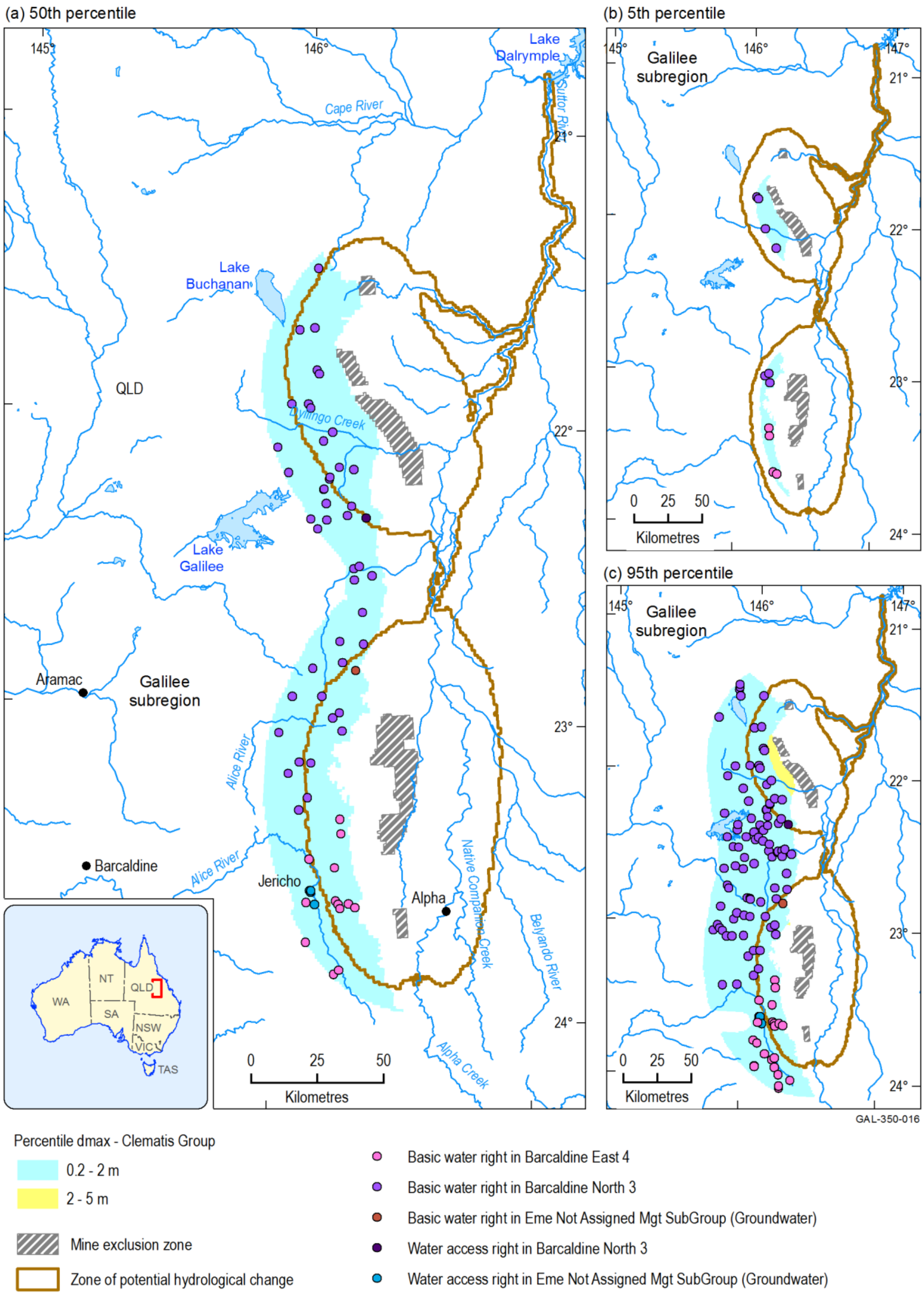

Figure 79 Variation in the extent and magnitude of groundwater drawdown for the 5th (a), 50th (b) and 95th (c) percentile results for the Clematis Group aquifer near the central-eastern margin of the Galilee subregion, overlain with relevant groundwater economic assets

Data: Bioregional Assessment Programme (Dataset 1, Dataset 3, Dataset 8)

Table 45 Impacts to groundwater-dependent economic assets sourced from the Clematis Group aquifer due to additional coal resource development in the Galilee subregion

Asset ID	Asset name	Total number of bores in assessment extent	Managed aquifers	Number of bores with additional drawdown 0.2–2 m			Maximum amount of drawdown predicted (m)		
				5th	50th	95th	5th	50th	95th
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

There is only one water access right in the Barcaldine North 3 Groundwater Management Unit that occurs within the area of predicted Clematis drawdown >0.2 m.
Data: Bioregional Assessment Programme (Dataset 6, Dataset 8)

In addition to the three economic assets that each have a specified groundwater management unit under the *Water Plan (Great Artesian Basin) 2006*, there are a further two groundwater-dependent economic assets that are potentially impacted, but not specifically assigned to GAB groundwater management units (Figure 78 and Figure 79). In the water-dependent asset register for the Galilee subregion (Bioregional Assessment Programme, 2017) these are identified as:

- water access right in Eme[2] Not Assigned Management Subgroup (Groundwater) (BA asset identification number 2287)
- basic right in Eme Not Assigned Management Subgroup (Groundwater) (BA asset identification number 2241).

There are two likely reasons why these assets are not assigned to specific groundwater management units. Firstly, the bores that comprise these assets may only occur within the area of the Burdekin Basin Water Plan area, which is mainly concerned with management of the surface water resources and generally does not assign bores to specific management subgroups. The other possible reason relates to any bores that are part of the GAB management area, but which access groundwater from an aquifer which is not a specified part of a groundwater management unit. For example, the Dunda beds and Rewan Group are not specified aquifers managed under the Barcaldine North Groundwater Management Area.

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

Within the zone of potential hydrological change, the unassigned water access right (BA asset identification number 2287) comprises fifteen individual bores that occur in three main clusters:

- seven bores near the township of Alpha, most of which are part of Alpha's town water supply system – information available from the Queensland bore database indicates that these are relatively shallow bores (around 35 to 50 m deep) that most likely source water from the Quaternary alluvium and Cenozoic sediment aquifer associated with Alpha Creek
- four bores near the township of Jericho, most of which are part of Jericho's town water supply system – information available from the Queensland bore database indicates that these are relatively deep bores (e.g. from 87 to 123 m deep) that likely source water from the confined aquifer system of the Clematis Group
- four irrigation bores near the southern end of the proposed Carmichael Coal Mine – the source aquifer of these bores is generally not specified in the Queensland bore database, although the bores are commonly greater than 50 m deep (some over 100 m deep), which suggests that they may access groundwater from a deeper confined aquifer system, such as the Dunda beds in the upper part of the Rewan Group.

As noted above, as this asset is not specifically assigned to any groundwater management unit there is some variability in the interpreted source aquifer. Thus, to better understand the potential impacts due to additional coal resource development on this asset, it is necessary to assess drawdown impacts separately for the three geographically different bore clusters.

Companion product 2.6.2 for the Galilee subregion (Peeters et al., 2018) noted that the hydrogeological conceptualisation that underpins the groundwater drawdown predictions from the AEM for the Galilee subregion is not appropriate for assessing potential impacts on the Alpha town water supply bores. This is mainly due to the poor understanding and characterisation of the hydrogeological properties of the deeper sequence of the Galilee Basin strata, particularly the basal Joe Joe Group. Although the town water supply bores at Alpha extract groundwater from alluvial aquifers associated with Alpha Creek, existing data from deeper bores in the area shows that these shallow Quaternary and Cenozoic sediments sit directly atop the rocks of the Joe Joe Group. Thus, the alluvial aquifer at Alpha is not connected to the alluvium and sediments that overlie the upper Permian coal measures for which drawdown is simulated in the AEM. Consequently, for drawdown impacts to propagate from the mines to the bores around Alpha, the drawdown in the upper Permian coal measures must first overcome the hydraulic resistance of the lower Permian units that separate the coal seams from the Joe Joe Group. Secondly, the hydraulic resistance between the alluvial deposits at Alpha and the Joe Joe Group also needs to be overcome. During development of the AEM for the Galilee subregion, research by the Assessment team indicated that scant information exists on the hydrogeological characteristics and groundwater flow systems of the Joe Joe Group, especially how this unit may contribute to (or impede) regional groundwater flow. Thus, the lack of understanding about groundwater systems and properties of the Joe Joe Group means that the conceptualisation used in the AEM is not suitable for assessing groundwater impacts due to additional coal resource development at the Alpha town water supply (including those bores that are part of this unassigned water access right). Further work using appropriate local-scale data is required to predict potential impacts on the Alpha town water supply bores due to the additional coal resource development.

The AEM for the Galilee subregion also does not explicitly simulate drawdown in the Dunda beds, the upper part of the predominantly low permeability Rewan Group (an aquitard). Thus, for the bores interpreted to extract water from the Dunda beds, it is only possible to assess drawdown impacts via a proxy unit (i.e. one that is specifically modelled in the AEM). In areas where the Clematis Group occurs, this aquifer could be used to estimate drawdown (although it may under predict the amount of drawdown). In other areas, the drawdown in the alluvial aquifer may be a suitable alternative proxy. In most cases, the drawdown estimates for the upper Permian coal measures are expected to substantially over predict drawdown impacts, as the impedance effect of the low permeability Rewan Group would not be adequately accounted for.

The caveats discussed in the preceding paragraphs indicate that potential drawdown impacts can be assessed for two of the three geographic areas where bores that belong to the unassigned water access right occur. In particular, it is possible to assess drawdown for the four bores that occur near Jericho, as well as the four bores near the site of the proposed Carmichael Coal Mine. The results of this analysis are shown in Table 46 (also see Figure 78). Drawdown at the 50th and 95th percentile exceed 0.2 m for all four bores near Jericho (although not at the 5th percentile), with the maximum predicted drawdown at the 95th percentile <0.6 m. There are two bores expected to experience greater than 2 m of drawdown near the southern boundary of the Carmichael mining lease, using the alluvial drawdown as a potential proxy indicator.

Table 46 Impacts to the water access right economic asset in the unassigned management group

Location of bore cluster	Interpreted source aquifer	Number of bores with drawdown >0.2 m			Number of bores with drawdown >2 m			Maximum modelled drawdown (m)		
		5th	50th	95th	5th	50th	95th	5th	50th	95th
Jericho	Clematis Group	0	4	4	0	0	0	<0.2	0.32	0.59
Southern Carmichael	Dunda beds - Rewan Group	2	2	4	1	2	2	3.31	7.13	9.34

As drawdown predictions for the Dunda beds and Rewan Group are not specifically modelled in the analytic element model for the Galilee subregion, the data for the southern Carmichael bores in this water access right are tabulated from the drawdown data for the Cenozoic aquifer, which is used here as a proxy indicator of drawdown impact.

The unassigned basic water right asset (BA asset identification number 2241) consists of seven individual bores, all of which are within the zone of potential hydrological change for the Galilee subregion (Figure 78). Only one of these bores also overlaps with the Clematis Group drawdown zone, occurring near the eastern-most edge of this unit's modelled spatial extent (Figure 79), near the boundary of the zone of potential hydrological change. Even though this bore occurs within the Barcaldine North Groundwater Management Area, the source aquifer is specified (in the Queensland bore database) as the Dunda beds, which is the upper and more permeable part of the Rewan Group. As the Dunda beds are not a designated aquifer managed as part of the Barcaldine North Groundwater Management Area, this bore is not assigned to a specific management unit. The modelled drawdown in the overlying Clematis Group aquifer at this bore is 0.45 m at the 50th percentile, and covers the 5th to 95th percentile range from 0.18 to 0.80 m.

The other six bores in this unassigned basic water right will be variably impacted due to additional coal resource development (assuming they source groundwater from the upper aquifer). As shown in Figure 78, one bore occurs within the proposed southern mining area at the Carmichael Coal

Mine, and hence direct impacts to this bore are highly likely to occur. Another bore near the southern boundary of the Carmichael mining lease lies within the 2 to 5 m drawdown zone (95th percentile) in the Quaternary alluvium and Cenozoic aquifer. However, all other bores in this asset occur much further away from the mine leases near the very margin of the zone of potential hydrological change, and predicted impacts at the 95th percentile for these bores just exceed 0.2 m for the upper aquifer (Figure 78).

3.5.3.3.2 Assessing impacts to groundwater economic assets

Provisions in Queensland's *Water Act 2000* help to manage the impacts that resource operations, such as coal mining and CSG extraction, may have on existing access to groundwater, for example, from an authorised water supply bore. The management framework specifies bore trigger thresholds (i.e. the amount of water level decline predicted for an aquifer as a result of the resource extraction) for different types of aquifers, with a:

- 5 m decline in groundwater level specified as the threshold for consolidated aquifers, such as sandstone aquifers
- 2 m decline in groundwater level specified as the threshold for unconsolidated aquifers, such as shallow alluvial aquifers.

Resource tenure holders (e.g. coal mining proponents) are generally required to determine the spatial extent of both the *immediately affected area* and the *long-term affected area* related to groundwater drawdown impacts caused by their activities. The immediately affected area encompasses areas around the resource operation where water levels in an aquifer are predicted to decline by more than the bore trigger threshold within 3 years of operation. In contrast, the long-term affected area covers the area where water level decline is predicted to exceed the trigger threshold at any future time (beyond 3 years) due to resource extraction.

For water bores that are predicted to be affected by drawdown in excess of the relevant threshold value, then a more detailed bore assessment may be required (particularly for bores within an immediately affected area). In cases where this type of assessment concludes that a bore's capacity may be impaired by the resource development, then a 'make good' agreement may need to be negotiated between the tenure holder and the bore owner. This agreement seeks to 'make good' the impact caused by the resource extraction activity and is recognised as a legally binding document. Further information about the process for determining if make good arrangements are required, including the recommended approach for undertaking bore assessments, is available from DEHP (2017).

Under the relevant aquifer interference thresholds specified in Queensland, the potential impacts to the five groundwater-dependent economic assets potentially affected due to additional coal resource development can be evaluated as part of this BA. This analysis indicates that none of the groundwater-dependent economic assets sourced from the Clematis Group aquifer are predicted to experience a greater than 2 m drawdown impact, even for modelling results at the 95th percentile (Table 44). As the Clematis Group is a consolidated rock aquifer, the relevant bore trigger threshold under Queensland legislation is 5 m of drawdown. 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 are part of an unassigned water access right (BA asset identification number 2287) that is classed as an economic asset for this BA. These bores are also interpreted to be sourced from the Clematis Group aquifer, in an area where the maximum predicted drawdown is less than 0.6 m at the 95th percentile of all modelling results (Table 46). This also suggests that any groundwater impacts at the Jericho town water supply due to additional coal resource development are unlikely to exceed specified bore trigger thresholds.

The town water supply bores at Alpha are also included as part of the unassigned water access right that occurs within the zone of potential hydrological change. However, as explained previously in this section, the outputs of the groundwater modelling for this BA were not able to accurately predict water level changes for these bores. Consequently, it is not possible to evaluate the potential for groundwater bore impacts to adversely affect the Alpha town water supply, flagging the need for further local-scale hydrogeological assessment in order to develop an appropriate management response to any potential impacts due to additional coal resource development.

3.5.3.4 Potentially impacted bores not in the water-dependent asset register

There are five groundwater-dependent economic assets potentially impacted due to additional coal resource development in the Galilee subregion. These assets consist of a variable number of bores grouped to the level of the relevant groundwater management unit (or unassigned group); with each bore representing an individual element of the asset. However, there are also a number of groundwater bores within and close to the zone of potential hydrological change that are registered in the Queensland groundwater bore database, but which are not included in the BA water-dependent asset register. Consequently, this section presents a brief analysis of potential impacts to bores that are not included as elements in the BA water-dependent asset register. This analysis is limited to those bores that are interpreted to source groundwater from the three aquifer systems that are modelled for this BA, namely the Quaternary alluvium and Cenozoic sediments (layer 1 in the AEM), Clematis Group (layer 3 in the AEM) and the upper Permian coal measures (such as the Betts Creek beds), which are represented as model layer 5 in the AEM. Some re-analysis of newly available data from various sources (such as publicly available coal company data) was done by the Assessment team to update the source aquifer information for some bores within the Queensland database, thereby allowing a more detailed assessment of a greater number of bores for this BA.

3.5.3.4.1 Bores sourced from Quaternary alluvium and Cenozoic sediments

The distribution of non-asset bores within the zone of potential hydrological change for the Galilee subregion that are interpreted to source groundwater from the relatively shallow (near-surface) alluvium and sediment aquifer is shown in Figure 80. These bores are included in the Queensland bore database but are not formally recognised as elements of an economic asset within the BA water-dependent asset register. There are approximately 105 such bores that access groundwater from the uppermost unconsolidated sediment aquifer within the zone, and most of these occur within the Burdekin Basin Water Plan area (i.e. they are not part of the GAB water plan). The

Cenozoic-sourced bores are clustered in several locations, such as around the township of Alpha in the south, at a site about 50 km downstream of Alpha on Native Companion Creek and in an area around the Carmichael River. Cross-checking these bores against information contained in various SEIS documents (and, where possible, confirming the status of this information as of late 2017 with the coal mine proponents) for six of the proposed coal mines in the central-eastern Galilee Basin indicates that about 26 of these bores have been installed as part of pre-development groundwater monitoring networks around the proposed coal mines (company bores shown in Figure 80 are depicted by a black outline around the bore, and most of these occur within or close to the mine exclusion zone). As these monitoring bores are owned by the mining proponents and are not used to extract groundwater for an economic benefit, they have been excluded from any further analysis of potential impact in this BA.

Most of the remaining 79 non-asset bores in the zone that extract groundwater from Quaternary alluvium or Cenozoic sediments have probably been drilled for stock and domestic supplies. According to the status information about these bores in the Queensland bore database six of the bores are recognised as being ‘abandoned and destroyed’, and consequently these six bores are also excluded from this analysis on the basis that they are no longer useable. A further 24 bores are classed as being ‘abandoned and useable’ (and hence these are retained for analysis purposes as the bore may possibly be reused at some point in the future).

Using GIS-overlay analysis it is possible to assess drawdown impacts to the 73 non-asset bores (included in this analysis) that are interpreted to source groundwater from the alluvium or other sediments aquifer (Table 47). Of the total number, three bores directly coincide with areas where coal mining development is planned to occur in future (i.e. the bore location overlaps with the spatial extent of planned open-cut or underground mine workings). In these cases, the bore is highly likely to be directly impacted (e.g. excavated) at some point in future as mining progresses, and hence no drawdown estimates are provided for these bores. As shown in Figure 80, there are also many bores that occur within the zone of potential hydrological change that do not have any reliable stratigraphic information associated with them. As the source aquifer for such bores is unknown, it is not possible to determine if these bores will be affected by additional coal resource development (apart from those that overlap with the extent of mining areas).

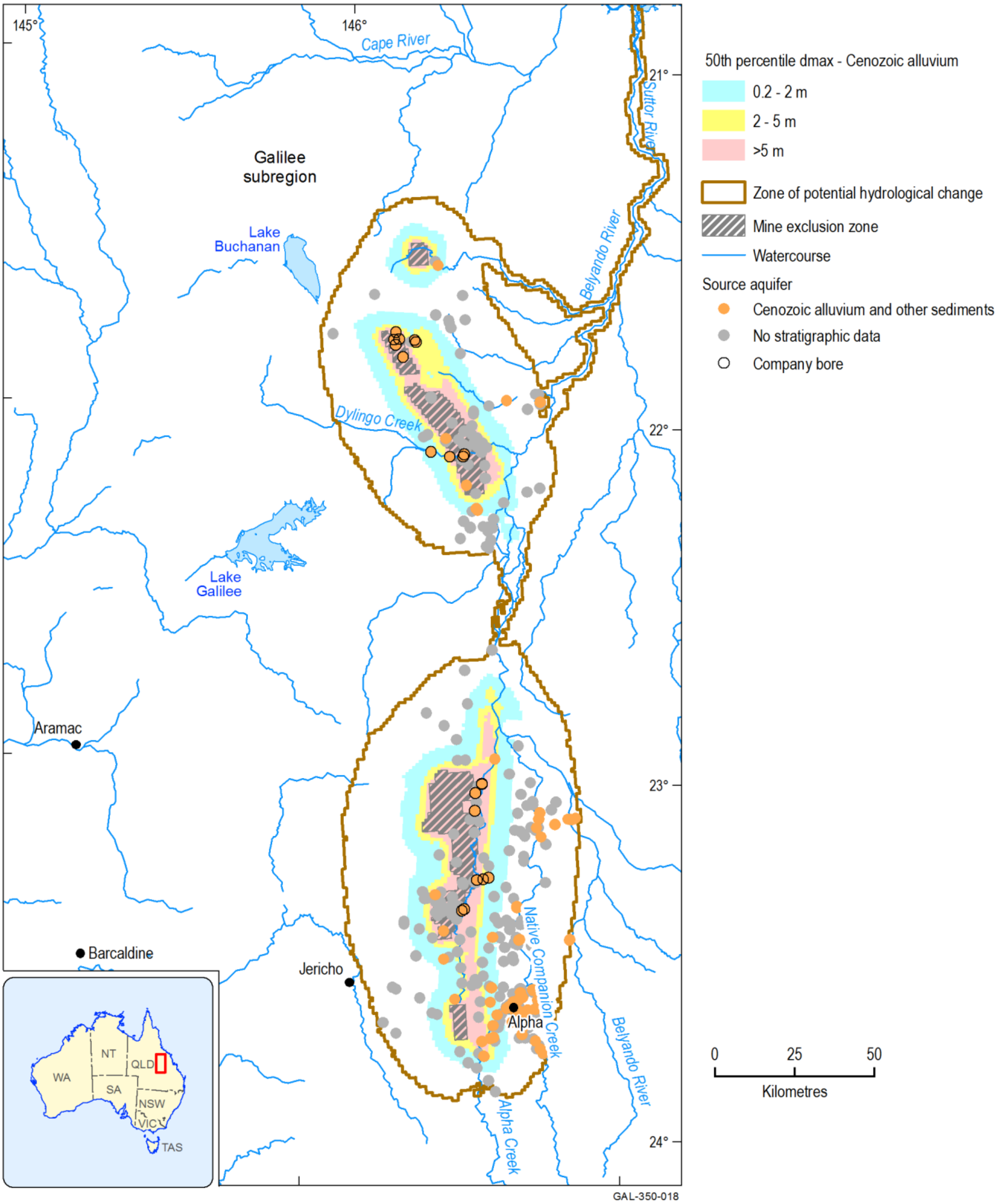

Figure 80 Potentially impacted bores that source water from Quaternary alluvium and Cenozoic sediments, and which are not included in the water-dependent asset register, within the zone of potential hydrological change in the Galilee subregion

Data: Bioregional Assessment Programme (Dataset 3, Dataset 8, Dataset 13, Dataset 14)

The Queensland bore trigger threshold for impacts to unconsolidated aquifers like the Cenozoic alluvium is 2 m of drawdown. The modelled median result where drawdown in the alluvial aquifer exceeds 2 m is estimated to impact 7 bores, and ranges from as low as 2 to as high as 13 bores (Table 47) across the range of modelling results (i.e. from 5th to 95th percentile). These results indicate that between 2 and 13 non-asset bores in the Cenozoic alluvial aquifer may require further assessment using more local-scale information, in order to determine if make good provisions may apply due to the additional coal resource development.

Table 47 Number of non-asset bores sourced from the Quaternary alluvium and Clematis Group aquifers that are potentially impacted due to additional coal resource development

Source aquifer	Number of bores within mine exclusion zone	Number of bores with >0.2 m drawdown			Number of bores with >2 m drawdown			Number of bores with >5 m drawdown			Maximum modelled drawdown value (m)		
		5th	50th	95th	5th	50th	95th	5th	50th	95th	5th	50th	95th
Cenozoic alluvium or other sediments	3	7	10	52	2	7	13	0	2	5	4.4	8.8	9.6
Clematis Group	0	1	17	31	0	0	0	0	0	0	0.2	0.5	1

A number of bores that have no stratigraphic information available in the Queensland groundwater bore database are not included in this table, even if they occur within areas of proposed coal mine development.
Data: Bioregional Assessment Programme (Dataset 8, Dataset 13, Dataset 14)

3.5.3.4.2 Bores sourced from the Clematis Group

The Clematis Group aquifer is one of the main groundwater sources managed under the Barcaldine North and Barcaldine East groundwater management areas. The potential impacts of additional coal resource development to these groundwater-dependent economic assets were previously presented in Section 3.5.3.3.1. However, a further 41 bores in the Queensland bore database are identified as being sourced from the Clematis Group, although these were not assigned to a particular management unit, and hence were not included as part of the BA economic asset analysis previously presented. Of these 41 bores, nine are excluded from this analysis as they are bores that are part of company-owned monitoring networks for some of the mines (this approach was also used for the Cenozoic bores previously discussed). There is also another bore excluded from the analysis as it is listed as ‘abandoned and destroyed’ in the Queensland bore database.

Excluding the company-owned monitoring bores and the bore that is no longer useable means that there are 31 non-asset bores that source water from the Clematis Group that may potentially be impacted due to additional coal resource development. The distribution of these bores is shown in Figure 81, and results of more detailed analysis are tabulated in Table 47. Similar to the results of the asset analysis, most of the non-asset bores that tap the Clematis Group aquifer are predicted to experience between 0.2 and 2 m of drawdown. At the 95th percentile of modelled results, there are 31 bores that occur within this drawdown range. The maximum modelled drawdown is about 1 m at the 95th percentile, which is predicted for a Clematis-sourced bore near the northern mining cluster. There are no non-asset bores with a Clematis Group source that exceed Queensland’s 5 m bore trigger threshold for make good provisions for consolidated rock aquifers.

3.5.3.4.3 Bores sourced from the upper Permian coal measures

The last group of non-asset bores that can be assessed for potential impacts using this GIS-overlay approach are those that have an upper Permian coal measures source aquifer, such as the Betts Creek beds or Colinlea Sandstone (Figure 81). The upper Permian coal measures are the main coal resource target in the Galilee Basin and will need to be dewatered in areas of mining operations to allow for the safe and efficient extraction of the coal resource. As a consequence of dewatering this geological unit, very substantial drawdown predictions are modelled in this BA using the AEM. However, it is important to recall (as explained in Section 3.2.3.1) that the AEM has used a simplified conceptualisation of the upper Permian coal measures and has modelled the entire sequence as a single hydrostratigraphic layer of constant thickness and extent. In reality though, this unit comprises a range of lithological compositions and stratigraphic/structural associations that include variably thick layers of coal as well as a variety of interburden types including sandstone, siltstone and mudstone (all with variable hydraulic parameters). While the simplified hydrostratigraphy implemented in the AEM is considered appropriate for the regional-scale analysis of the BA for the Galilee subregion, this approach may potentially lead to over or under estimated drawdown predictions at a local scale.

Analysis of the available data from the Queensland bore database, combined with some updated interpretations resulting from this BA, has shown that there are approximately 168 bores within the zone of potential hydrological change that are interpreted to source water from the upper Permian coal-bearing units. However, analysis of available information from SEIS documents and company feedback indicates that about 131 of these bores have been installed as part of pre-development company-owned groundwater monitoring networks. As shown in Figure 81 (with coal company bores shown with a black outline), 74% of the company bores occur in areas of the mine exclusion zone which indicates that these bores would be directly impacted as mining progressed in the future.

Of the 37 non-company bores that extract groundwater from the upper Permian coal measures, three are listed in the Queensland bore database as being ‘abandoned and destroyed’. Due to their status these three bores have been excluded from further analysis in this BA. Most of the remaining 34 bores screened in the upper Permian coal measures that are potentially impacted due to additional coal resource development are likely to be pastoral bores that have previously been installed for stock and domestic water supplies. Importantly though, this geological unit is not actively managed as a groundwater source under the auspices of the GAB Water Plan, or the Burdekin Basin Water Plan (although it will be included under the new GABORA Water Plan).

Outside of the actual mine footprint areas (where drawdown predictions using the AEM may not be reliable, and the bores are highly likely to be directly impacted by development activity anyway), very substantial drawdowns are predicted for most bores that tap the upper Permian coal measures. For example, the median prediction results indicate that 23 bores will experience drawdowns of greater than 100 m. This number is as low as 21 bores at the 5th percentile, and rises to 30 bores at the 95th percentile. Relatively few bores are predicted to experience less than 20 m of drawdown in the upper Permian coal measures, varying from 24% at the 5th percentile to 12% at the 50th percentile (and none at the 95th percentile).

The results of this analysis clearly indicate that nearly every groundwater bore interpreted to source water from the upper Permian coal measures is likely to be substantially impacted due to additional coal resource development. Most of these bores that are owned and operated by landholders for stock and domestic purposes (i.e. that are not also the resource tenure holder or development proponent) may be eligible for more detailed bore assessments as a prelude to negotiated make good agreements, as applicable under existing Queensland water legislation and policy.

Figure 81 also highlights a number of other non-asset bores with different source aquifers that occur either within the zone of potential hydrological change, or its Clematis Group aquifer corollary. For these cases, the groundwater modelling undertaken for this BA is not able to directly assess aquifer drawdowns, as these hydrogeological units were not explicitly included in the conceptualisation and modelling. However, as these units are stratigraphically adjacent to the modelled layers, it is possible to qualitatively evaluate drawdowns based on the most suitable proxy layer. This can provide an approximation of potential drawdown impacts, even though the actual drawdown amount will likely be either underestimated or overestimated. For example, the Moolayember Formation overlies the Clematis Group, and so the Clematis Group aquifer could be used to provide an approximation of drawdown magnitude, even though any amount of drawdown in the Moolayember Formation would always be less than the predicted response in the Clematis Group at any particular point.

There are also a number of other bores for which stratigraphic information is not available in the Queensland groundwater bore database (e.g. these are shown as grey bores in Figure 80). For these bores, it is not possible to further assess potential drawdown impacts in this BA, due to the absence of relevant information about the source aquifer.

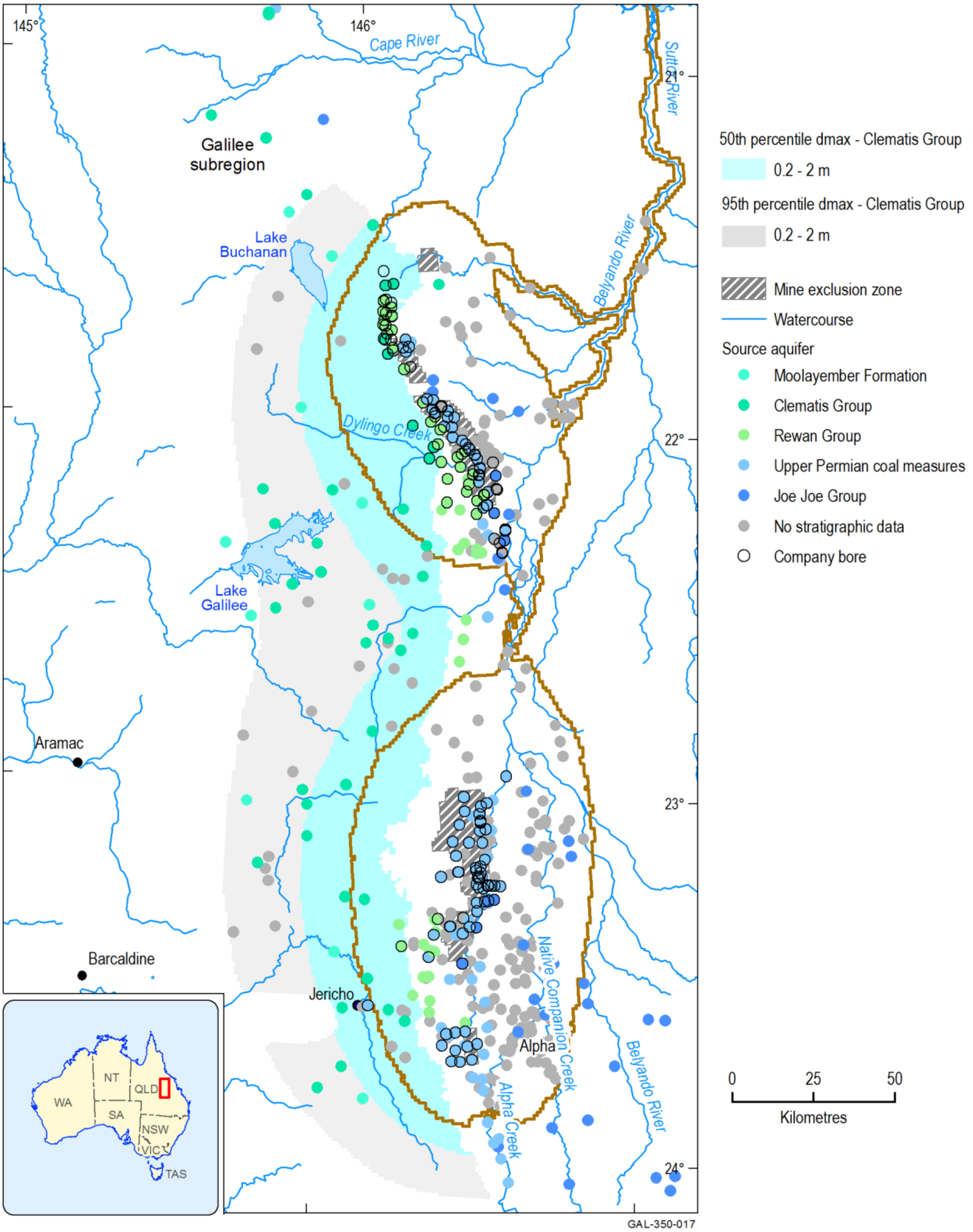

Figure 81 Potentially impacted bores sourced from various aquifer units of the Galilee Basin that are not included in the water-dependent asset register

Data: Bioregional Assessment Programme (Dataset 3, Dataset 8, Dataset 14)

3.5.4 Sociocultural assets

The water-dependent asset register for the Galilee subregion lists 151 sociocultural assets, all of which have been assessed for this BA to have some level of dependency on either groundwater and/or surface water resources. All of these assets are of the 'Cultural' subgroup and are either classed as heritage sites or Indigenous sites. Most of the assets 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). An updated version of the water-dependent asset register for the Galilee subregion is available at Bioregional Assessment Programme (2017).

The most recent version of the water-dependent asset register for the Galilee subregion contains 69 entries that have been added since the register was first published in 2015 (Sparrow et al., 2015). These additional assets all are culturally significant Indigenous features (such as specific sites or species) within the Galilee assessment extent, which were added to the water-dependent asset register following consultation with local Indigenous groups. The results of the consultation undertaken with a variety of Indigenous people for this BA are documented in a separate report (Constable and Love, 2014), which is available at www.bioregionalassessments.gov.au. This work noted that 24 of the Indigenous water-dependent assets are various types of fauna and flora that are considered to be of critical cultural heritage value. These include six bird species, five mammals, three reptiles, two fish and two crustacean species, as well as six species of plants (Table 48). The 24 plant and animal species did not have any specific spatial information provided about them during the consultation process, which means it is not possible for this BA to assess the location of these assets relative to the zone of potential hydrological change. Although it may be possible to use species distribution data from other independent sources (e.g. the Atlas of Living Australia) to assess if these species occur within the zone, the Assessment team does not consider this approach to be valid or justified within the BA context. This is because this method would conflate and potentially misrepresent Indigenous- and Western-science views of species and their distributions. In particular, the values associated with these species by Indigenous people with traditional lands in the Galilee assessment extent cannot simply be represented by species distribution mapping; rather, it involves a much more nuanced understanding of locations built around dreaming stories and cultural beliefs. It is also unclear if there is a simple one-to-one correspondence between Indigenous- and Western-science taxonomies of species (i.e. species definitions may differ). More detailed research and cultural understanding of the values associated with Indigenous assets is required to assess such intricacies, rather than a simple overlay analysis with spatial species distribution data.

Consequently, and consistent with the overall BA approach to assessing Indigenous assets that do not have specific spatial information, it has not been possible to further evaluate if the additional coal resource development will potentially affect these Indigenous assets. This means that impacts to these 24 Indigenous assets have not been 'ruled out' on the basis of this BA.

Table 48 Flora and fauna identified during consultation with local Indigenous groups and compiled in the water-dependent asset register for the Galilee subregion

Asset identifier	Name	Traditional name	Type	Status
GA9	*Pittosporum angustifolium*	Gumbi Gumbi	Plant	Critical local significance
GA12	*Eremophila mitchellii*	False Sandalwood	Plant	Important ceremonial plant
GA48	*Canis familiaris*	Kobbera (Dingo)	Mammal	Critical cultural heritage
GA49	*Pseudonaja nuchalis*	Brown snake	Reptile	Critical cultural heritage
GA50	*Morelia spilota metcalfei*	Carpet snake	Reptile	Critical cultural heritage
GA51	*Burhinus grallarius*	Curlew	Bird	Critical cultural heritage
GA52	*Lasiorhinus krefftii*	Weareah (Wombat)	Mammal	Critical cultural heritage
GA53	*Eucalyptus microtheca* s. lat	Coolibah	Plant	Critical cultural heritage
GA54	*Capparis lasiantha*	Split jack	Plant	Critical cultural heritage
GA55	*Corymbia opaca*	Dooloo kamboona	Plant	Critical cultural heritage
GA56	*Grevillea* sp.	Grevillea	Plant	Critical cultural heritage
GA57	*Varanus gouldii*	Pyeburra (Goanna)	Reptile	Critical cultural heritage
GA58	*Cacatua roseicapilla*	Bankarra (Galah)	Bird	Critical cultural heritage
GA59	*Cacatua galerita*	Tiggery (or Tiggardi) (White Cockatoo)	Bird	Critical cultural heritage
GA60	*Rhipidura leucophrys*	Teegungra (Willie wagtail)	Bird	Critical cultural heritage
GA61	*Amniataba percoides*	Banded grunter/trumpet fish	Fish	Critical cultural heritage
GA62	*Bidyanus bidyanus*	Silver perch (black bream)	Fish	Critical cultural heritage
GA63	*Cherax destructor*	Karkoora or Munya (Crayfish)	Crustacean	Critical cultural heritage
GA64	*Macropus rufus*	Tiggera (or Boda) (Red Kangaroo)	Mammal	Critical cultural heritage
GA65	*Trichosurus vulpecula*	Kuttera (Possum)	Mammal	Critical cultural heritage
GA66	*Tachyglossus aculeatus*	Bubbera (Echidna)	Mammal	Critical cultural heritage
GA67	*Velesunio ambiguus*	Bidgee (Fresh water mussel)	Mollusc	Critical cultural heritage
GA68	*Podargus strigoides*	Mopo (Tawny Frogmouth)	Bird	Critical cultural heritage
GA69	*Dromaius novaehollandiae*	Goalberry (Emu)	Bird	Critical cultural heritage

Most of the Indigenous water-dependent assets listed in this table did not have any spatial information provided as part of the consultation process, which means that they cannot be assessed relative to the zone of potential hydrological change in the Galilee subregion. The punctuation and typography of the fauna and flora listed in this table may differ slightly from that in the source document and dataset, *Aboriginal cultural water values – Galilee subregion* (Constable and Love, 2014). The information in this table is also provided in an updated version of the water-dependent asset register for the Galilee subregion (Bioregional Assessment Programme, 2017).
Data: Bioregional Assessment Programme (Dataset 1)

About 97% of the sociocultural assets listed in the water-dependent asset register do not geographically intersect with the zone of potential hydrological change for the Galilee subregion. This indicates that potential impacts to these assets due to additional coal resource development are *very unlikely* (less than 5% chance). The complete list of the sociocultural assets that do not intersect with the zone are provided in the updated water-dependent asset register (Bioregional Assessment Programme, 2017). The sociocultural assets that are *very unlikely* to be impacted include several iconic national features such as the Great Barrier Reef world heritage area, the national heritage listed Simpson Desert and the Birdsville and Strzelecki Tracks Area, Edgbaston Springs Natural Indicative Place, and the Dig Tree Reserve Historic Registered place. In addition, there are approximately 15 national parks in the Galilee assessment extent that occur entirely beyond the zone of potential hydrological change, including the Diamantina, Idalia and Snake Range national parks.

The zone of potential hydrological change does intersect with parts of four different sociocultural assets from the water-dependent asset register, namely:

- 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.

A brief discussion of the potential impacts to these four sociocultural from additional coal resource development is outlined below.

3.5.4.1 Doongmabulla Springs natural indicative place

The cluster of individual spring vents and mounds collectively known as the Doongmabulla Springs is recognised as a natural indicative place on the Register of the National Estate. The potential impacts due to additional coal resource development on Doongmabulla Springs have previously been discussed in this product, as it is also recognised as a regionally important ecological asset (this illustrates that some assets can have multiple values associated with them). The Doongmabulla Springs are listed under three separate entries in the water-dependent asset register for the Galilee subregion, once as an ecological asset due to its vegetation providing habitat for potential species distributions, once as a surface water feature associated with a wetland, and once as a sociocultural asset (heritage site). Interestingly, the geographic area covered by each of these separate entries for Doongmabulla Springs is slightly different, with the entry for the heritage site covering about 3.6 km^2. Given the comprehensive analysis of potential impacts to Doongmabulla Springs already provided in this product, no further analysis is considered necessary here.

3.5.4.2 Lake Buchanan and catchment natural registered place

Lake Buchanan and its catchment area are recognised as a natural registered place on the Register of the National Estate. This sociocultural asset occurs in the north-western part of the northern groundwater zone of potential hydrological change and is predicted to be subject to varying levels of drawdown in the near-surface Quaternary alluvium and Cenozoic sediment aquifer. The maximum area predicted to be impacted by drawdown is about 444 km^2 (based on the 95th percentile of 0.2 m of drawdown in the alluvial/sediment aquifer). However, the potentially impacted area is much smaller at the 50th percentile (about 30 km^2) and reduces to less than 0.1 km^2 at the 5th percentile. Although some level of drawdown in the upper aquifer may affect the Lake Buchanan catchment area, it does not intersect with the area of the lake itself and is unlikely to directly affect the surface water systems. The varying levels of groundwater drawdown on the Lake Buchanan catchment area may potentially affect any GDEs that rely on access to the near-surface aquifer. However, analysis of standing water level data undertaken for this BA (available from the catchment and surrounding area) suggests that water levels are mostly deep in this part of the zone of potential hydrological change (commonly greater than 20 m below surface, as shown in Figure 39), and hence any potential impacts to GDEs are likely to be minimal.

3.5.4.3 Old Bowen Downs Road historic indicative place

Parts of the Old Bowen Downs Road intersect with the zone of potential hydrological change for the Galilee subregion. In particular, this road cuts across the zone where it occurs buffering the main channel of the Belyando and Suttor rivers, downstream of the groundwater component of the zone and upstream of Lake Dalrymple. Two of these river crossings coincide with the location of individual surface water modelling nodes on the river network (i.e. surface water nodes 51 and 53, see Figure 12), and hence it is possible to evaluate the maximum predicted changes in the surface water system at the locations where the Old Bowen Downs Road crosses the river. These modelled surface water changes are shown in Table 49. Although the impacts of these surface water changes on the road itself are expected to be minimal, the modelled predictions suggest that the river crossings may experience a minor reduction in the number of high-flow days each year (i.e. potential flood events that may cut road access), particularly for model results at the 95th percentile.

Table 49 Modelled surface water changes to annual flow, high-flow days and zero-flow days at nodes proximal to river crossings of the Old Bowen Downs Road, within the zone of potential hydrological change for the Galilee subregion

Surface water model node	Location details	Percent reduction in annual flow volume (%)			Decrease in high-flow days each year			Increase in zero-flow days each year		
		5th	50th	95th	5th	50th	95th	5th	50th	95th
51	Situated on the Suttor River downstream of the junction with the Belyando River, this model node occurs very close to the northern-most river crossing of the Old Bowen Downs Road.	<1	<1	<1	1	1	3	0	68	238
53	Situated on the Belyando River downstream of all inflow tributaries directly affected by coal mining, and just upstream of the junction with the Suttor River, this model node occurs very close to the southern-most crossing of the Old Bowen Downs Road.	<1	<1	1.2	1	1	6	19	77	260

Data: Bioregional Assessment Programme (Dataset 3)

3.5.4.4 Cape River Indigenous asset

The inclusion of the Cape River Indigenous asset within the zone of potential hydrological change for the Galilee subregion is essentially an artefact of the GIS processing approach used in the impact and risk analysis database (Bioregional Assessment Programme, Dataset 3). This is because only 1.4 km of the Cape River occurs within the zone extent, at the most downstream part of the Cape River where it joins the Suttor River. Hence, this asset is only included in the zone as it occurs with an assessment unit associated with the Suttor River just above the junction with Lake Dalrymple. Independently, the surface water modelling undertaken for this BA included several specific modelling nodes on the Cape River (Section 3.3.3), and all of these confirmed that the additional coal resource development is *very unlikely* to impact the Cape River.

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3.6 Commentary for coal resource developments that are not modelled

Summary

There are over 20 identified coal resources known from the Galilee subregion, most of which are hosted in Permian-age strata near the northern and eastern margins of the Galilee Basin. In central and western parts of the basin, the coal-bearing layers are buried under a substantial thickness of sedimentary cover, and some initial coal seam gas (CSG) resources have been discovered at subsurface depths of around 1000 m. Analysis of all the known coal and CSG resources in the Galilee subregion for this bioregional assessment (BA) helped to define the coal resource development pathway (CRDP), thereby focusing this BA on areas where coal resource development may potentially affect water-dependent ecosystems and assets in the future.

The main focus of the impact and risk analysis for the Galilee subregion is centred on the central-eastern part of the basin, where the initial seven coal mines in the CRDP are most likely to begin operations. However, a further seven potential coal mining projects, and three CSG projects, were included in the CRDP (though not modelled), reflecting the Galilee subregion's potential for a prolonged and multi-staged coal resource development portfolio across the coming decades. Most of these later-stage coal resource developments will occur in parts of the subregion distant from the initial focal point where the modelling analysis was undertaken for this BA. 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 overlying Eromanga Basin. The seven non-modelled coal mining projects in the CRDP are (from north to south) Clyde Park, Hughenden, Pentland, West Pentland, Milray, Alpha West and Blackall. The three CSG projects are Glenaras, Gunn and Blue Energy.

Beyond the seven mines modelled in this BA, any subsequent stages of coal resource development in the Galilee subregion would likely involve similar types of open-cut and/or underground mining methods as proposed for the central-eastern mining area (although detailed development plans and time frames for any of the later-stage projects were largely unknown as of December 2017). Consequently, a similar set of causal pathways are expected for the non-modelled CRDP projects, indicating that these mines would also have the potential to affect nearby water-dependent ecosystems and assets. Numerical modelling of hydrological impacts, adequately informed by accurate mine design, scheduling and planning information, would be needed in future to quantitatively evaluate the impacts of such

developments, and estimate the full extent and magnitude of changes to surface water and groundwater systems.

Preliminary spatial analysis has identified the water-dependent ecosystems and assets within a radius of 20 km from each of the non-modelled coal mines in the Galilee subregion's CRDP. Although actual hydrological impacts may extend over a wider area, an initial focus on those assets and landscape classes within 20 km of each mine site provides a clear indication of which ones would likely experience the greatest levels of hydrological change, particularly to surface water systems and the watertable aquifer. Although the most common landscape group near each of the mining projects is classified as 'Dryland' (and hence not a water-dependent ecosystem in the context of this BA), about 10% to 20% of the immediate area is classed as a water-dependent ecosystem. In most cases, the 'Terrestrial GDE, remnant vegetation' and 'Non-floodplain, terrestrial GDE, remnant vegetation' landscape classes are most widespread within 20 km of each coal project, although various floodplain landscape classes may also be locally important, for example, near Blackall.

There are also many water-dependent assets that could be impacted by any future development of the non-modelled coal mines in the Galilee subregion. In most cases, these are mainly classed as ecological assets of the 'Vegetation' subgroup, typically recognised as either some type of groundwater-dependent ecosystem (GDE) (e.g. dry eucalypt woodlands) or the distribution of habitat of a particular species of flora or fauna. There are also some higher profile water-dependent assets nearby these non-modelled developments, including the White Mountains National Park adjacent to the Clyde Park, Pentland and West Pentland sites, and the Porcupine Gorge National Park just east of the Hughenden Coal Project. Additional to these, several economic assets occur around the coal projects, and these mostly relate to basic water rights or water access rights associated with either the Barcaldine North or Barcaldine South groundwater management areas.

The most likely area for any future CSG development in the Galilee subregion spans the central part of the basin, from the Glenaras Gas Project in the west to the Gunn Project in the east. All of the Galilee subregion CSG projects remain at exploration and early appraisal stages (as of December 2017), with no clear understanding at present as to the timing, scale and longevity of CSG production fields. The areas of most interest for CSG development all occur within the Cooper Creek – Bulloo river basin, and any future CSG field development could affect a variety of water-dependent assets and ecosystems that inhabit this catchment. Of particular note is the proximity of the Gunn Project to the 'Floodplain, disconnected wetland' landscape class that coincides with Lake Galilee, a large ephemeral salt lake that has a range of ecological and sociocultural values. There are also a number of regionally important springs sourced from the Great Artesian Basin that occur within the Blue Energy CSG project area.

The CRDP for the Galilee subregion comprises 14 coal mining projects and 3 CSG projects. Relevant details about these projects (as at mid-2015), including their location, size and proposed development time frames, are given in Section 2.3.4 of companion product 2.3 for the Galilee subregion (Evans et al., 2018b). As described in Evans et al. (2018b), the Galilee subregion is a greenfield basin for coal resource development, and thus there is no baseline coal resource development in the CRDP (i.e. no coal mines or CSG fields were in commercial production as of December 2012). The 17 projects in the CRDP are at various stages in their resource evaluation and planning, as well as the requisite environmental, water and mining-related approvals under relevant Australian and Queensland legislation. As of December 2017, none have yet started construction or mining operations.

Although there are 17 projects in the Galilee subregion CRDP, there were only sufficient data and information available to specifically include the seven most advanced coal mining projects in the quantitative BA hydrological modelling. As previously described in this product, the coal mining projects assessed by numerical modelling in the Galilee subregion are (from south to north): South Galilee, China First, Alpha, Kevin's Corner, Carmichael, China Stone and Hyde Park (Figure 6). The projected impacts on, and risks to, water-dependent landscape classes and assets from the cumulative development of these seven coal mines are discussed in Section 3.4 and 3.5 of this product.

This section focuses on the remaining seven coal mining projects and three CSG projects in the Galilee subregion CRDP that were unable to be assessed in this BA using numerical modelling. The main objectives of this section are to:

- make users of the BA aware of the most likely areas within the Galilee subregion where subsequent phases of coal resource development are likely to occur, following the initial mining focus in the central-eastern Galilee Basin (particularly the Belyando river basin)
- summarise important information known about these proposed coal mine and CSG projects, to assist any future assessment of cumulative impacts across the wider Galilee Basin
- present qualitative analysis of the potential for impacts on the water-dependent landscape classes and assets that are proximal to these sites, including any overlap with hydrological changes caused by the seven coal mines that were modelled for this BA.

As depicted in Figure 6, the seven coal mining projects that were not modelled are Hughenden, Clyde Park, West Pentland, Pentland, Milray, Alpha West and Blackall. The potential hydrological changes and subsequent impacts of all three CSG projects in the Galilee subregion CRDP were also not modelled (i.e. Gunn, Blue Energy and Glenaras). The justification for not modelling these ten projects is detailed in Table 13 and Section 2.3.4 of companion product 2.3 for the Galilee subregion (Evans et al., 2018b). Briefly, most of these projects were either at exploration or early development planning stages when the BA CRDP and numerical modelling were being developed (late 2014 to early 2015). Consequently, none were sufficiently advanced in their various environmental and mining approvals processes for the type of data and information (needed for numerical modelling) to be publicly available (consistent with the criteria specified in companion submethodology M04 (as listed in Table 1) for developing a coal resource development pathway (Lewis, 2014)). This meant that there were major uncertainties relating to future development time frames, as well as minimal information available on how development of the project may proceed, including critical information such as mine design and layout (e.g. location of open-cut mine pits, underground longwall panels and associated mine infrastructure areas), and the number and position of CSG production wells.

3.6.1 Potential impacts for coal mine developments that cannot be modelled

The main focus of this product is on quantitatively evaluating the potential impacts and risks due to the development of the seven large-scale coal mines in the central-eastern Galilee subregion. These proposed mines all occur within the surface water basin of the Belyando River and its main tributaries, which are headwater catchments of the larger Burdekin river basin (Figure 12). Consequently, all of the modelled hydrological changes from coal mining activity that potentially cause impacts to water resources and water-dependent assets are restricted to a relatively small part (less than 3% of the total area) of the much larger Galilee assessment extent.

In comparison to the modelled coal mining projects, most of the Galilee subregion coal resource developments that are the focus of the qualitative analysis are outside of the Belyando river basin. There are three main geographic areas of the Galilee subregion where these non-modelled coal resource developments occur:

1. Northern Galilee – five potential coal mining projects are situated along the northern margin of the Galilee Basin, spread over an approximately 140 km long corridor to the north and north-east of Hughenden. All of these coal resources are over 100 km north-west from the nearest mine which is modelled in this BA (i.e. the Hyde Park Coal Project)
2. Central Galilee – along with one potential new underground coal mine (Alpha West) within the central-eastern Galilee mining fairway, this area also has the three CSG projects that are in the CRDP (see Section 3.6.2)
3. Southern Galilee – one potential new coal mine (Blackall) occurs in the southern Galilee Basin, targeting thermal coal resources of the Eromanga Basin, which is geologically younger than the Galilee Basin and overlies it across much of the subregion (Lewis et al., 2014).

3.6.1.1 Coal mine projects in the northern Galilee subregion

There are five potential new coal mining developments near the far northern boundary of the Galilee subregion (Figure 82). These include the Hughenden and Clyde Park coal projects in the Flinders river basin, and the Pentland, West Pentland and Milray projects in the catchment area of the Cape River (which, like the Belyando River, is also part of the larger Burdekin river basin). Similar to the seven modelled mines, all of these projects propose to develop thermal coal resources hosted in the upper Permian coal measures of the Galilee Basin, specifically the Betts Creek beds (companion product 2.3 for the Galilee subregion (Evans et al., 2018b)). Although detailed mine design and resource extraction planning is much less advanced than it is for the seven projects that are modelled, similar types of mining methods and associated mine infrastructure and water management systems are likely to be developed at these sites. Consequently, causal pathways are expected to be similar to those presented in companion product 2.3 for the Galilee subregion (Evans et al., 2018b); these causal pathways describe how an impact from a mining-related hazard may propagate and potentially affect regional hydrological systems and water-dependent assets (as summarised in Section 3.2.2).

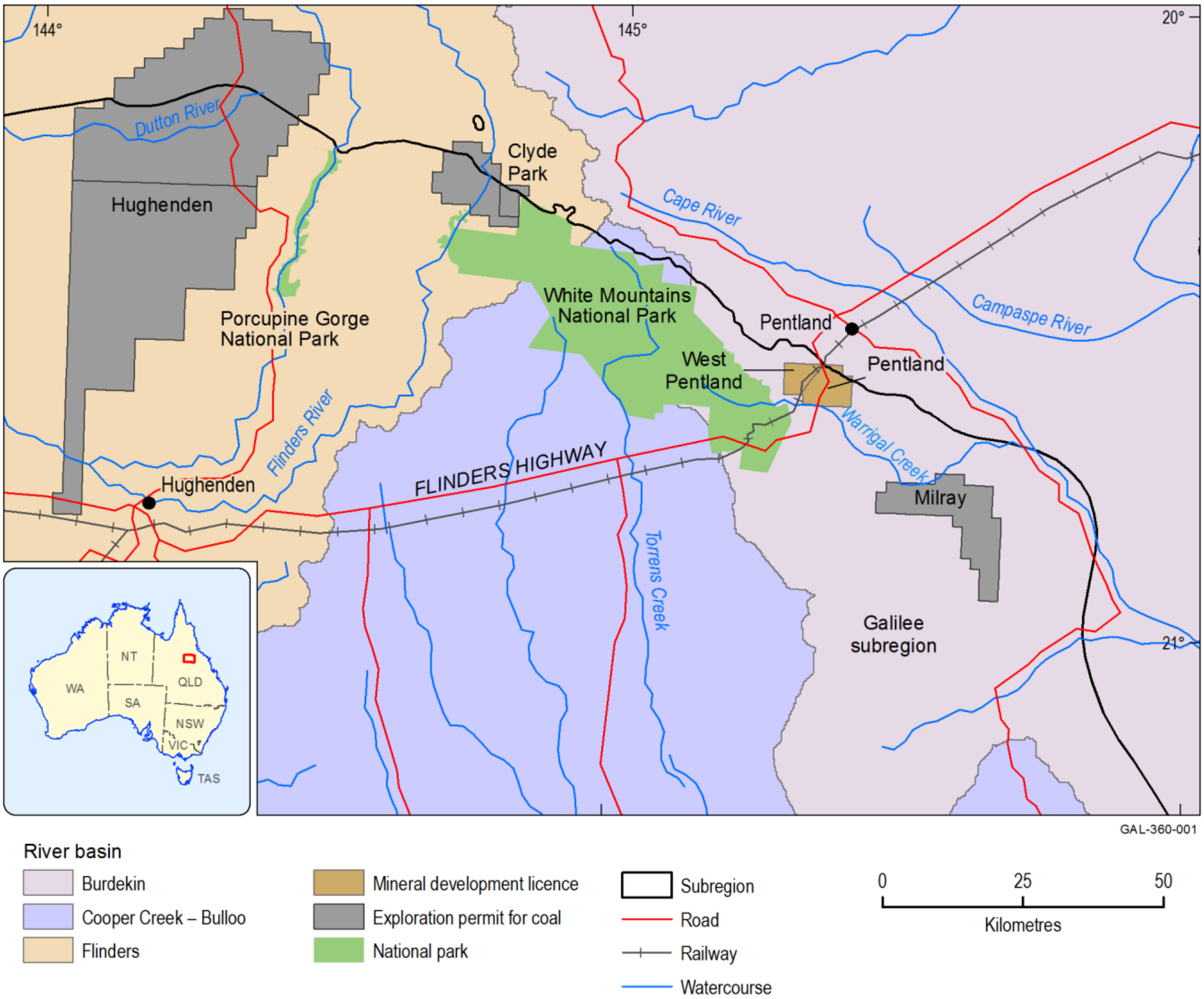

Figure 82 Potential coal mining projects in the northern Galilee Basin

To improve presentation and display, not all coal exploration tenements in the northern Galilee Basin are included on this map. Only the main exploration and mineral development tenements associated with identified coal resources at the Hughenden, Clyde Park, West Pentland, Pentland and Milray projects are shown.
Data: Bureau of Meteorology (Dataset 1); Geological Survey of Queensland (Dataset 2, Dataset 3)

One notable point of difference from the proposed coal mines in the central-eastern part of the subregion is that the coal resources in the northern Galilee Basin are much smaller tonnages (Table 50). Some of this difference may be due to the less advanced nature of resource evaluation and appraisal in the northern Galilee Basin, as most of these coal resources have lower levels of geological assurance (i.e. resources mainly fall into the inferred category of the Joint Ore Reserves Committee (JORC) Code) compared to those from the central-eastern basin. However, even for the few deposits that have indicated or measured coal resources as per the JORC Code (indicating an enhanced level of geological knowledge), the total size is typically several billion tonnes less than the massive deposits found at places like Carmichael, China First and Kevin's Corner (Table 50). The smaller tonnage coal resources targeted for mining in the northern Galilee Basin suggest that:

- The life of mine for these operations will generally be much shorter than the proposed mines in the central-eastern part of the subregion.

- Hydrological impacts will likely be relatively smaller in extent and magnitude (e.g. affect less area of surface water catchments), due to smaller mine footprints and lower extraction rates. The smaller mining operations will also potentially require lower volumes of groundwater to be extracted during mine dewatering. Consequently, aquifer drawdown may be less extensive, although the actual dewatering volume will depend greatly on the local hydrogeological architecture and aquifer characteristics of the target coal-bearing units and associated aquifer systems.

In addition, as the existing Mount Isa to Townsville railway line cuts across the north of the Galilee Basin, the proposed mining operations in the northern Galilee subregion may be able to access and utilise the existing rail network. Access to existing logistical services would reduce the need for development of new rail infrastructure (as is required for the central-eastern Galilee Basin), thereby limiting hydrological effects caused by mine-enabling infrastructure.

Table 50 Comparison of coal resource tonnages for coal mine projects in central-eastern and northern Galilee Basin

Region	Coal mine project	Total coal resources (Mt)	Measured resource (Mt)	Indicated resource (Mt)	Inferred resource (Mt)
Central-eastern Galilee Basin	Alpha	1,821	821	700	300
	Carmichael	10,140	1160	3240	5740
	China First	3,680	1975	565	1140
	China Stone	3,786	NA	286	3500
	Hyde Park	1,694	NA	364	1330
	Kevin's Corner	4,269	229	1040	3000
	South Galilee	1,179	167	206	806
Northern Galilee Basin	Clyde Park	728	NA	51	677
	Hughenden	1,209	NA	133	1076
	Milray	610	NA	NA	610
	Pentland	100	65	15	20
	West Pentland	266	NA	176	90

The categories of measured resource, indicated resource and inferred resource all have specific meaning as part of the Joint Ore Reserves Committee (JORC) Code. The JORC Code is a professional code of practice that sets minimum standards for public reporting of exploration results, mineral resources and ore reserves. The resource tonnages stated here were current (as publicly disclosed) as at December 2017.
NA = data not available
Source: Evans et al, (20018b)

3.6.1.1.1 Coal mine projects in the Flinders river basin

3.6.1.1.1.1 Potential causal pathways

The Hughenden and Clyde Park coal projects are located in the headwaters of the Flinders river basin, between 50 to 70 km north and north-east (respectively) of the town of Hughenden (Figure 83). The main coal resource identified at Hughenden occurs in the north-east of exploration permit for coal (EPC) 1477, which is owned by the Australian-based company

TerraCom Limited (formerly Guildford Coal). TerraCom also holds the major stake in the nearby Clyde Park Coal Project in EPC 1260.

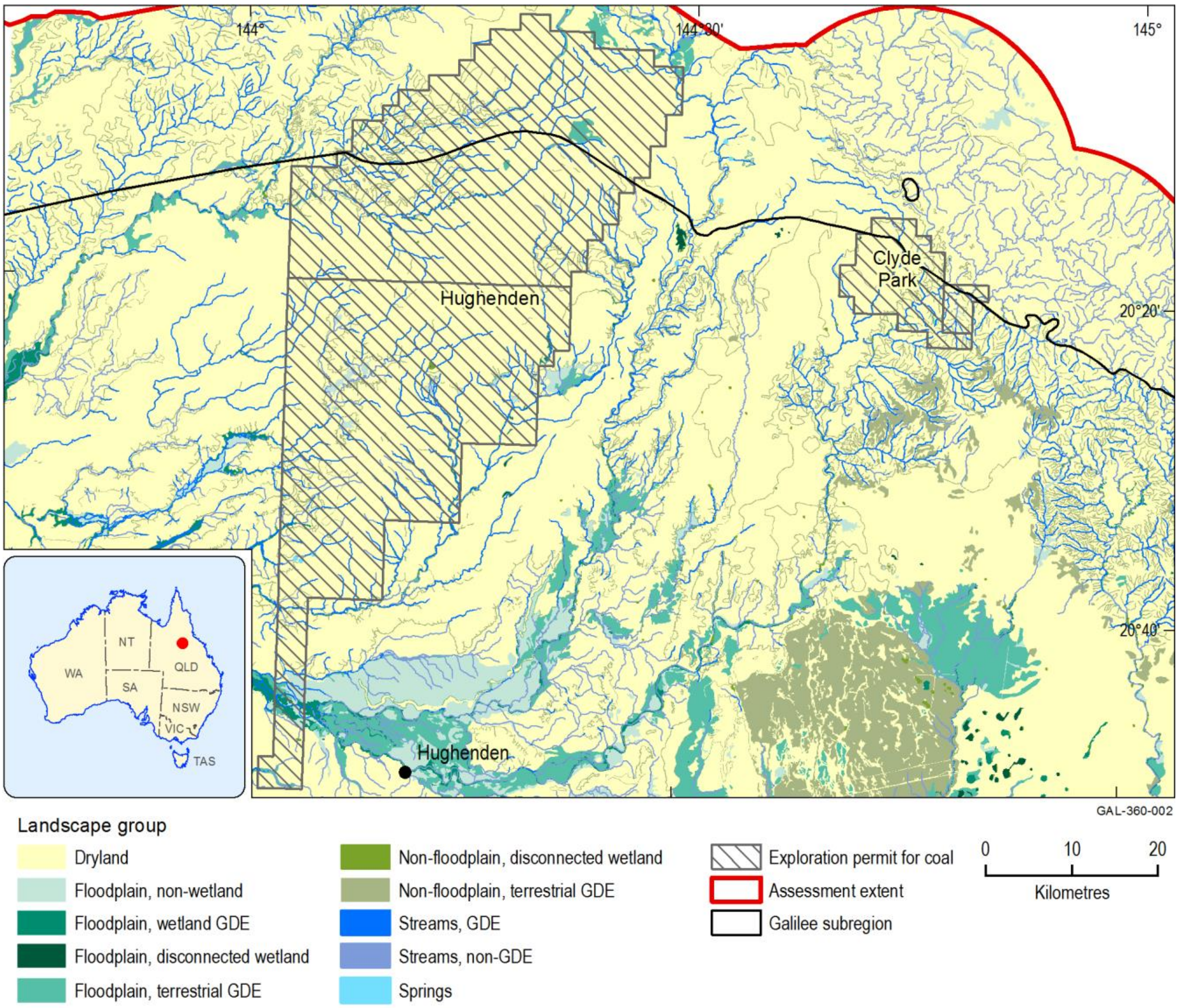

Figure 83 Landscape groups near the Hughenden and Clyde Park coal projects in the northern Galilee Basin

The two exploration permits for coal (EPC) that contain identified coal resources at the Hughenden Coal Project are shown on this map, namely EPC 1477 (in the south), and EPC 1478 (in the north). Company announcements by TerraCom Limited indicate that the main area of likely coal mining development occurs in the north-east of EPC 1477. The main coal resource at Clyde Park occurs in EPC 1260, the larger of the two exploration tenements associated with this deposit.
GDE = groundwater-dependent ecosystem
Data: Geological Survey of Queensland (Dataset 3); Bioregional Assessment Programme (Dataset 4)

The black coal resources at the Hughenden Coal Project are between 300 and 600 m below surface (Guildford Coal, 2012). This substantial thickness of overburden means that underground longwall mining would be the most likely type of development for the Hughenden Coal Project. In comparison, coal seams in the Clyde Park area are much closer to surface, and even occur in outcrop in some places near the margins of the Galilee Basin. The coal resources defined at Clyde Park occur from 25 to 300 m below surface, and would likely be mined by a combined open-cut and underground operation. In their 2012 mining lease application for the Clyde Park Coal Project (mining lease application MLA 10369, which has subsequently expired), Guildford Coal suggested that the underground operations would be undertaken using longwall mining, accessed via a highwall entry through the open-cut pit (Guildford Coal, 2012).

There are currently no detailed plans publicly available to indicate the mine layout, development time frame or extraction rates for either the Hughenden or Clyde Park coal projects. However, the overall style of mining operations, whether open-cut or underground, are expected to share many general similarities with the more advanced mining projects of the Galilee Basin, situated about 200 to 300 km away to the south-east. Thus, the Assessment team considers that the four causal pathway groups outlined in companion product 2.3 for the Galilee subregion (Evans et al., 2018b) would also equally apply to both the Hughenden and Clyde Park projects. In particular, the main causal pathways that potentially have the greatest level of impact on hydrology in the central-eastern Galilee subregion would also be critical to further characterise and evaluate for the coal projects in the northern Galilee Basin. These would include the important subsurface dewatering causal pathways of 'groundwater pumping enabling open-cut coal mining' and 'groundwater pumping enabling underground coal mining', as well as 'unplanned groundwater changes in non-target aquifers'. The causal pathway 'fracturing and subsidence above underground mine longwall panels' and 'subsidence of land surface' would be directly applicable to both the Hughenden Coal Project, and any underground operations at Clyde Park. The main causal pathways to consider as part of the surface water drainage group would include 'altering surface water system' and 'intercepting surface water runoff'. Any future qualitative hydrological modelling and risk analysis of the Hughenden and Clyde Park projects in the northern Galilee Basin would benefit from adopting a similar approach to understanding the various causal pathways, as described in companion product 2.3 for the Galilee subregion (Evans et al., 2018b).

Along the north-eastern margin of the Galilee subregion, in the vicinity of the Hughenden and Clyde Park coal projects, the Rewan Group aquitard does not occur between the upper Permian coal measures and the Clematis Group aquifer (see Figure 20 in companion product 2.1-2.2 for the Galilee subregion (Evans et al., 2018a)). The absence of the Rewan Group in this part of the basin suggests either that it was never deposited within this area, or that it has subsequently been removed through a geological process such as faulting or erosion. Whatever the cause, the lack of the Rewan Group aquitard here may have implications for how the effects of subsurface dewatering for mining operations propagate away from open-cut mine pits or longwall panels. In particular, there is potential for a more direct hydraulic pathway in this area between the Clematis Group aquifer and the upper Permian coal measures, the main dewatering target. Consideration would need to be given to impacts to any groundwater assets or GDEs that may be sourcing water from the Clematis Group aquifer (specifically the Warang Sandstone in this region). It would be important for any future groundwater modelling of these mines to accurately represent the likely hydraulic pathways that connect the coal-bearing resource units and the main aquifer systems that may be hydrologically connected (either partially or completely).

Aquifers of the Great Artesian Basin (GAB) form part of the overlying stratigraphic sequence above the coal seams of the Hughenden Coal Project, and this is an important hydrogeological difference from the mines of the central-eastern Galilee Basin. In particular, the Hutton Sandstone to Cadna-owie – Hooray Sandstone and equivalents are important regional aquifers within this part of the Galilee subregion (see Figure 13 and Figure 14 in companion product 2.1-2.2 (Evans et al., 2018a) for distribution of these GAB aquifers). In contrast to Hughenden, the Clyde Park Coal Project occurs about 5 to 10 km to the east of the Eromanga Basin boundary, which means that the aquifers of the GAB are less likely to be directly affected by mining operations at Clyde Park.

The potential for fracturing and subsidence associated with underground mining at Hughenden to affect groundwater systems in these aquifers would need to be considered in future investigations, as well as source aquifers for nearby springs. Springs from the Flinders River spring group are thought to source groundwater from GAB aquifers (Fensham et al., 2016), and several of these occur in the vicinity of the Hughenden Coal Project. Other springs nearby are fed through discharge from Cenozoic basalts that locally overlie the GAB aquifers.

3.6.1.1.1.2 Landscape classes near Hughenden and Clyde Park

To provide an initial assessment of potentially impacted water-dependent landscape classes and assets around the Hughenden and Clyde Park coal projects, spatial overlay analysis using a geographic information system (GIS) was used to identify proximal ecosystems. An approximately 20 km radius zone was centred over the location of each coal resource to define a preliminary area in which to identify nearby landscape classes and assets. Although this 20 km zone has been chosen with regard to the area where the largest groundwater drawdowns are modelled for this BA (see Section 3.3), it is important to note that this does not imply that any future mining-related hydrological impacts associated with either of these projects will necessarily be restricted to this zone. As was the case for this BA, any future impact and risk analysis based on new hydrological modelling will need to use specific data relevant to each coal resource development. This would be critical to more accurately quantify the range of potential hydrological changes for key aquifer systems and surface water networks around each coal project.

Analysis of the spatial query outputs indicates that the ecosystems around both the Hughenden and Clyde Park coal projects are dominated by the 'Dryland, remnant vegetation' landscape class (as defined for this BA, see Section 2.3.3 of companion product 2.3 for the Galilee subregion (Evans et al., 2018b)), comprising almost 90% of the total surface area within a 20 km radius of each project. Within the context of the BA for the Galilee subregion, the dryland landscape classes are not considered water dependent as these ecosystems rely on incident rainfall and associated surface water run-off for their water requirements. The main water-dependent landscape class around the Hughenden and Clyde Park coal projects is 'Non-floodplain, terrestrial GDE, remnant vegetation', which generally comprises between 8% to 12% of the surface area within 20 km of each site (Figure 83). Other minor water-dependent landscape classes include 'Wetland GDE, remnant vegetation' and 'Floodplain disconnected non-wetland, remnant vegetation'.

Any potential surface water changes resulting from future mining operations at Hughenden and Clyde Park will likely be confined to streams within the Flinders river basin, such as the Flinders River, Dutton River and Porcupine Creek (Figure 82). All nearby stream networks are classed as temporary streams in the BA landscape classification, and include both lowland and upland GDE streams (Figure 83). Several small discharge springs are also mapped within this area.

3.6.1.1.1.3 Water-dependent assets near the Hughenden Coal Project

Within an approximately 20 km radius of the Hughenden Coal Project there are over 60 individual water-dependent assets, as listed in the water-dependent asset register for the Galilee subregion

(Bioregional Assessment Programme, 2017). Most of these are ecological assets of the vegetation subgroup, and are typically either GDEs or habitat classed as the potential distribution of a particular species of fauna or flora. Three of the GDEs within this zone cover a total area greater than 50 km^2, these being:

- moist to dry eucalypt open-forests to woodlands mainly on basalt areas – this is considered a GDE with moderate potential for groundwater interaction (this asset covers about 93 km^2 of the area)
- dry eucalypt woodlands to open-woodlands primarily on sandplains or depositional plains – this GDE has moderate potential for groundwater interaction (about 59 km^2)
- *Acacia cambagei* / *A. georginae* / *A. argyrodendron* dominated associations – these GDEs have low potential for groundwater interaction (about 54 km^2).

Note that in the three examples above, the classification of these GDEs as having either 'moderate' or 'low' potential for groundwater interaction reflects the naming conventions in one of the key source datasets used for defining the water-dependent assets in the Galilee subregion. This is the *National atlas of groundwater dependent ecosystems* (Bureau of Meteorology, 2017), also known as the GDE Atlas, which provides a national-scale inventory of GDEs. The GDE Atlas defines three classes of ecosystems based on their potential to interact with groundwater, namely those with high potential, moderate potential or low potential for groundwater interaction. In these cases, the term 'potential' is used to reflect the uncertainty inherent in identifying ecosystems as groundwater dependent using the various desktop methods employed by the authors of the GDE Atlas (Bureau of Meteorology, 2017). This terminology has been adopted to help name the many GDEs that are included as water-dependent assets in the Galilee subregion, and is also used elsewhere in this section.

The main species habitat (potential distribution) includes that of pink gidgee (*Acacia crombiei*) and the squatter pigeon (southern) (*Geophaps scripta scripta*), each of which covers about one-third of the area within 20 km of the Hughenden Coal Project. The potential habitat distribution of several species of grass listed as water-dependent assets, including bluegrass (*Dichanthium setosum*), hairy-joint grass (*Arthraxon hispidus*) and king blue-grass (*Dichanthium queenslandicum*), is also widespread across this area.

Other water-dependent assets within the vicinity of the Hughenden Coal Project include:

- Porcupine Gorge National Park, which is recognised multiple times in the asset register for both its ecological and sociocultural values, as well as being an Indigenous asset
- various groundwater features, including the extent of regionally important aquifers such as the Clematis Group, or areas of recharge beds for aquifers of the GAB (e.g. Gilbert River Formation)
- basic water rights (a type of economic asset) in the Flinders East 2 and Flinders East 3 groundwater management units
- various rivers, lakes and other wetlands regarded as ecologically important surface water features.

3.6.1.1.1.4 Water-dependent assets near the Clyde Park Coal Project

The list of water-dependent assets within an approximately 20 km radius of the Clyde Park Coal Project is very similar to that for Hughenden, although there are slightly more listed assets around Clyde Park (about 75 assets). About half of these assets are GDEs of various size, shape and complexity, with dry eucalypt woodlands being the most abundant type. There are several discrete areas of dry eucalypt woodland covering more than 100 km^2, although these are considered to have variably low to moderate potential for groundwater interaction (based on the classification scheme used in the source dataset of the GDE Atlas). The other main type of water-dependent asset within 20 km of Clyde Park is the potential habitat of different flora and fauna. This includes nine different plant and grass species, including *Acacia ramiflora* and bluegrass, three bird species, including the squatter pigeon and black-throated finch (*Poephila cincta cincta*), as well as one species each of fish (largetooth sawfish (*Pristis pristis*)), reptile (yakka skink (*Egernia rugosa*)) and mammal (ghost bat (*Macroderma gigas*)).

As shown in Figure 82, the White Mountains National Park borders part of the Clyde Park coal exploration tenement. This national park is listed multiple times in the water-dependent asset register for the Galilee subregion, and is recognised for ecological and sociocultural values, as well as being an important place for local Indigenous people (Constable and Love, 2014).

3.6.1.1.2 Coal mine projects in the Burdekin river basin

A cluster of identified coal resources occurs near the small country township of Pentland in the north-east of the Galilee Basin (Figure 84 and Table 50). The Milray, Pentland and West Pentland coal projects are all in the Galilee subregion's CRDP, as explained in companion product 2.3 for the Galilee subregion (Evans et al., 2018b). However, none of these deposits could be included in the BA hydrological modelling as all have not advanced beyond initial exploration and appraisal stages. There are individual mineral development licences covering both Pentland (MDL 356 owned by Glencore) and West Pentland (MDL 361 owned by United Mining Group, a subsidiary of United Queensland Resources), with the Milray resource occurring in EPC 771 (owned by Glencore). There is relatively scant information publicly available as to how these coal resources will be mined in the future, and when such development is likely to occur.

The Milray, Pentland and West Pentland coal projects are all situated in the Cape river basin (Figure 82). The Cape river basin is immediately north of the Belyando river basin and comprises part of the headwaters for the larger catchment of the Burdekin river basin (Figure 12). The surface water modelling undertaken for this BA included several model nodes along the Cape River, and modelling results for all of these nodes indicated that the Cape River is *very unlikely* (less than 5% chance) to be impacted by the seven coal mines in the central-eastern Galilee subregion (i.e. the mines modelled in the CRDP for this BA). Consequently, any surface water hydrological changes that may potentially arise from development activities at Milray, Pentland or West Pentland are likely to be the first coal mining impacts experienced within the Cape river basin. However, as the Cape River eventually flows into the Belyando/Suttor rivers just upstream of Lake Dalrymple (the lake created by the Burdekin Falls Dam), these coal mining impacts would largely be expected to be restricted to the Cape river basin. This reflects one of the important outcomes of the hydrological analysis from this BA which indicates that coal mining impacts in the

Belyando river basin will not extend beyond the limit of Lake Dalrymple (see Section 3.3.3 and Section 3.3.4 for further detail).

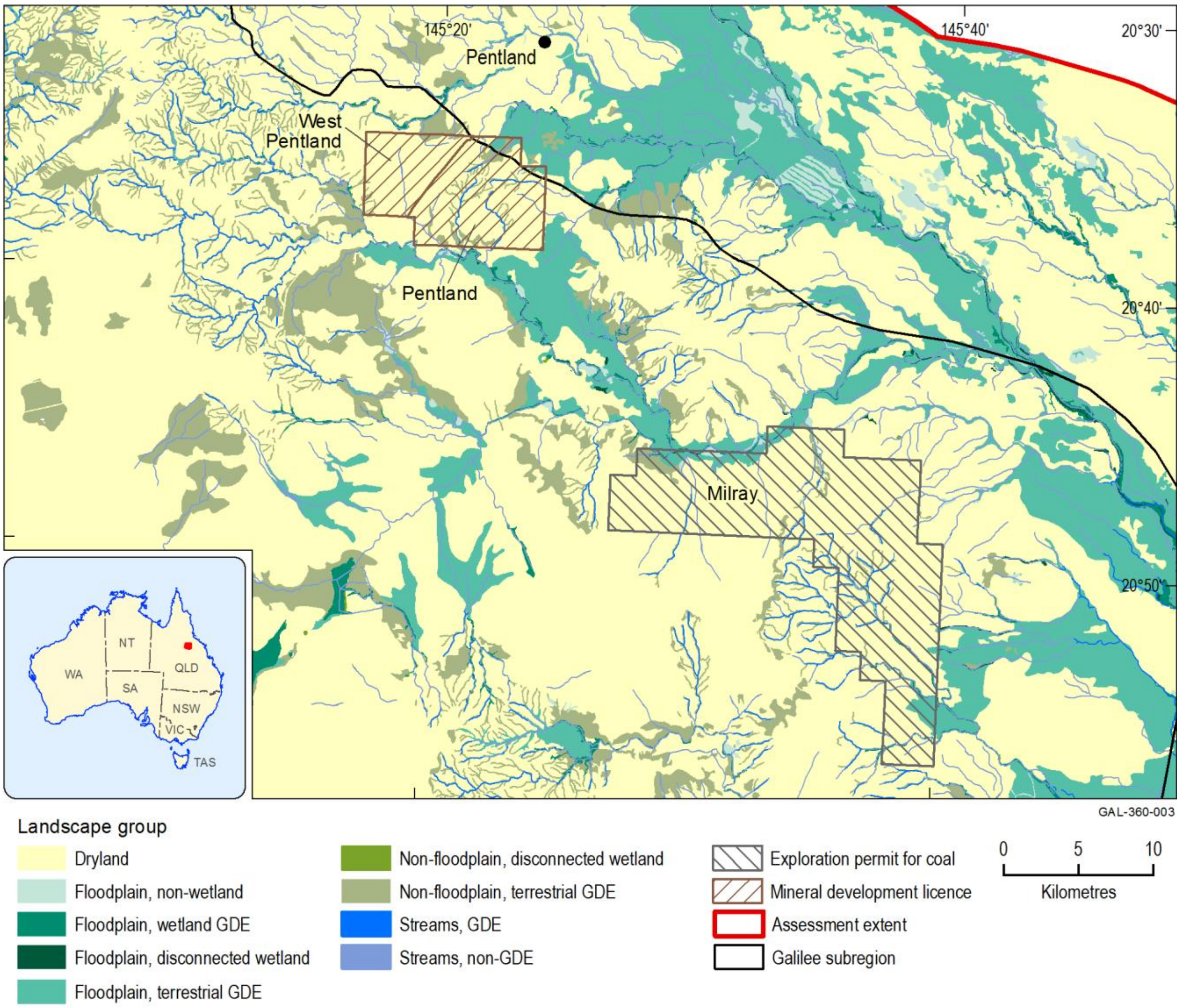

Figure 84 Landscape groups near the Milray, Pentland and West Pentland coal projects in the northern Galilee Basin

This map does not include all of the coal exploration permits that exist within this part of the north-eastern Galilee Basin. It only focuses on the mineral development licence (MDL) tenements relevant to the Pentland (MDL 356) and West Pentland (MDL 361) coal deposits, and the exploration permit for coal (EPP) that contains Milray (EPP 771).
GDE = groundwater-dependent ecosystem
Data: Geological Survey of Queensland (Dataset 2, Dataset 3); Bioregional Assessment Programme (Dataset 4)

3.6.1.1.2.1 Potential causal pathways

The publicly available information about Milray, Pentland and West Pentland indicate that the coal resources are buried within several hundred metres of the surface. Information in Glencore (2016) indicates that both Milray and Pentland could be mined by a combination of open-cut and underground mining methods. In comparison, most of the coal resource at West Pentland is between 100 and 200 m below surface, suggesting that open-cut mining is a viable option. However, as there is no detailed mine development information available, further mine optimisation and planning is undoubtedly required to evaluate the most suitable style of mining operation. Assuming that any future mining development at Milray, Pentland and West Pentland would involve open-cut, and potentially also longwall mining, then most of the coal mine causal pathways outlined in companion product 2.3 for the Galilee subregion (Evans et al., 2018b) will likely be applicable to this area. The overburden for these coal projects consists largely of sedimentary rocks of the Clematis Group and a variety of shallow Cenozoic sediments closely associated with the main surface water drainages. As is the case for the Hughenden and Clyde Park coal projects (Section 3.6.1.1.1.2), the Rewan Group aquitard is largely absent from this area, which may have implications for hydrological connectivity between the Clematis Group aquifer (specifically the Warang Sandstone) and the upper Permian coal measures. No discharge springs have been mapped in the Burdekin river basin in the vicinity of these three coal projects (Figure 84).

The proximity of coal resources at Milray, Pentland and West Pentland (all are within 30 to 40 km) indicates that there is the potential for mining to cause spatially and temporally overlapping hydrological changes in both the groundwater and surface water systems. Depending on the scale and timing of each operation, this may lead to cumulative impacts to water resources and water-dependent assets. However, with the current understanding of the extent of the zone of potential hydrological change for the Galilee subregion (Section 3.3), it is unlikely that dewatering of the watertable aquifer around the Pentland cluster will overlap with dewatering effects of coal projects further south in the central-eastern Galilee Basin. There may be potential for cumulative drawdown interference to occur in the deeper confined aquifers of the Clematis Group and the upper Permian coal measures (given that drawdown effects propagate further in these confined systems than in the watertable), and further investigation of that possibility may be warranted.

3.6.1.1.2.2 Landscape classes near Milray, Pentland and West Pentland

The tenements that host the Pentland and West Pentland coal projects share a common border (Figure 82), and thus analysis of landscape classes has been undertaken jointly for an approximately 20 km radius zone centred on their shared boundary. The dominant landscape class is ‘Dryland, remnant vegetation’, which covers nearly 70% of the total surface area in the vicinity of Pentland and West Pentland. However, there are some relatively large areas of remnant vegetation associated with terrestrial GDEs (about 13% of area within 20 km of these coal projects), as well as non-floodplain terrestrial GDEs in areas up-slope of the floodplain (about 14% of this area). Further information about floodplain and non-floodplain terrestrial GDEs, including important hydrological response variables, is outlined in companion product 2.7 for the Galilee subregion (Ickowicz et al., 2018).

The distribution of landscape classes within 20 km of Milray is similar to that of Pentland and West Pentland, with the ‘Dryland, remnant vegetation’ class comprising over 75% of the area. Likewise, the two main water-dependent ecosystems are ‘Terrestrial GDE, remnant vegetation’ (about 13%) and ‘Non-floodplain, terrestrial GDE, remnant vegetation’ (about 7%). Although there are 19 different landscape classes that occur within 20 km of Milray, the total combined area of 13 of these amounts to less than 1% of this entire surface area.

The main landscape classes associated with surface water systems around the Milray, Pentland and West Pentland coal projects are ‘Temporary, lowland stream’ or ‘Temporary, lowland GDE stream'. There are no near-permanent streams in these areas, nor are there are any springs mapped within 20 km of these coal projects.

3.6.1.1.2.3 Water-dependent assets near Pentland and West Pentland

The Pentland and West Pentland coal projects occur near the south-eastern margin of the White Mountains National Park (Figure 82). This is an important regional water-dependent asset which is listed multiple times in the BA asset register for a variety of ecological, sociocultural and Indigenous values. The White Mountains National Park is also included on the Register of the National Estate (Sparrow et al., 2015).

There are also a variety of other ecological assets within the vicinity of the Pentland and West Pentland coal projects, including over 40 GDEs, and 15 potential species distributions. These include the potential distributions of eight different types of flora (of which *Acacia ramiflora* and bluegrass are the most widespread), three types of birds (squatter pigeon, star finch (*Neochmia ruficauda ruficauda*) and black-throated finch), two reptiles and two mammals (northern quoll (*Dasyurus hallucatus*) and ghost bat).

3.6.1.1.2.4 Water-dependent assets near Milray

There are about 60 water-dependent assets within an approximately 20 km radius of the Milray Coal Project, most of which are ecological assets of the 'Vegetation' subgroup. There are a variety of assets classed as GDEs, with the most widespread types being:

- *Eucalyptus populnea* or *E. melanophloia* (or *E. whitei*) dry woodlands to open-woodlands on sandplains or depositional plains – these are classed as GDEs with low to moderate potential for groundwater interaction (as per the GDE Atlas)
- dry eucalypt woodlands to open-woodlands, mostly on shallow soils in hilly terrain (mainly on sandstone and weathered sedimentary rocks) – these are considered to be GDEs with low to moderate potential for groundwater interaction
- *Acacia* spp. on residual landforms (species include *A. stowardii*, *A. shirleyi*, *A. microsperma*, *A. catenulata* and *A. rhodoxylon*) – these are considered GDEs with low to moderate potential for groundwater interaction.

The other main type of ecological asset near Milray is vegetation habitat forming the potential distribution of particular flora and fauna. This includes habitat for three different bird species, namely the star finch (about 940 km^2), squatter pigeon (720 km^2) and black-throated finch (540 km^2). Additionally, the habitat of a number of different plant species exceeds 100 km^2 within an approximately 20 km radius of Milray, including *Acacia ramiflora*, *Kardomia squarrulosa* and bluegrass.

Other water-dependent assets within about 20 km of Milray include:

- two economic assets associated with the Barcaldine North 3 groundwater management unit (one being a basic water right and the other a water access right)
- several subsurface groundwater features, including the extent of various regional aquifers such as the Clematis Group, or areas of GAB recharge beds

- a number of surface water features such as rivers, creeks, wetlands and floodplains in the Burdekin river basin.

3.6.1.2 Coal mine projects in the central Galilee subregion

The Alpha West Coal Project is adjacent to the Alpha Coal Project in the central-eastern Galilee Basin (Figure 6). Both projects will largely target the same coal seams, although operations at Alpha West are expected to extract coal using underground longwall mining methods from the more deeply buried coal resources west of the open-cut pits at Alpha (Lewis et al., 2014). Any hydrological and associated ecosystem impacts from underground mining at Alpha West could potentially be cumulative with those associated with other mining operations in this part of the Galilee subregion, especially the adjacent longwall mines planned at Kevin's Corner to the north, and China First to the south. Although not quantified here due to lack of relevant data, the additional groundwater pumping required for dewatering the proposed longwall operations at Alpha West may lead to some increased drawdown impacts to the near-surface aquifer, as well as to the confined groundwater systems of the Clematis Group aquifer and the upper Permian coal measures.

The current development time frame for Alpha West remains unknown, although it would clearly begin only after open-cut operations at the nearby Alpha Coal Mine were suitably advanced. By the time that Alpha West development began, dewatering at the adjacent Alpha open-cut mine would likely already be lowering the local watertable. Hence, future dewatering operations at Alpha West would need to factor the prior effects of pumping at Alpha, as well as cumulative effects from the other nearby mining operations to both the north and south.

The main causal pathways that will likely impact hydrological systems in and around the Alpha West mining lease are captured by the underground mining causal pathways specified in companion product 2.3 for the Galilee subregion (Evans et al., 2018b) and include:

- 'groundwater pumping enabling underground coal mining'
- 'unplanned groundwater changes in non-target aquifers'
- 'subsurface fracturing above underground longwall panels'
- 'altering surface water systems'
- 'subsidence of land surface'.

Given the location of the Alpha West Coal Project, readers are referred to earlier sections of this product for a more detailed analysis of potential impacts and risks to the hydrology (Section 3.3), ecosystems (Section 3.4) and water-dependent assets (Section 3.5) within the central-eastern Galilee subregion.

3.6.1.3 Coal mine projects in the southern Galilee subregion

The Blackall Coal Project is the only operation in the Galilee subregion's CRDP where the coal resources lie within the geological Eromanga Basin, rather than the upper Permian coal measures of the older Galilee Basin (Lewis et al., 2014). The coal resources at Blackall are hosted in the mid Cretaceous Winton Formation, and are thus about 150 million years younger than the Galilee Basin's upper Permian coals. The Winton Formation coals are sub-bituminous and have moisture contents of 18% to 22%, meaning that they are coals of lower rank and higher moisture content than most Permian coals of the Galilee Basin. Across much of the Galilee subregion the sedimentary sequences of the Eromanga Basin form the overburden for the underlying rocks of the Galilee Basin. In addition, many stratigraphic units of the Eromanga Basin are major regional aquifers of the GAB and contain extensive, good quality groundwater resources.

3.6.1.3.1 Potential causal pathways

According to published information from East Energy Resources, the coal resources at the Blackall Coal Project will be mined using open-cut mining methods (East Energy Resources, 2014). The identified coal resource occurs in six main coal seams and the uppermost of these subcrops across much of the tenement area (i.e. it occurs close to the surface). Based upon the results of extensive exploration drilling, a large-scale thermal coal resource has been defined in the area of Mineral Development Licence (MDL) 464. This resource could support a large-scale open-cut mining operation, targeting around 30 Mt/year of mineable coal over at least 30 years life-of-mine.

Considering the suggested large-scale open-cut mining operation at Blackall, the types of hazards and potential impacts to water-dependent assets may be analogous to those associated with similar coal mine projects such as the Alpha Coal Project. The main causal pathways arising from large-scale open-cut mining operations associated with the Blackall Coal Project could include:

- ‘groundwater pumping enabling open-cut coal mining’
- ‘altering surface water systems (coal mining)’
- ‘intercepting surface water runoff’.

Fundamental differences exist between the hydrogeological systems that occur in the Winton Formation and those of the upper Permian coal measures, which will affect how groundwater systems will respond to mine dewatering. Preliminary mine planning indicates that the most likely type of operation will involve open-cut mining to depths of no more than 150 m below surface, and will likely remain within the same stratigraphic unit (Winton Formation). This suggests that mine dewatering impacts will mainly affect the regional watertable in the near-surface aquifer, which in this area is likely to be hosted in the weathered rocks of the Winton Formation. Within the near vicinity of the Blackall Coal Project, there is some potential for impacts to groundwater levels in pastoral and/or stock and domestic bores that tap the near-surface aquifer in the Winton Formation. However, dewatering of the Winton Formation (part of the wider regional Winton-Mackunda aquifer, Ransley et al. (2015)) is unlikely to affect the deeper confined groundwater systems of the GAB, such as those hosted in the Cadna-owie Formation, Hooray Sandstone and Hutton Sandstone. This is because the groundwater systems of the Winton-Mackunda aquifer are separated from the underlying confined aquifers by up to several hundred metres of low permeability strata, which form the basal aquitard sequence of the Rolling Downs Group. These aquitards would be expected to impede the transmission of any near-surface drawdown effects into the deeper GAB aquifers (although this would clearly need to be further evaluated via purpose-built groundwater models).

The isolation of open-cut pits and mine infrastructure areas from the rest of the Barcoo river basin will result in changes to runoff volumes to nearby surface water catchments, such as those of Four Mile Creek and Ravensbourne Creek. The likely reductions in runoff may then affect the volume and timing of any surface water flows that occur in these ephemeral drainages. There may also be localised changes to water quality as a result of mine-related impacts to surface water systems, such as increases in total suspended solid loads in minor streams due to enhanced levels of erosion, which may occur following heavy rainfall events. However, given the distances (at least 150 km) from Blackall to the other coal mines in the Galilee subregion CRDP, and its occurrence in the younger strata of the Eromanga Basin, there is (conceptually) very low potential for cumulative hydrological impacts associated with these other operations.

3.6.1.3.2 Landscape classes near Blackall Coal Project

The Blackall Coal Project is situated in the headwaters of the Barcoo river basin, which is part of the larger Cooper Creek – Bulloo river basin. As for most of the Galilee subregion, the 'Dryland' landscape group dominates the area within an approximately 20 km radius of the Blackall Coal Project (Figure 85), comprising over 80% of the surface area. There are only three water-dependent landscape classes that cover more than 1% of the surface area within 20 km of Blackall, these being 'Terrestrial GDE, remnant vegetation' (about 13.5%), 'Floodplain disconnected non-wetland, remnant vegetation' (about 3.5%) and 'Floodplain disconnected non-wetland' (about 1.5%).

The combined area of the ten other landscape classes that occur within 20 km of Blackall Coal Project amount to less than 1% of the total area. Most rivers and creeks are classed as 'Temporary, lowland streams', and there are no groundwater-fed springs within this vicinity. The main streams within the Blackall tenement are Bride Creek and Four Mile Creek, which join towards the north of the tenement and flow into the larger Ravensbourne Creek (Figure 85), a tributary of the Barcoo River.

3.6.1.3.3 Water-dependent assets near Blackall Coal Project

In contrast to the areas surrounding the coal projects of the northern Galilee Basin, there are considerably fewer water-dependent assets within about 20 km of Blackall Coal Project. There are approximately 20 ecological assets in the water-dependent asset register, which include:

- ten GDEs of the vegetation subgroup, most of which are location-specific GDEs associated with particular waterways (e.g. Bride Creek GDE, Ravensbourne Creek GDE, and Hope Creek GDE) – many are considered to have only a low potential for groundwater interaction
- four potential species distributions (two plants, one bird and one mammal), as defined by habitat. The plant species are ooline (*Cadellia pentastylis*) and climbing caustic (*Euphorbia sarcostemmoides*), and animal species are the painted honeyeater (*Grantiella picta*) and the koala (*Phascolarctos cinereus*)
- various groundwater and surface water features, such as aquifer boundaries (e.g. the extent of the Cadna-owie Formation and Clematis Group), GAB recharge beds and several lakes and rivers of the Barcoo river basin.

In addition to the ecological assets, there are six economic assets within 20 km of Blackall Coal Project. These include basic water rights across five groundwater management units in the Barcaldine South and Warrego West groundwater management areas. Each of these basic water rights consists of a variable number of individual groundwater bores which are mainly used for stock and domestic purposes. There is also a single surface water access right in the Barcoo Subcatchment Management Group.

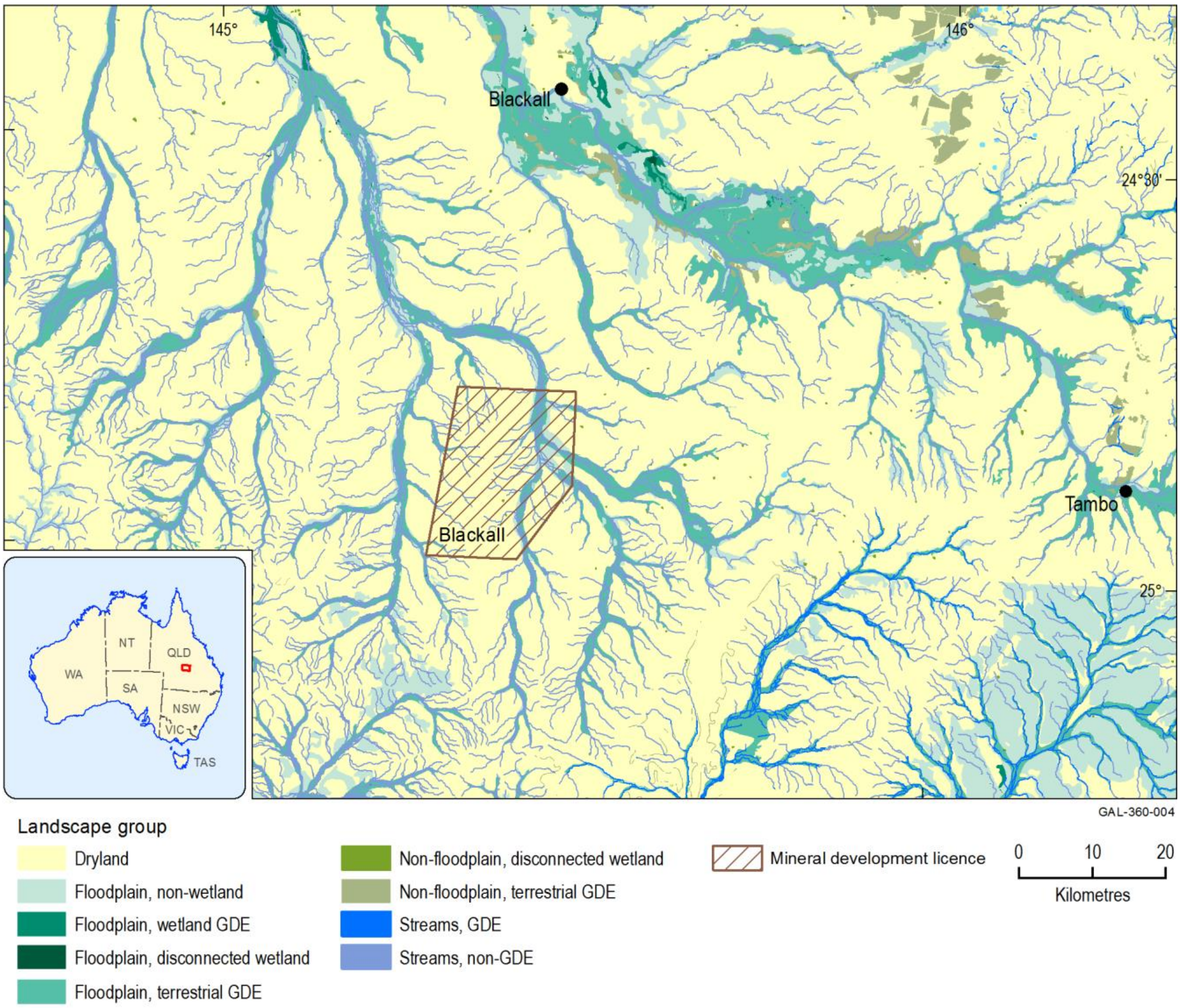

Figure 85 Landscape groups near the Blackall Coal Project in the central Galilee Basin

The identified coal resource at Blackall is in Mineral Development Licence (MDL) 464, which is the only tenement shown on this map. Other exploration permits for coal which occur in this area are not depicted.
GDE = groundwater-dependent ecosystem
Data: Geological Survey of Queensland (Dataset 2); Bioregional Assessment Programme (Dataset 4)

3.6.2 Potential impacts for coal seam gas developments that cannot be modelled

Three CSG projects are included in the CRDP for the Galilee subregion (Figure 86), namely the:

- Glenaras Gas Project, owned and operated by Galilee Energy Limited in the south of petroleum exploration tenement, Authority to Prospect (ATP) 2019
- Gunn Project, owned and operated by Comet Ridge in ATP 744, and mainly focused in an area just to the east of Lake Galilee

- Blue Energy exploration project in ATP 813, which occurs in the central Galilee Basin, flanked by Glenaras to the west and Gunn to the east.

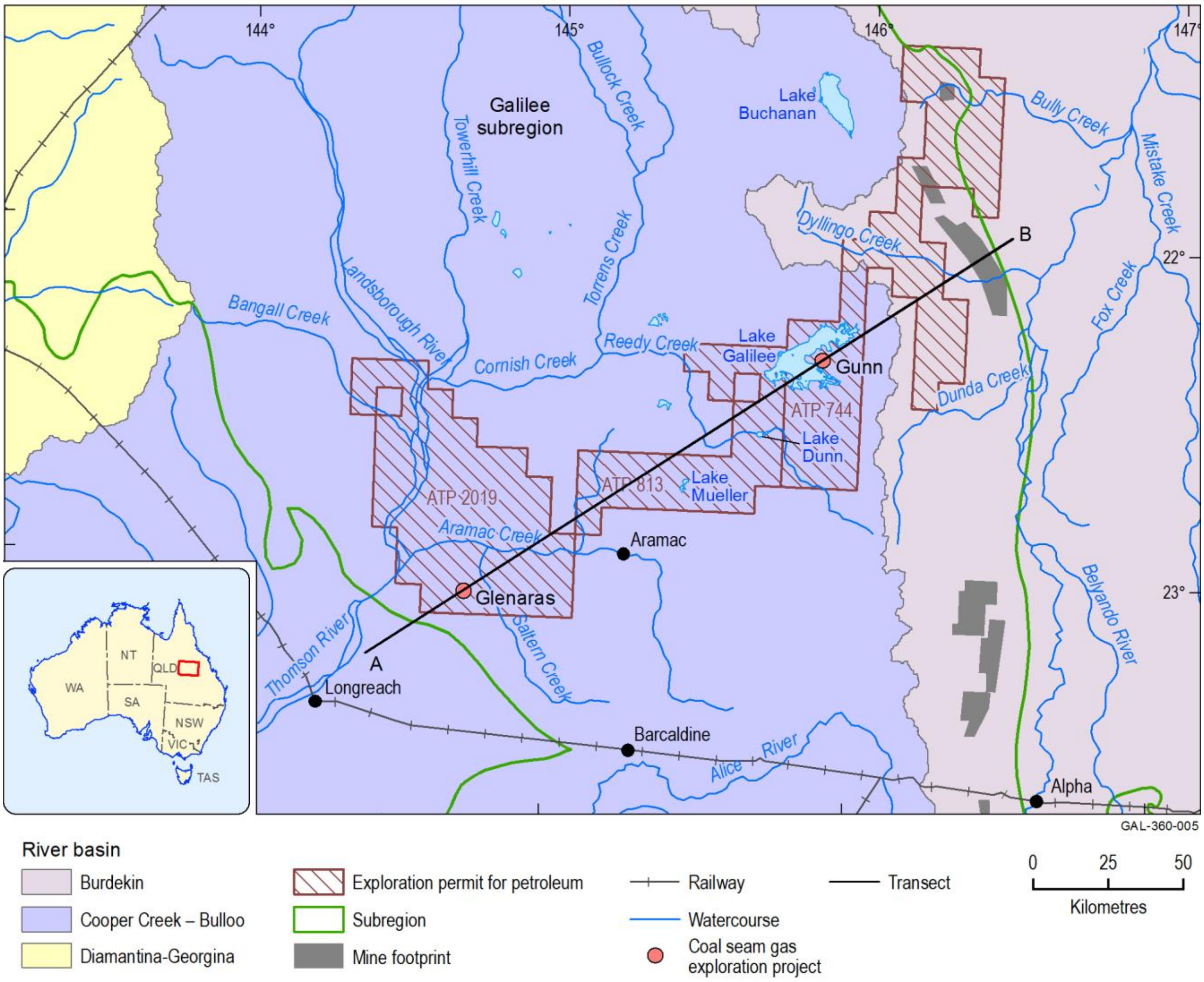

Figure 86 Map of main coal seam gas projects in the Galilee Basin

The transect line A–B depicted on this map is the approximate location of the geological cross-section shown in Figure 87, which extends from the south-west (A) to the north-east (B). Unlike Glenaras and Gunn, the Blue Energy CSG project is not yet focused on a specific location, although several CSG exploration wells have been drilled in ATP 813.
Data: Bureau of Meteorology (Dataset 1); Geological Survey of Queensland (Dataset 5); Bioregional Assessment Programme (Dataset 6)

As discussed in companion product 2.3 for the Galilee subregion (Evans et al., 2018b), it was not possible to quantitatively evaluate the potential hydrological impacts of any CSG project as part of this BA. Consequently, this section presents a qualitative discussion and analysis of the potential causal pathways that may result from future CSG development in the Galilee subregion, as well as the main water-dependent ecosystems and assets potentially affected within existing CSG exploration tenements.

The CSG projects in the Galilee subregion CRDP occur west of the Great Dividing Range in the Cooper Creek – Bulloo river basin (Figure 6). This means that the surface water and shallow groundwater systems are largely hydrologically disconnected from the coal mining projects in the central-eastern Galilee Basin. These projects target CSG resources in the Permian coal measures, predominantly under a thick cover of sedimentary rocks that are either part of the upper Galilee Basin sequence, or the overlying Eromanga Basin. In the vicinity of the three CSG projects, the depth to the upper Permian coal measures varies from about 800 to 1050 m below surface (Figure 87). Figure 10 in companion product 2.3 for the Galilee subregion (Evans et al., 2018b) provides further detail on variation in overburden thickness for the upper Permian coal measures across the entire Galilee subregion.

One of the many factors that influence the commercial viability of CSG development and production is the in situ gas content of the coal. Previous exploration and appraisal studies have shown that the gas content of coals in the upper Permian coal measures varies considerably across the areal extent of the Galilee subregion and also with depth below surface. As outlined in Figure 24 of companion product 2.1-2.2 for the Galilee subregion (Evans et al., 2018a), coals with higher gas content mainly occur at depths of 900 to 1200 m. The gas contents of coal seams rapidly decrease to relatively low levels at depths of less than 700 m (commonly less than 1 m^3/tonne (dry ash free)). Figure 25 and Figure 26 of companion product 2.1-2.2 for the Galilee subregion (Evans et al., 2018a) illustrates the understanding (as of April 2016) of the variability of gas contents across the upper Permian coal measures, and with depth. The most elevated gas contents are clustered in the central part of the Galilee subregion (i.e. north of Barcaldine), in the vicinity of the three CSG projects in the CRDP.

The timing and extent of future CSG development (and eventual commercial-scale production) in the Galilee Basin are currently uncertain. However, based on the known distribution of gas contents within the basin’s main coal-bearing strata, future CSG development is considered unlikely to occur at the scale of the entire basin, or at depths of less than 700 m below surface. Based on the current understanding of prospective CSG host rocks, the most likely CSG development fairway extends from the area around the Glenaras Gas Project in the central-western part of the basin (i.e. east of Longreach) towards the north-east, past the town of Aramac and across to the Comet Ridge tenements near Lake Galilee (Gunn Project area). The most likely production will occur within the depth zone where elevated gas contents exist, typically at depths of 900 to 1200 m below surface (Figure 87).

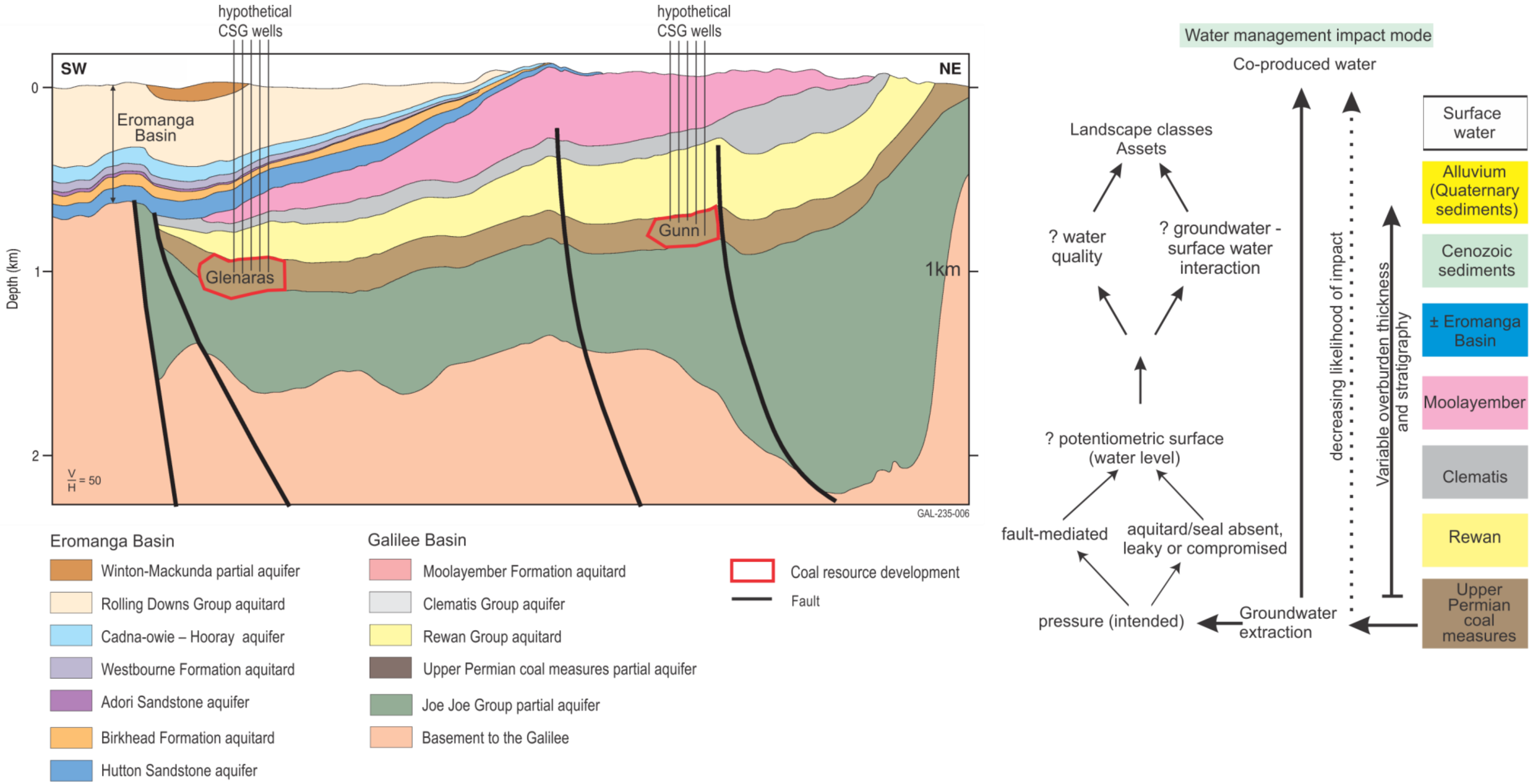

Figure 87 Cross-section through the central Galilee Basin highlighting target strata for the Glenaras and Gunn coal seam gas (CSG) projects relative to other geological units in the Galilee and Eromanga basins

The potential hydrological links that may develop due to subsurface depressurisation of coal seams is schematically depicted on the right. The stratigraphic units shown in the legend are classified according to their dominant hydrogeological characteristics (i.e. either as aquifers or aquitards).

3.6.2.1.1 Potential causal pathways

Causal pathways through which CSG activities may result in hydrological impacts are detailed in Section 2.3.5.3.1 of companion product 2.3 for the Galilee subregion (Evans et al., 2018b). The main causal pathways identified include:

- 'groundwater pumping enabling coal seam gas extraction'
- 'unplanned groundwater changes in non-target aquifers'
- 'failure of well integrity'
- 'hydraulic fracturing'.

The extent and magnitude of subsurface hydrostatic depressurisation required for CSG production, and how depressurisation may propagate laterally and vertically through a series of aquifers and aquitards, depends on a variety of geological, hydrological and operational factors (Figure 87). A detailed discussion of how these factors may influence causal pathways associated with future CSG production in the Galilee subregion is in Section 2.3.5.3.1.1 of companion product 2.3 (Evans et al., 2018b). Depressurisation effects within the coal seams will propagate laterally through the coal measures at a certain rate and (usually to a much lesser extent) vertically through the adjacent geological units. The extent and magnitude of depressurisation will also depend on the overall size (footprint), spacing and layout of production wells at each future CSG field. These types of important design details are currently unknown for the most advanced CSG exploration and appraisal projects in the Galilee subregion.

Any future groundwater drawdown in the upper Permian coal measures due to CSG production has the potential to be additional (cumulative) to drawdown attributed to the coal mine projects in the modelled CRDP (see Section 3.3 for detail). The groundwater modelling results outlined in companion product 2.6.2 for the Galilee subregion (Peeters et al., 2018) for the modelled CRDP suggest that in the vicinity of the Gunn CSG project area, the median percentile of maximum drawdown (due to the seven coal mines modelled in this BA) is slightly less than 25 m in the upper Permian coal measures (Figure 88). Further westwards, the median of maximum drawdown across the Blue Energy tenement is less than 20 m, with the boundary of the groundwater modelling domain (for this BA) occurring between the Blue Energy tenement and the Glenaras Gas Project. At Glenaras, the depth to the coal measures is commonly around 1000 m below surface, and there are no water-dependent assets (at the surface) in the vicinity of Glenaras that are likely to be directly affected by groundwater depressurisation (due to CSG extraction) in the deep coal-bearing units. However, when this water is pumped to surface it will require a long-term, sustainable water management plan to handle what are potentially very large volumes of water in a surface environment where ecosystems are generally not adapted to coping with such large and sustained quantities. The quality of the water released from the deep coal seams may also be such that it will require further treatment at the surface (e.g. reverse osmosis to decrease salinity), prior to any release off site or for other uses, such as irrigation water. There may also be large volumes of brine and/or salt (a by-product of the extraction and treatment of co-produced water) that will need to be effectively managed on site, or removed for disposal at an approved waste management facility. A potential positive impact could be that CSG fields within the cumulative drawdown cone for the coal mine projects may have to pump less water in order to achieve sufficient gas flows.

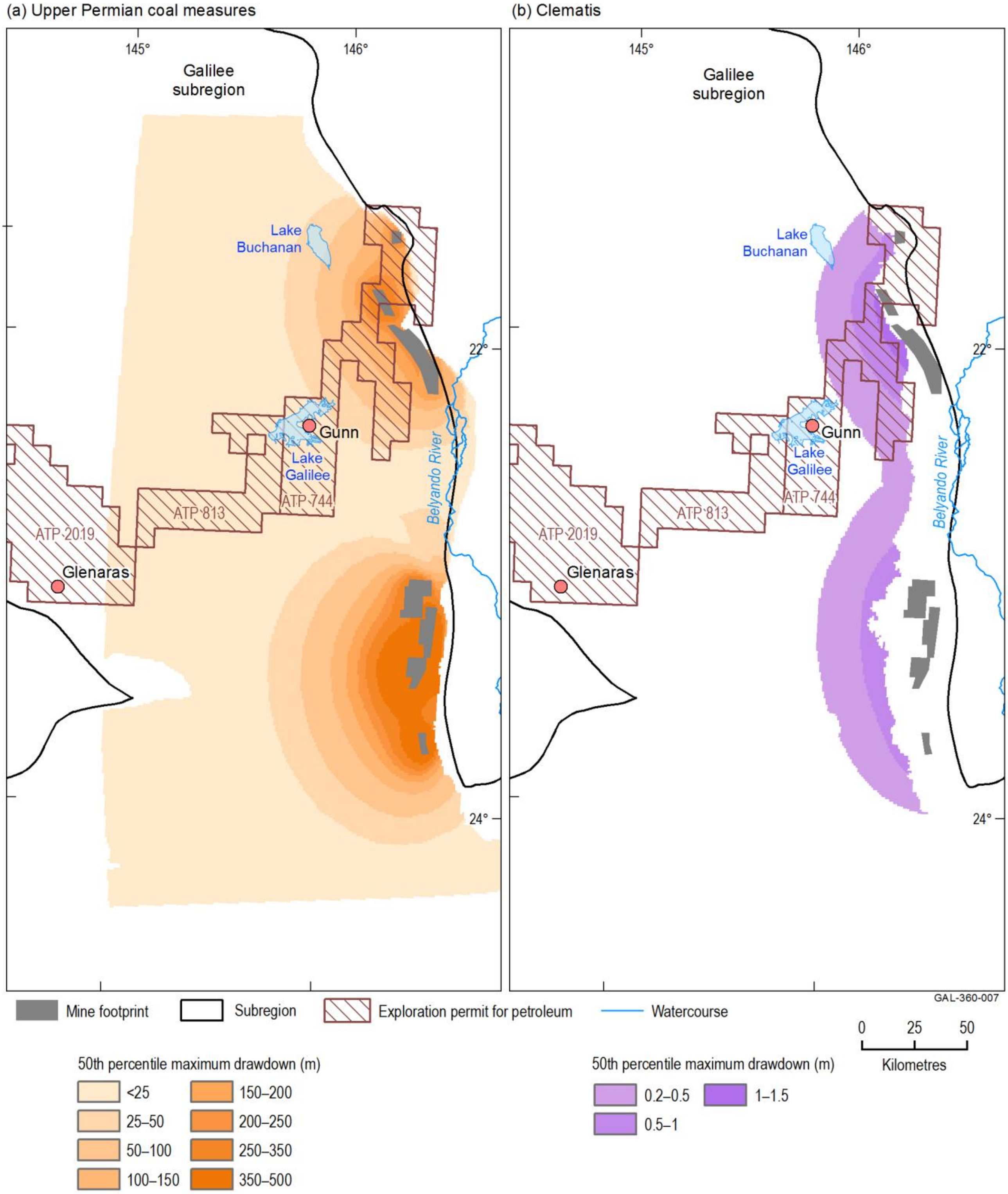

Figure 88 Comparison of groundwater drawdown predictions (at the 50th percentile) for the upper Permian coal measures and Clematis Group aquifer, due to dewatering of seven coal mines included in the modelled coal resource development pathway for the Galilee Basin

Data: Geological Survey of Queensland (Dataset 5); Bioregional Assessment Programme (Dataset 6, Dataset 7)

The Clematis Group aquifer is the main water supply for many pastoral bores in the Galilee subregion, and is a key aquifer for several groundwater management units (e.g. the Barcaldine North 3 and Barcaldine East 4 groundwater management units). It is also likely to be a contributing source aquifer for some springs within the central-eastern Galilee Basin, including the Doongmabulla Springs complex near the Carmichael Coal Mine (companion product 2.3 for the Galilee subregion (Evans et al., 2018b)). The results outlined in companion product 2.6.2 (Peeters et al., 2018) suggest that where present, the Rewan Group aquitard (Figure 87) effectively impedes vertical propagation of depressurisation from the upper Permian coal measures into overlying hydrostratigraphic units such as the Clematis Group. This is clearly seen in comparative drawdown maps in Figure 88, where the magnitude and extent of drawdown in the Clematis Group aquifer due to coal mine dewatering (in the modelled CRDP) is substantially less than the modelled drawdown in the upper Permian coal measures.

In the vicinity of the Gunn Project the Rewan Group aquitard is greater than 300 m thick (companion product 2.1-2.2 for the Galilee subregion (Evans et al. 2018a)). Here, the probability of cumulative drawdown from coal mines in the modelled CRDP (at the 50th percentile) is less than 0.2 m in the Clematis Group aquifer (Figure 88). However, any potential drawdown in the Clematis Group aquifer due to pumping at the Gunn CSG Project (which has not been modelled for this BA) would be in addition to drawdown from the coal mine projects.

The Glenaras Gas Project is situated near the western margin of the Galilee Basin (Figure 86). In this area, the Rewan Group aquitard is much thinner than in the central and eastern parts of the basin (Figure 87). Near Glenaras, the Rewan Group is only about 20 m thick, and progressively pinches out further westwards towards the margin of the Galilee Basin (companion product 2.3 for the Galilee subregion (Evans et al., 2018b)). The thin to absent nature of the Rewan Group in the western part of the basin means that the upper Permian coal measures may be (at least partly) in direct contact with overlying aquifers of the GAB, such as the Hutton Sandstone. Groundwater modelling results from companion product 2.6.2 (Peeters et al., 2018) did not extend as far west as the Glenaras Gas Project, as it occurs beyond the edge of the modelling domain (at the western-most edge of the groundwater modelling domain, the 50th percentile of drawdown in the upper Permian coal measures was much less than 25 m). However, if depressurisation due to production from Glenaras were to extend westward to areas where the Rewan Group aquitard was missing, then there may be some potential for drawdown in the coal-bearing units to propagate upwards and impact on groundwater systems in overlying aquifers such as the Hutton Sandstone. Figure 7 in companion product 1.5 for the Galilee subregion (Evans et al., 2015) indicates that some pastoral bores near the Glenaras Gas Project draw groundwater from the Hutton Sandstone aquifer. Consequently, further evaluation and modelling of depressurisation effects would be required to better understand the extent of both lateral and vertical propagation, once the CSG development plans at Glenaras are more advanced.

3.6.2.1.2 Landscape classes and assets near coal seam gas projects

The Glenaras Gas Project is near the far western margin of the Galilee subregion, and most of the surrounding area is dominated by the 'Dryland' landscape group (Figure 89). However, some areas of the 'Floodplain, terrestrial GDE' landscape group are associated with surface water systems near Glenaras, such as Rodney Creek, several kilometres to the east, and Aramac Creek further north. These are mostly classed as temporary non-GDE streams, and both are tributaries of the larger Thomson River, which is the main surface water feature within this part of the subregion. There are no known GAB springs in the vicinity of the Glenaras Gas Project.

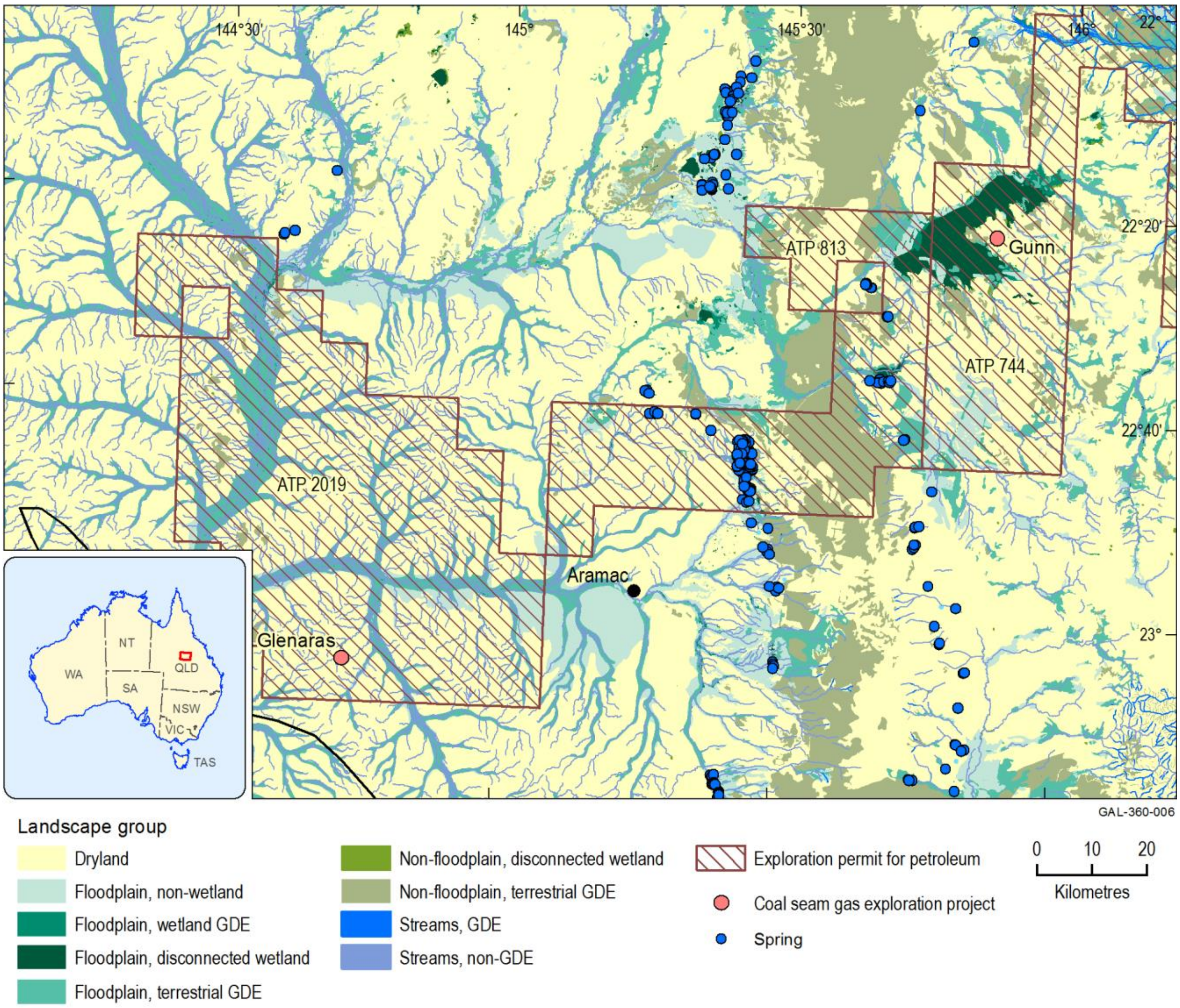

Figure 89 Landscape groups near coal seam gas exploration tenements in the central Galilee Basin

This map only shows the petroleum exploration tenements (known as Authority to Prospect, ATP) that relate to the Glenaras, Blue Energy and Gunn coal seam gas projects. To improve display, some other coal seam gas and coal exploration tenements are not depicted.

GDE = groundwater-dependent ecosystem

Data: Bioregional Assessment Programme (Dataset 4); Geological Survey of Queensland (Dataset 5, Dataset 8); Bureau of Meteorology (Dataset 9); Queensland Herbarium, Department of Science, Information Technology, Innovation and the Arts (Dataset 10)

One of the main landscape classes near the Gunn CSG Project is ‘Floodplain, disconnected wetland’, which coincides with much of the mapped extent of nearby Lake Galilee. This is a large ephemeral salt lake within a hydrologically enclosed catchment in the headwaters of the Cooper Creek – Bulloo river basin (Figure 89). Other water-dependent ecosystems that occur within the vicinity of Lake Galilee and the Gunn CSG Project include ‘Floodplain, non-wetland’, ‘Floodplain terrestrial GDE’, and ‘Non-floodplain, terrestrial GDE’ landscape groups. Lake Galilee is included in *A directory of important wetlands* and the Register of the National Estate and is widely recognised as an Important Bird Area (Sparrow et al., 2015). Any changes to the surface water regime due to CSG production in this area (i.e. changes to water flow volumes or timing, or water quality) may potentially be cumulative as the lake occurs within a hydrologically closed surface water basin (i.e. the local surface water system cannot be flushed clean, even following heavy rainfall events). Potential hydrological impacts of any future CSG development at Gunn would need to be considered in the context of Lake Galilee's many ecological, sociocultural and Indigenous values.

A variety of landscape classes occurs across ATP 813, Blue Energy's CSG exploration tenement in the central Galilee Basin. These include extensive areas of dryland landscapes, as well as non-floodplain, terrestrial GDEs. Many different floodplain ecosystems, including those associated with the 'Floodplain, disconnected wetland' and 'Floodplain, terrestrial GDE' landscape groups also occur in the vicinity of Lake Dunn (Figure 90). Temporary west- and south-flowing streams in the upper catchment of Aramac Creek, including some potential areas of GDE streams, also occur in the central and western parts of ATP 813.

Figure 90 Lake Dunn in the central Galilee subregion

Source: Constable J and Love K (2014)

Importantly, there are many springs within ATP 813, most of which belong to the larger Barcaldine supergroup (Figure 89). Of particular note are Edgbaston springs (part of the Pelican Creek Springs Complex) which are a recognised centre of endemism within the broader system of GAB springs across the Galilee subregion. There are multiple threatened endemic flora and fauna species known only from this spring system (Fensham et al., 2016). Due to the important ecological values of Edgbaston springs, they are listed on the Register of the National Estate, in *A directory of important wetlands* and in the Collaborative Australian Protected Area Database (companion product 1.3 for the Galilee subregion (Sparrow et al., 2015)). The springs are also part of a nationally threatened ecological community that is listed under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999*, 'The community of native species dependent on natural discharge of groundwater from the Great Artesian Basin' (Fensham et al., 2010).

3.6.3 Summary

The CRDP for the Galilee subregion specifies a particular suite of proposed coal mine and CSG projects that may become commercially producing operations at some stage in the future. Most of the focus of this BA is on understanding the potential impacts and risks that may result from the seven most advanced, large-scale coal mining projects in the central-eastern Galilee Basin. However, the Galilee subregion CRDP also includes seven other potential coal mines and three CSG projects, although these could not be explicitly modelled for this BA due to lack of required data and information.

Instead, this section has provided preliminary commentary around the likely causal pathways that could result from the non-modelled projects in the CRDP. It has also provided initial spatial analysis of the main water-dependent ecosystems and assets that could potentially be affected by these developments. This information should provide future users of the BA with an early indication of 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 with future planning and management of potential water-related impacts and risks of further coal resource development in the Galilee subregion.

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3.7 Conclusion

Summary

The future development of seven large coal mines in the central-eastern Galilee Basin is *very likely* (greater than 95% chance) to lead to cumulative hydrological changes in regional groundwater and surface water systems. These changes will affect a larger area (i.e. of groundwater drawdown) and total length of stream network than previously predicted from any individual mine-scale impact assessments. The combined extent of changes to surface water and groundwater above specified thresholds define the zone of potential hydrological change for the Galilee subregion, outside of which impacts to water resources and water-dependent assets are *very unlikely* (less than 5% chance) to occur.

Changes to surface water systems are mostly confined to the Belyando river basin (and the lowermost parts of the Suttor river basin downstream of its junction with the Belyando), and are likely to have the greatest level of impact on the low-flow component of streamflow, such as zero-flow days. Increases in the number of zero-flow days accumulate along the length of the affected stream network, as the various local tributaries affected by mining impacts join the main channel of the Belyando River. Cumulative streamflow changes are greatest along an approximately 250-km long stretch of the main channel of the Belyando River from downstream of its junction with Native Companion Creek, as far as Lake Dalrymple (Burdekin Falls Dam). Changes in hydrological response variables for the high-flow and annual flow components of streamflow will also occur, although these impacts are relatively less than those associated with low flow. Many of the species that inhabit water-dependent ecosystems in the region are adapted to the high levels of natural variability in these surface water systems. However, if thresholds of tolerance to variability are exceeded by sustained changes to the hydrological regime then it is possible that important components of the water-dependent ecosystems may be impacted.

Cumulative groundwater impacts due to dewatering the seven coal mines in the Belyando river basin will variably affect three main groundwater systems, including near-surface Quaternary alluvium and Cenozoic sediments, and the deeper confined aquifers of the Clematis Group and upper Permian coal measures (e.g. Betts Creek beds and stratigraphic equivalents). The total area of the groundwater component of the zone of potential hydrological change, which affects the near-surface aquifer, is well over 13,000 km^2, forming two geographically separate areas. In the south, cumulative groundwater impacts are *very likely* to occur around the four proposed mines at South Galilee, China First, Alpha and Kevin's Corner. However, in the north, cumulative drawdown in the upper aquifer due to interaction caused by dewatering of Carmichael, China Stone and Hyde Park is only evident at the 95th percentile of modelling results. The pattern and spatial extent of drawdown zones for the two deeper confined aquifers (Clematis Group and upper Permian coal measures) differs substantially from that of the alluvial aquifer, occurring only to the west of the mines and extending much further beyond the extent of the zone, towards central parts of the Galilee

Basin. Drawdown in the coal-bearing unit is particularly large, and *very likely* (>95% chance) to exceed 5 m in most places in the modelling domain.

The impact and risk analysis of the Galilee subregion is primarily a cumulative, regional-scale analysis focused on the effects of the seven coal mines modelled in the coal resource development pathway (CRDP). This focus does limit the degree to which results can be used to assess local-scale effects. Furthermore, there are important knowledge and data gaps that may add to the uncertainty around future predictions of local impacts. These gaps include: lack of ecohydrological understanding of vegetation water requirements and how these relate to hydrological response variables, long term effectiveness of rehabilitation and post mine-closure legacy issues, and the absence of long-term, high-quality monitoring data relating to ecological components, groundwater levels, and water quality.

There is considerable opportunity to build upon the work undertaken for this bioregional assessment (BA) and further enhance the understanding of impacts and risks to the subregion's water resources and many water-dependent assets.

Areas outside of the zone of potential hydrological change are very unlikely to be impacted by the seven coal mines modelled in the coal resource development pathway (CRDP). Given the high degree of confidence in ruling out areas based on the BA modelling approach, more refined modelling and impact analysis using higher-resolution local-scale information could be applied to the central-eastern Galilee Basin to enhance the understanding of cumulative impacts at a far more detailed scale than originally assessed. A purpose-built numerical groundwater flow model (the Galilee Basin hydrogeological (GBH) model), developed as a complementary tool for this BA, could be adopted as a robust starting point for any future finer-scale analysis of cumulative impacts, especially for the series of stacked aquifers that occur in the eastern Galilee Basin (although considerable investment would be required to enable this). There are also other opportunities to improve and update the findings from this BA, including integrating the wealth of geological and geophysical data acquired during the past decade to enhance the current understanding of the structural and stratigraphic architecture around the area of the proposed coal mining developments. This work could form the foundation for enhanced hydrogeological conceptualisations and more sophisticated modelling in areas of known uncertainty or complexity, such as the Doongmabulla Springs complex. There is also considerable scope for applying time-series remote sensing data to enable a better understanding of variability in ecosystem responses to natural climate cycles, thereby providing an important level of baseline knowledge against which any future impacts could be compared. Further research opportunities to improve knowledge of the complex interactions between riverine and terrestrial ecosystems, and groundwater systems, would also help address important knowledge gaps recognised from this BA.

The findings from this BA can be used to help the Australian and Queensland governments, the coal mining industry and members of the community to make better-informed decisions about the management of water resources in the Galilee subregion. Further, these results can be used to focus future monitoring networks, critical for testing and validating (or invalidating) the Assessment's predictions of impacts and risks. The modular nature of the Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources (BA methodology) (Barrett et al., 2013) means that various components of the investigation can also be updated in future as the need arises, such as any future changes in the CRDP or the availability of specific coal mine project data to include in any revised future modelling and analysis. Other data and information, such as the water-dependent asset register and lists of hazards and causal pathways, will remain relevant for future assessments. The full suite of data, information and knowledge generated during the course of the BA for the Galilee subregion is available at www.bioregionalassessments.gov.au/assessments/galilee-subregion.

3.7.1 Key findings

A substantial body of transdisciplinary scientific research has greatly improved the understanding of geology, hydrology and ecology of the central-eastern Galilee Basin, where at least seven large coal mining developments are planned to commence operations in the coming decade. This BA has culminated in the impact and risk analysis presented here, which has illustrated that impacts to the groundwater and surface water systems of this area are *very likely* (greater than 95% chance) to accumulate at a regional scale, due to the spatial and temporal proximity of proposed mining operations. The high likelihood of cumulative hydrological changes means that the impacts previously predicted for individual mines in this region are likely to be larger in both extent and magnitude due to the expected interaction between nearby operations. However, the probabilistic modelling approach generates a broad range of predictions, reflecting inherent uncertainty in important physical parameters applied in the hydrological modelling (e.g. hydraulic conductivity and storage of aquifers). Additionally, the scale of impact affects the system components differently, exemplified by the variability of drawdown impacts for the different modelled aquifers (i.e. near-surface Quaternary alluvium and Cenozoic sediments, Clematis Group and upper Permian coal measures), and the differences in streamflow impacts across the low-flow, high-flow and annual flow components of the surface water regime. Collectively, these findings have important implications for future management of water resources in this region, particularly given the relatively low level of water extraction and use that has occurred in the past.

The modelled component of the CRDP for the Galilee subregion clearly indicates that the zone of potential hydrological change is largely confined to the Burdekin river basin, in particular, the upper catchment area of the Belyando River. Only relatively small areas at the western margin of the zone, where drawdown is less than 0.5 m, occur in the adjacent Cooper Creek – Bulloo river basin. The basis for defining most of the zone is the modelled cumulative groundwater drawdown in the near-surface aquifer, forming separate areas that define the northern part of the zone, and the southern part of the zone (refer to Figure 20 in Section 3.3). The northern sector encompasses the proposed Carmichael, China Stone and Hyde Park coal mines, with the southern part including the proposed Alpha, Kevin's Corner, China First and South Galilee mines. Complementary surface water modelling, in places partially integrated with the groundwater modelling, indicates that potential cumulative surface water impacts may extend downstream along the main channel of the Belyando River, and the Suttor River below its junction with the Belyando, as far as Lake Dalrymple (i.e. the Burdekin Falls Dam), but not beyond. In particular, these changes in surface water hydrology of the Belyando and Suttor rivers, as well as in some headwater tributaries close to mining areas such as Sandy Creek, Native Companion Creek and North Creek, will most substantially affect the low-flow component of streamflow.

The median estimate (50th percentile) of changes to zero-flow days due to additional coal resource development is for increases of between 20 and 80 days along the Belyando and lower Suttor rivers. This will affect an approximately 250-km long section of the main Belyando River channel (and lowermost Suttor River) below its junction with Native Companion Creek. This change is either less than or comparable to variation that occurs naturally in the Belyando River. However, at the 95th percentile of modelling results these changes to the low-flow regime are substantially greater, with potentially (along similar stream reaches) over 200 days of increased zero flow. While impacts to the low-flow regime may propagate downstream in the Belyando river basin as far as Lake Dalrymple, potential ecological impacts along these stretches may be relatively limited. However, the level of impact experienced by different components of water-dependent ecosystems will vary. Although the water-dependent ecosystems of this region are well adapted to the high level of natural variability in surface water flow and availability, if thresholds of tolerance to variability in surface water are exceeded by sustained changes to the hydrological regime then important components of the ecosystem may be impacted. While many component species of these ecosystems are well adapted to wide variations in hydrological conditions, there are other species that may not be.

Annual flows are predicted to decrease by 5% to 20% in the near vicinity of the additional coal resource developments, and the magnitude and location of these modelled changes are very consistent across the range of probabilistic modelling results (i.e. 5th, 50th and 95th percentiles). Such reductions in modelled annual flow are mainly restricted to the tributary network that feeds into the Belyando River, concentrated along the stretches of Tallarenha Creek, Lagoon Creek and Sandy Creek that run close to the southern mining cluster, and on parts of North Creek and Bully Creek in the northern zone. However, reductions in annual flow above 5% are predicted to dissipate within 10 to 20 km downstream of the mines, to a point where surface water modelling suggests there will be no significant hydrological changes to annual flows in the downstream stretches of the Belyando and Suttor rivers.

It is *very likely* that cumulative drawdown exceeding 0.2 m in the near-surface aquifer will occur due to the interaction of dewatering the four mines in the southern mining cluster. At the 5th percentile of results the area affected covers about 1663 km^2 (including the area of the planned mines), although this area is modelled to be as large as 7898 km^2 at the 95th percentile, highlighting the relatively wide range in the extent and magnitude of drawdown predictions for the Galilee subregion. In the northern part of the zone, cumulative drawdown impacts in the near-surface aquifer due to all three proposed mines (Hyde Park, China Stone and Carmichael) are only evident at the 95th percentile of modelled results, although it is *very likely* that cumulative impacts due to interaction of the adjacent China Stone and Carmichael mines will occur. The patterns and extents of drawdown in the two deeper aquifers modelled for this BA (Clematis Group and upper Permian coal measures) differ from those of the uppermost aquifer. In particular, these deeper confined aquifers do not occur east of the mines, although drawdown impacts for these layers extend considerably further westwards into the central part of the Galilee Basin than they do for the near-surface aquifer, particularly for the Permian coal-bearing unit.

There are three clusters of springs within the zone of potential hydrological change, and these have a range of ecological, economic and sociocultural values. The proximity of some of these springs to the main mining clusters, particularly in the north, suggests that potential exists for mining-related impacts to occur and affect the ecological functioning of spring ecosystems. Potentially affected springs in the Galilee subregion are the Doongmabulla Springs complex, Permian springs cluster and Triassic springs cluster. A point of some scientific contention and debate in recent times has been the source aquifer(s) of the Doongmabulla Springs complex. The available scientific evidence, as outlined earlier in this product, has been evaluated as part of this assessment, and generally supports the Clematis Group as the main source aquifer for these springs, possibly with some contribution of groundwater from the underlying Dunda beds. However, evaluation of time-series Landsat data indicates that, regardless of the source aquifer, there is heterogeneity in the rate, timing and dynamics of supply for groundwater that supports the 187 individual spring vents of the Doongmabulla Springs complex.

Additional drawdown in excess of 0.2 m in the Clematis Group, as determined from the groundwater analytic element modelling (companion product 2.6.2 for the Galilee subregion (Peeters et al., 2018)), is *very likely* to affect 181 of the 187 springs in the Doongmabulla Springs complex. This result is consistent between the two different mine dewatering conceptualisations implemented in the analytic element model (AEM), as evaluated for this BA. However, under the alternative groundwater model conceptualisation (no drawdown propagation through the alluvium layer, which is considered to be a more appropriate conceptualisation for these springs), no springs in the Doongmabulla Springs complex are predicted to experience median additional drawdown in excess of 0.2 m. In the Permian springs cluster, five to seven of the springs are predicted to experience additional drawdown in excess of 5 m as their source aquifer is the upper Permian coal measures (Betts Creek beds and equivalents), the main target for coal mine dewatering. However, it is *very unlikely* (less than 5% chance) that aquifers in the Eromanga Basin (Great Artesian Basin (GAB)) or springs with source aquifers in the Eromanga Basin (e.g. Hutton Sandstone aquifer) will be impacted by drawdown due to additional coal resource development.

Almost half of the streams in the zone of potential hydrological change are groundwater dependent. Where receptor impact modelling results are available, up to 8% of groundwater-dependent streams are 'at some risk of ecological and hydrological changes', including additional groundwater drawdown in excess of 5 m, increased low-flow days, increased low-flow day spells and decreased overbank flows. This includes parts of Native Companion Creek, North and Sandy creeks, and the Belyando and Carmichael rivers. Most remaining streams are not groundwater dependent and so are unlikely to be affected by drawdown, including many temporary streams that are potentially impacted (e.g. as they occur in an area where open-cut mining or mine-site infrastructure is planned) but not represented in the surface water model. Up to 0.5% of the non-GDE streams in the zone (with receptor impact modelling) are 'at some risk of ecological and hydrological changes' from increased low-flow days and low-flow day spells, mainly on downstream parts of the Belyando and Suttor rivers upstream of Lake Dalrymple.

Most groundwater-dependent ecosystems in the zone of potential hydrological change occur on floodplains (64% of groundwater-dependent vegetation in the zone). Within large uncertainty bounds, up to 3% of groundwater-dependent ecosystems (where receptor impact modelling results are available) on floodplains are 'at some risk of ecological and hydrological changes' from additional drawdown and decreased overbank floods along parts of Alpha, North, Sandy and Tallarenha creeks and the Belyando and Carmichael rivers. Remaining groundwater-dependent vegetation in the zone (i.e. non-floodplain ecosystems) relies on groundwater associated with clay-rich plains, loamy and sandy plains, inland dunefields, and fine-grained and coarse-grained sedimentary rocks of the Galilee Basin. Up to 5% of groundwater-dependent vegetation outside of floodplains or wetlands is classed as being 'at some risk of ecological and hydrological changes' (again within large uncertainty bounds) near the proposed mines, where additional drawdown is greatest.

Of the 241 ecological assets in the zone, 148 meet criteria for potential hydrological impacts that place them 'more at risk of hydrological changes' due to additional coal resource development. A concentration of ecological assets occurs in the 'Springs' landscape group within the zone. Although the 200 springs in this landscape group occupy less than 1% of the area of the zone, 48 ecological assets (20% of all ecological assets in the zone) intersect with it, including 16 that are confined entirely to the zone. The Doongmabulla Springs complex is where most of these assets occur, which include the springs themselves as well as some nationally listed plants such as blue devil (*Eryngium fontanum)* and salt pipewort (*Eriocaulon carsonii)*. Consideration of multiple lines of evidence – including signed digraphs, qualitative mathematical models, interpretation of various products derived from archived Landsat imagery and expert ecological knowledge of the threatened plant species – indicates that this level of drawdown will impact the ecological functioning of some ecological assets; however, there will be considerable variation in response across springs and spring complexes.

Additional drawdown in the deeper aquifer of the Clematis Group may occur in the vicinity of the Jericho town water supply. However, it is *very unlikely* that drawdown exceeds 2 m for any bore assigned to an economic water-dependent asset that sources water from the Clematis Group, including any of those near Jericho. Potential impacts on many of the bores near Alpha township cannot be ruled out, but it is not possible to quantify drawdown impacts for these bores due to limitations in the resolution of the BA groundwater modelling approach. Thus, this remains a key knowledge gap requiring further local-scale data and a more appropriate site-specific conceptualisation for groundwater modelling.

3.7.2 Future monitoring

Post-assessment monitoring is important to test and validate (or invalidate) the risk predictions of the assessment. At the highest level, hydrological and ecological monitoring effort should reflect the risk predictions, and focus the effort where the changes are expected to be the largest and incorporate those areas where modelling limitations did not allow the risk to be quantified. However, it is also important to place some monitoring effort at locations with lower risk predictions or where no impacts are expected (as control sites) so as to confirm the range of potential impacts, identify any unexpected outcomes, and provide baseline information to assist any future assessment of other developments (e.g. any of the developments included in the CRDP that could not be quantitatively assessed for this BA, as discussed in Section 3.6).

The BA for the Galilee subregion has identified that potential hydrological or ecosystem impacts are likely in areas concentrated around the locations of the seven proposed coal mines in the

CRDP that were modelled in this BA (as outlined in the qualitative assessment in Section 3.6, the other seven coal mines and three CSG developments in the CRDP were unable to be modelled due to lack of relevant information when the models were being developed). Groundwater monitoring effort should concentrate on the discrete drawdown zones identified in the hydrological modelling, particularly focusing on areas where gaps may exist in the current monitoring bore network for individual mines or near key assets. For instance, monitoring bores targeting confined parts of the Clematis Group aquifer and Dunda beds, up-hydraulic gradient (particularly to the west and south) of the discharge springs in the Doongmabulla Springs complex, would provide additional information around variations in groundwater pressures and hydrochemistry in what may be a significant source aquifer these springs. Monitoring of the unconfined Cenozoic aquifers in key areas of the Belyando River floodplain would assist in determining the degree of near-surface drawdown and potential connectivity with deeper aquifers. An important location for monitoring groundwater changes in the Cenozoic alluvial aquifer is the area around Alpha township where the regional groundwater AEM could not rule out potential impacts nor quantify any such changes. Targeted monitoring efforts could include installation of nested piezometers at key sites where drawdown impacts are predicted to affect multiple stacked aquifers, so that water levels could be monitored to better understand potential fluxes between aquifers, as well as with the surface water network. 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 BA modelling results indicate the most substantial changes across the spectrum of the low-flow, high-flow and annual flow regime.

While the main focus of monitoring efforts should be on areas in the zone of potential hydrological change, it is also appropriate to consider monitoring of groundwater and surface water near important assets that may occur just outside the zone (e.g. any key assets within about 10 km of the zone boundary). This is because it is plausible that the regional-scale hydrological modelling for this BA may not necessarily be able to predict local-scale variations that may influence groundwater systems near the margins of the zone. Likewise, there is also merit in considering possible hydrological and ecological monitoring options for the broader suite of developments in the CRDP (i.e. those mines and CSG projects that could not be modelled in this BA). As these future developments occur in several discrete areas away from the zone of potential hydrological change defined in this assessment (see Section 3.6), establishing a well-planned monitoring network prior to the start of operations in these areas could provide important biophysical data that could be used to better understand the environmental baseline within and around these planned sites of coal resource development. Ideally, such pre-development monitoring should start well in advance of mining operations (i.e. at least 5 to 10 years), so as to maximise the temporal extent of baseline data collection prior to extraction.

Besides future targeted monitoring points outlined in the previous paragraphs, a number of gaps and limitations identified in Section 3.7.4 would benefit from consistent and regular data collection. Filling some of these data gaps would improve the risk quantification component of this Assessment. This includes surface water and ecological baseline data collection to improve the understanding of environmental conditions and parameters, including those related to surface water and groundwater quality. In particular, the collection of such information prior to the onset of development activities, as well as ongoing through the early stages of mine construction and production, would enhance the baseline understanding of important ecosystems within the zone and help to track any potential responses due to the additional coal resource development.

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, including those developments in the CRDP that could not be assessed by the hydrological modelling in this BA (as outlined in Section 3.6).

In mid-2017, following consultation with the Assessment team, an airborne electromagnetics survey (a type of geophysical survey technique) was flown over select parts of the Galilee subregion by Geoscience Australia. The main objective of this survey was to determine whether this method could be used to cost-effectively detect a variety of near-surface geological structures (i.e. such as geological faults and other structural features within about 200 m of the land surface) in a range of landscape and geological settings in the Eromanga and Galilee basins. Another aim was to refine the conceptualisation of groundwater dynamics in the Galilee and Eromanga basins. Target areas for collection of electromagnetics data included the Doongmabulla and Edgbaston spring complexes, the lakes Galilee and Buchanan, Cenozoic sediment deposits in the Belyando River valley, GAB aquifer recharge beds in the Eromanga Basin, and faulting associated with the western margin of the Galilee subregion. These airborne electromagnetics data and interpretations will be released in coming years as they become available over the course of Geoscience Australia's investigations for *Exploring for the Future* (Geoscience Australia, 2017). These data could be used to inform location of future monitoring bores through the improved understanding of the role of geological structure and architecture as a controlling factor on groundwater hydrodynamics, particularly in near-surface aquifers.

3.7.3 Using this impact and risk analysis

Findings from the BA of the Galilee subregion 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, and where further attention is not necessary. The zone of potential hydrological change is the area where the magnitude of the hydrological changes due to additional coal resource development suggests that impacts to water-dependent ecosystems and assets are possible, particularly for those that rely on access to surface water or relatively shallow groundwater systems. Outside of this zone, adverse impacts on most water-dependent ecosystems and assets due to additional coal resource development are considered *very unlikely*. However, it is important to also consider potential impacts to any ecosystems or assets that may access groundwater sourced from deeper (confined) aquifers, as these may require further evaluation using modelling results that are specific to such deeper hydrostratigraphic layers.

This assessment identified a suite of potential coal mining and CSG developments that defined the CRDP for the Galilee subregion (as reported in companion product 2.3 for the Galilee subregion (Evans et al., 2018)). However, the main focus of the impact and risk analysis reported here, especially the quantitative analysis of hydrological and ecological impacts, is on the seven coal mines that could be included in the BA numerical modelling. The zone of potential hydrological change is based exclusively on the results from this probabilistic hydrological modelling, and does not incorporate the other seven potential mines and three CSG fields that are part of the CRDP (as discussed in Section 3.6). The limited amount of information for these less-advanced development projects at the start of the BA modelling meant that it was only possible to qualitatively assess potential impacts of these non-modelled components of the CRDP. Consequently, it is important that users of this impact and risk analysis understand this limitation of the assessment, and that most results presented here are constrained to the part of the Galilee subregion where future coal mining development is most likely to start. However, as there are seven other mining operations and three CSG developments that were not modelled for this BA, any future updates to the BA modelling suite (i.e. that were able to include any of these other developments) would likely increase the spatial extent of the zone of potential hydrological change, thereby potentially meaning that future updates to the impact and risk analysis could incorporate other water-dependent assets and landscape classes.

This Assessment predicts the likelihood of exceeding levels of potential hydrological change at a **regional level**. It also provides important context to identify potential issues that may need to be addressed in local-scale environmental impact assessments of new coal resource developments. It should help project proponents to meet legislative requirements to describe the environmental values that may be affected by the exercise of underground water rights, and to adopt strategies to avoid, mitigate or manage these predicted impacts. This Assessment does not investigate the broader social, economic or human health impacts of coal resource development, nor does it consider risks of fugitive gases and non-water-related impacts.

BAs are not a substitute for careful assessment of proposed coal mine or coal seam gas (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. 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 specific coal resource development proposals.

BAs have been developed with the ability to be updated, for example, to incorporate new coal resource developments in the hydrological modelling. This is particularly important for the Galilee subregion, given that only half of the mines (and no CSG fields) in the CRDP were included in the modelled assessment presented here. Existing datasets, such as the water-dependent asset register, remain relevant for future assessments. If new coal resource developments emerge in the future, the data, information, analytical results and models from this Assessment would provide a comprehensive basis for subregion-scale re-assessment of potential impacts under an updated CRDP. It may also be applicable for other types of land use or resource developments (e.g.

agricultural developments or other types of mining operations) that can potentially affect water resources and associated assets.

The full suite of information, including information for individual assets, is provided at www.bioregionalassessments.gov.au with more detailed results available using the online BA Explorer tool for:

- potential hydrological changes at www.bioregionalassessments.gov.au/explorer/GAL/potentialhydrologicalchanges
- potential impacts on landscapes at www.bioregionalassessments.gov.au/explorer/GAL/landscapes
- potential impacts on water-dependent assets at www.bioregionalassessments.gov.au/explorer/GAL/assets.

Other related investigations that inform the BA of the Galilee subregion include the Lake Eyre Basin Rivers Assessment (LEBRA) and Lake Eyre Basin Springs Assessment (LEBSA). The LEBSA and LEBRA programmes encompass a number of complementary projects funded by the Department of the Environment and Energy. Of particular relevance to the Galilee subregion is the work of Fensham et al. (2016), which reported on the hydrogeology, history and biological values of many spring groups in central and western Queensland, including the three spring clusters that occur within the zone of potential hydrological change for the Galilee subregion. Other reports and data for the LEBRA and LEBSA projects will be released at www.bioregionalassessments.gov.au in the near future.

The Galilee Basin hydrogeological (GBH) model is a regional-scale numerical groundwater flow model (built using the industry standard MODFLOW code) developed utilising data and interpretations compiled to support the BA of the Galilee subregion. This model incorporates hydrogeological and geological information for both the Galilee Basin and the overlying Eromanga Basin. The model was jointly funded by the Department of the Environment and Energy, and the Queensland Government, and involved collaboration with the Assessment team charged with undertaking the BA of the Galilee subregion. A consultant firm – HydroSimulations – was engaged to produce a calibrated and stress-tested transient numerical groundwater flow model capable of simulating the cumulative impacts of proposed coal mining developments in the central-eastern Galilee Basin. The detailed GBH model report (Turvey et al., 2015) and associated model files are available at www.bioregionalassessments.gov.au. Companion product 2.6.2 for the Galilee subregion (Peeters et al., 2018) provides an overview of the GBH model as well as a summary of its strengths and current limitations. The GBH model provides a more sophisticated representation of the hydrostratigraphy of the Galilee and Eromanga basins, and could provide the basis for any future cumulative impact assessments, building upon the initial work undertaken for this BA.

Access to underpinning datasets, including shapefiles of geographic data and modelling results, can assist decision makers at all levels to review the BA work undertaken to date; to explore the results using different thresholds for the various hydrological response variables; and to extend or update the assessment if new models, data or mine or CSG development plans become available. Additional guidance about how to apply the Programme’s overarching methodology is also documented in a detailed series of scientific submethodologies (Table 1), covering everything from surface water and groundwater modelling to developing the CRDP and undertaking the impact and risk analysis.

Lastly, 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.

3.7.4 Gaps, limitations and opportunities

This impact and risk analysis allows governments, industry and the community to focus on areas that are potentially impacted by future coal mining in the Galilee Basin when making regulatory, water management and planning decisions. Due to the conservative nature of the BA modelling and the application of the precautionary principle, the greatest confidence in results is for those areas that are *very unlikely* to be impacted (that is, areas outside the zone of potential hydrological change, or the equivalent zones that can be defined for the two deeper aquifers of the Clematis Group and upper Permian coal measures).

Where the potential for impacts to occur has been identified, further work may be required to improve the predictions of the potential magnitude of impacts to ecosystems and individual assets. This important consideration needs to be explicitly emphasised here; given the regional-scale nature of the assessment and the application of a relatively low resolution modelling approach to assess cumulative impacts across a very broad area, the Assessment team cautions against adopting any specific point-scale results as the basis for future management or regulatory decisions. Although the probabilistic approach to modelling provides a high level of confidence that the reported range that spans the 5th to 95th percentile for a particular hydrological response variable is robust, it would be inappropriate to simply adopt a single probabilistic result (even the median) as basis for future decision making. For such cases, further work incorporating an appropriate level of local data and information may be required to refine and improve confidence in finer-scale modelling results.

Below is a summary of the key knowledge gaps identified during the course of this BA, where understanding the potential impacts of coal resource development could be improved through further targeted research. This is particularly important for the Galilee subregion given it is a greenfield basin for coal production, and so does not have the same history of data and information surrounding baseline coal resource developments as many of the other regions evaluated as part of the Bioregional Assessment Programme.

3.7.4.1 Overall

The CRDP for the BA of the Galilee subregion was originally defined in December 2014 and, once decided, was 'locked in' for the duration of this assessment (companion product 2.3 for the Galilee subregion (Evans et al., 2018)). This approach, consistent with companion submethodology M04 (as listed in Table 1) for developing a coal resource development pathway (Lewis, 2014), was needed to provide certainty for the subsequent stages of data analysis and modelling that underpinned the impact and risk analysis. However, by locking in the CRDP at this time, it was not possible to later review or revise the focus for the quantitative analysis, even if mine development changes were made that invalidated aspects of the CRDP.

Future iterations of surface water and groundwater modeling to support management or planning decisions in the Galilee Basin should revisit the choice of individual mining projects (and their development characteristics) in the CRDP and assess if any updates or changes are required. This may be as simple as revising (as needed) the development schedules for the seven coal mines that were modelled in this Assessment. Alternatively, a different selection of proposed mining operations of characteristics may need to be considered in a future iteration of the CRDP, potentially leading to a revised zone of potential hydrological change.

Some consideration could also be given to the merits (or otherwise) of evaluating multiple potential development scenarios for the Galilee Basin to assess a range of future development options. This could, for example, look at varying the number of mining operations both in the central-eastern part of the basin, as well as in the other areas where future mining could proceed (i.e. the northern part of the basin near Hughenden and Pentland, as discussed in Section 3.6). Additionally, future modelling iterations could also evaluate the potential for hydrological interaction between coal mining operations and CSG development in the basin's most prospective central CSG fairway.

As explained in companion product 2.6.1 (Karim et al., 2018b) and companion product 2.6.2 (Peeters et al., 2018) for the Galilee subregion, the BA modelling approach focussed on the maximum predicted change in hydrological response variables (such as maximum drawdown or annual flow) during the 90-year simulation period of 2013 to 2102. This timeframe covers the proposed operational period of the seven mines in the modelled CRDP, but extends only 30 to 40 years beyond the expected mining period. Consequently, the modelling did not examine potential hydrological changes post-2102, or factor in the long-term effectiveness of rehabilitation or any post mine closure legacy issues such as impact of open pits on groundwater systems. Consequently, there is an opportunity for any future modelling efforts to cover a longer simulation period post-mining, as well as to capture the potential effects of rehabilitation and other post-closure issues.

3.7.4.2 Geology

Significant effort was devoted in this BA to building a regional-scale geological model of the Galilee Basin, integrating it (where applicable) with the existing model of the overlying Eromanga Basin from the GAB Atlas (Ransley et al., 2015). This geological model was used to enhance the Assessment team's conceptual understanding of the geology and hydrogeology of the Galilee subregion, aid in the development of the groundwater modelling, and provide a suitable framework for visualising the regional-scale stratigraphic and structural architecture. However, despite these important advances in better understanding the geology of the Galilee Basin, there are limitations in the resolution of the regional geological model for supporting more localised applications, for example, mapping the finer-scale structure and stratigraphy of the Galilee Basin and overlying Cenozoic alluvium and regolith/sediment cover within the zone of potential hydrological change.

The Assessment team considers that a significant opportunity exists to improve the surface geological and structural mapping along the central-eastern margin of the Galilee Basin, which would aim to 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 discussed below) and exploration/resource drilling, as well as any available finer-scale mapping or geological modelling that may have been completed to aid in coal exploration or evaluation activities. In particular, compiling and integrating the extensive amount of drill-hole and other company data collected since the mid-2000s would provide new information that would undoubtedly help fill existing knowledge gaps and uncertainties. For example, new or revised structural and stratigraphic data would help to refine the known extents of Galilee Basin stratigraphic units in key areas within the zone of potential hydrological change (Section 3.3). It would also likely improve understanding of the thickness of Cenozoic sediment cover across the eastern part of the Galilee Basin. Information such as this could then be used to refine knowledge of the three-dimensional geological architecture within this main area of interest, potentially leading to more robust and reliable hydrogeological conceptualisations to underpin subsequent modelling.

As previously mentioned, the application of targeted geophysical surveys, such as airborne electromagnetic surveys, would help improve understanding of the geological structure and stratigraphic architecture of the Galilee and Eromanga basins, as well as the overlying Cenozoic sediment/regolith. Airborne electromagnetic data would provide especially valuable data for the upper 200 to 300 m of the subsurface (depending upon the relative conductivity of the various regolith and rock types), thereby improving the definition of near-surface faults that could potentially act as pathways for groundwater flow and interaction between different source aquifers. Such data could also provide useful information on the potential for connectivity between shallow aquifers in Cenozoic sediments and the deeper aquifer systems of the Galilee Basin. Fortunately, the aforementioned Galilee – Eromanga airborne electromagnetics surveys recently completed by Geoscience Australia as part of the *Exploring for the Future* program (Geoscience Australia, 2017) will be gradually released in the next few years, thereby providing an important source of new data to help address such questions in the future.

3.7.4.3 Groundwater and surface water

The probabilistic approach to modelling undertaken in the Assessment is ideally suited to deal with data and knowledge gaps. The Assessment team focused on integrating data and information that were quality assured and relevant for this regional-scale analysis. However, this meant that some data and information about the Galilee subregion were not used to inform the modelling – for instance, because it was localised and ad hoc in its coverage, lacked reliable metadata to quality assure the data, was not available to the Assessment team at the time of analysis, or because operational constraints prevented collating and scrutinising the data to the standards set out in the BA.

An important aspect of the groundwater modelling approach for this BA was the choice of a wide array of model parameterisations (i.e. within bounds of several orders of magnitude around known point-scale data for parameters such as hydraulic conductivity). These parameter ranges were used to represent the possibility of a variably connected hydrogeological system ranging from highly conductive and highly connected aquifers through to low-conductivity, poorly connected aquitards. This approach provided results that effectively put an upper limit on the area of potentially significant hydrological change (i.e. the definition of the zone of potential hydrological change). In flagging gaps and identifying opportunities for improvement in the modelling, it is important to be aware that more and better data will not necessarily improve the predictions from the regional-scale modelling, but could contribute to better constraining model results for local-scale application.

As previously described, the groundwater modelling approach that underpinned the impact and risk analysis for this BA used a relatively low-resolution AEM with simplified hydrogeological conceptualisation. Although this was considered appropriate to address the overarching objective of the BA for the Galilee subregion (Section 3.3), future groundwater modelling efforts focused on the seven coal mines within the zone of potential hydrological change would be enhanced by adopting a more sophisticated modelling approach. Fortunately, a complementary regional-scale numerical groundwater flow model was developed as a supporting product for this BA (although it was not sufficiently advanced during the course of the BA to allow it to be used as the basis for the BA probabilistic modelling assessment). Thus, the Assessment team recommends that any further groundwater modelling and analysis focused on the proposed mining operations in the zone would benefit by adopting and further developing the existing GBH model (Turvey et al., 2015; companion product 2.6.2 for the Galilee subregion (Peeters et al., 2018)). However, it should be noted that considerable further investment in time and resources would be required to advance the model, and enable it to be used for future cumulative impact assessment. Enhancing the GBH model would help to better understand the overall water balance and hydraulic fluxes between different aquifers and the surface water system, allow for the evaluation of different coal resource development scenarios (i.e. update the CRDP future used as basis for the modelling in this BA), and provide a suitable platform for future planning and management of water resources in the Galilee subregion. The existing strengths and limitations of the GBH model, as well as suggested areas for further work and improvement, are well described in Turvey et al. (2015) and companion product 2.6.2 for the Galilee subregion (Peeters et al., 2018).

The impact assessment would benefit from better characterisation of surface water – groundwater interactions along the Belyando River (and its 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. As mentioned above, the acquisition of new regional-scale airborne electromagnetics data in selected parts of the Galilee Basin in mid-2017 by Geoscience Australia as part of *Exploring for the Future* (Geoscience Australia, 2017) affords considerable potential to address these issues.

Hydrogeological interpretation of spring source aquifers within the zone (a noted point of current scientific debate) would benefit from additional field-based measurements and data collection, for example, using suitable environmental tracers, geophysical data and application of local-scale groundwater modelling. Additionally, an improved understanding of the geological structure and stratigraphy within the zone (as previously flagged) would help underpin development of a more suitable local-scale hydrogeological conceptualisation to use as basis for further groundwater modelling of potential cumulative impacts to springs and their source aquifers.

An enhanced understanding of water balance components, including recharge, evapotranspiration, inter-aquifer leakage, and groundwater fluxes between the Galilee and Eromanga basins would improve future updates to this Assessment. This work would build upon the higher-level water balance reporting presented for this BA (companion product 2.5 for the Galilee subregion (Karim et al., 2018a)), and include revised/updated estimates of mine water extraction, on-site use and any potential stream releases (if appropriate).

The distribution of surface water model nodes in this BA did not enable a comprehensive extrapolation to network reaches, and resulted in definition of some ‘potentially impacted’ 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 also enable better spatial coverage of the results of the receptor impact modelling.

3.7.4.4 Assessing ecological impacts

An improved understanding of the water dependency of the various threatened species, threatened ecological communities and endangered regional ecosystems that occur within the zone of potential hydrological change would assist in their future management, and in understanding their potential to be impacted by coal resource development. For example, the response of various water-dependent species and ecosystems to predicted decreases in the low-flow component of the surface water system would provide valuable insights to better understand how the predicted hydrological changes could lead to potential ecological impacts.

More refined vegetation mapping and ongoing research to enhance the identification of groundwater-dependent ecosystems in the subregion would improve assessment of impacts on ecological water-dependent assets. In particular, groundwater dependency for the purposes of this BA was largely determined by spatial intersection of the ecological assets identified as GDEs (most of which were derived from the *National atlas of groundwater dependent ecosystems* (GDE Atlas) (Bureau of Meteorology, 2012). with the various landscape groups. This approach estimates groundwater-dependent vegetation, which are but one component of a potentially dependent ecosystem, but not the complexity inherent across the broader ecosystem. Further, it does not assess interaction between groundwater and surface water. In the case of the approach taken in the BA, groundwater dependency is based on one ecological attribute, although there may be more complex hydrological dependencies within the landscape group (i.e. multiple ecosystems may exist within such a group).

The actual dependency on groundwater of the GDEs in the water-dependent asset register is mainly based on a spatial association with accessible groundwater (e.g. in areas where the water table occurs at relatively shallow depths below surface), rather than any actual demonstrated level of dependency. To demonstrate a level of dependency requires more detailed information on the system in question than is currently available. Thus, further research to track key biophysical processes of the groundwater-dependent ecosystems, such as rate of actual evapotranspiration and vegetation growth rates, and interpreting these processes in an ecohydrological framework will improve understanding of the interactions between changes in groundwater availability and the health of terrestrial vegetation that relies on groundwater. This type of analysis can be performed by field measurement and/or use of time-series remote sensing methods (e.g. building on the preliminary use of such remotely sensed data described in Section 3.5.2).

In general, in the Galilee subregion, there is limited understanding of interactions between riverine and terrestrial ecosystems and groundwater. For instance at finer scales, it would be useful to have a clearer understanding of the level of reliance on groundwater in gaining-stream systems such as Dyllingo Creek and Carmichael River, their role in ecological and hydrological connectivity in the landscape, and whether small changes in groundwater pressure might alter refugial pool persistence during dry times. Interactions among groundwater dependent ecosystems are important, as is the representativeness of the indicators selected as receptors of the various landscape class ecosystems. The receptor impact modelling approach was strongly influenced by the availability of expertise; therefore, the suitability of the selected indicators could be re-assessed because the hydrological thresholds were extrapolated based on the assumed responses of quite a small subset of ecosystem components.

As actual water requirements of different plant communities are only approximately known, future assessments and expert elicitation would be assisted by more work to identify suitable bio-indicators of ecosystem condition, or alternative methods of assessing the condition of water-dependent ecosystems. Again, this is likely best performed using field measurement and/or time-series remote sensing data.

The remote sensing techniques applied for this BA (see Section 3.2 and Section 3.5) demonstrates the potential for multi-decadal earth observation data to provide insight into the spatial and temporal dynamics of vegetation and wetlands and can be used to assess potential groundwater dependency of surface features (e.g. such as streams). Although the Hovmöller plots are useful for visualising these data and help to highlight both spatial and temporal features of interest, further quantitative analysis can be done to separate the features that are likely to be:

- rainfall dependent (i.e. greenness/wetness features that show a strong correlation with rainfall)
- streamflow dependent (i.e. features distributed along the stream channel network, or that are highly correlated with proximal gauging stations)
- groundwater dependent (i.e. features that are show high levels of persistence (greenness or wetness) with weak – no correlation with antecedent rainfall conditions).

Placing these types of data into the temporal context of the rainfall record and the spatial context of known groundwater assets further enhances its utility. This information can be placed into additional context through the use of suitable terrain analysis, and with reference to the history of any known disturbance events.

Remote sensing imagery suggests that different spring groups within the Doongmabulla Springs complex have markedly different responses in the persistence of water at surface. This could be due to variations in spring flow to different spring groups, as well as localised variations in vegetation cover and geomorphology (among other factors). This suggests that the response near-surface from changes in groundwater pressure (due to additional coal resource development) could vary between spring groups, which in turn may have a bearing on spring water balance and resilience of ecological communities inhabiting different spring groups. Better understanding of how hydrological changes may propagate through ecological communities at springs would assist with management of the threatened ecological communities and species associated with individual spring groups.

Four water-dependent landscape groups within the zone of potential hydrological change were not considered for receptor impact modelling in this BA due to their relatively small areas of overlap with the zone, and as part of prioritising resources within the operational constraints of the BA. Given that these landscape groups are potentially impacted though, potential impacts to each group could be evaluated more explicitly in future through the application of receptor impact modelling. More generally, there is also an opportunity to address some of the limitations of the overall receptor impact modelling approach identified for specific cases (see companion product 2.7 for the Galilee subregion (Ickowicz et al., 2018)). For example, this could focus on:

- considering the interconnections between adjacent landscape groups (or classes) in more detail, particularly in cases where impacts on different trophic structures outside of the affected class are plausible
- expanding the receptor impact modelling focus to also consider short-term pulse perturbations (relative to the long-term press perturbations that arise from more sustained changes)
- investigating how the boundaries of specific landscape classes and their responses to hydrological change may change over time.

3.7.4.5 Assessing impacts to economic assets

The assessment of impacts to groundwater economic assets for this BA was done using the management framework of the *Water Plan (Great Artesian Basin) 2006* and its associated resource operations plan. However, this plan was superseded in September 2017 by the *Water Plan (Great Artesian Basin and Other Regional Aquifers) 2017*, implemented through a new water management protocol. Consequently, there is now an opportunity to update the account of impacts to economic groundwater assets in light of these recent management changes. Importantly, the new planning regime now specifically includes groundwater sourced from the upper Permian coal measures (e.g. Betts Creek beds) within the Galilee Basin which, as shown from the modelling undertaken for this BA, is expected to be the hydrostratigraphic unit in which drawdown will be of greatest extent and magnitude. Consequently, the register of water-dependent assets compiled for the Galilee subregion should be updated to reflect the new planning arrangements. These changes will likely mean that the number of groundwater economic assets potentially affected by drawdown will be greater than the five assets reported in Section 3.5.2 for this BA.

The town water supply bores at Alpha are part of an economic asset that occurs within the zone of potential hydrological change. However, as explained in Section 3.5.3, the outputs of the groundwater modelling for this BA were not able to accurately predict water level changes for bores that source water from the Cenozoic sediment aquifer near Alpha. Consequently, it is not possible on the basis of the BA modelling to evaluate the potential for groundwater impacts to adversely affect the Alpha town water supply borefield. Clearly, these bores are part of an important water-dependent asset in the zone, and there is a need for further local-scale hydrogeological assessment, in order to develop an appropriate management response to any potential impacts due to additional coal resource development.

Additional information around the depth of bore screens and stratigraphic information for those bores for which the source aquifer is currently unknown would improve the ability to assess the potential for impact from the groundwater modelling results. Further, knowledge of which aquifer a bore taps into will improve estimates of water take from different aquifers, which has potential implications for the regional aquifer water balance.

3.7.4.6 Water quality

Due to large yearly variation in annual streamflow volumes in the Belyando River, changes in hydrology due to additional coal resource development may not necessarily lead to substantial changes at a regional scale in many water quality parameters, such as salinity, at least beyond the naturally occurring annual variability already experienced. However, available baseline water quality data are patchy. Sampling programs to determine water quality in wet and dry seasons in different parts of the river basin would provide an improved regional baseline and could be beneficial for future studies, such as assessment of potential changes in water quality parameters that could occur, with a shift in the relative contributions of surface runoff and groundwater to streamflow.

Available groundwater quality data are relatively sparse in many parts of the Galilee subregion, including within the zone of potential hydrological change. Existing groundwater analytical data for this area cover broad timeframes and a range of different sampling and analysis methods, meaning that there is considerable variability in the coverage (both areally and with depth) and quality of data. Sufficient baseline hydrochemistry data measured at a number of key sites (guided with reference to the groundwater modelling predictions from the BA) would be important to provide a useful reference standard for the key aquifer systems, against which potential future changes to groundwater quality due to additional coal resource development could be assessed. Particular emphasis could be placed on collecting a suite of stable isotopes and trace element data that may assist in determining important hydrogeological characteristics, and which would help to better define groundwater flow paths both within and between different aquifers, improve the characterisation of the source aquifers for various springs (especially the Doongmabulla Springs complex), evaluate the likelihood of aquifer compartmentalisation, and improve the definition of aquifer recharge processes and groundwater residence times within the main aquifers.

3.7.4.7 Climate change and land use

In comparing results under two different futures in this assessment, factors such as climate change and land use are held constant. Future assessment iterations could look to include a broader range of potential climate scenarios, along with a more accurate representation of competing land and water uses (particularly in and around the zone of potential hydrological change). Incorporating a broader range of development types (such as water used for agricultural purposes) and other potential hydrological stressors to the system would generate a more comprehensive understanding of cumulative impacts on the landscapes and water resources of the region. Identifying potential interactions among certain types of land use and the hydrological and chemical effects of coal resource development would test some of this BAs underlying assumptions. If such interactions are found to be minimal, this would help support the assumption that land-use differences over time can be 'factored out' by the differential approach currently used in the assessment. Of course, adding further complexities and a much broader scope to the modelling scenarios would likely require increased resourcing and novel assessment approaches, in order to generate robust impact predictions.

There is a relatively low density of meteorological stations in the Galilee subregion which has implications for the development of some types of hydrological models. Therefore, to increase the level of predictability of rainfall estimates for rainfall-runoff modelling, it would be beneficial if additional rainfall and temperature gauges were installed at key areas in the subregion (such as along the eastern margin, particularly near the zone of potential hydrological change where multiple coal resource developments are planned). While other meteorological variables would also benefit from being measured with enhanced spatial density, the overall gain would be minimal when compared to measuring rainfall with greater accuracy. Improved resolution in meteorological parameters, such as temperature and rainfall, would improve the resolution of site and semi-regional scale water balances in areas such as the Doongmabulla Springs complex, or the northern Belyando river basin in the vicinity of the proposed Carmichael, China Stone and Hyde Park coal mines.

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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 (note that terms and definitions are respectively listed under the 'Name' and 'Description' columns in this register). This register is a list of terms, which are the preferred descriptors for concepts. Other properties are included for each term, including licence information, source of definition and date of approval. Semantic relationships (such as hierarchical relationships) are formalised for some terms, as well as linkages to other terms in related vocabularies.

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

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

analytic element model: a groundwater model in which the groundwater flow equations are solved based on the representation of internal boundary conditions, points, lines or polygons where constant groundwater level, constant flux or flux dependence on groundwater level is imposed (Bakker, 2013). The resulting groundwater flow equations can be evaluated at arbitrary points in space and time. The solution is therefore independent of a spatial discretisation of the model domain into grids, and a temporal discretisation into time steps, as is necessary for finite element or finite difference groundwater models.

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

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

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.

assessment unit: for the purposes of impact analysis, a geographic area that is used to partition the entire assessment extent into square polygons that do not overlap. The spatial resolution of the assessment units is closely related to that of the bioregional assessment groundwater modelling and is, typically, 1 x 1 km. Each assessment unit has a unique identifier. The partitioned data can be combined and recombined into any aggregation supported by the conceptual modelling, causal pathways and model data.

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

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 portion of streamflow that comes from shallow and deep subsurface flow, and is an important part of the groundwater system

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

basement: the crust below the rocks of interest. In hydrogeology it means non-prospective rocks below accessible groundwater. Commonly refers to igneous and metamorphic rocks which are unconformably overlain by sedimentary beds or cover material, and sometimes used to indicate 'bedrock' (i.e. underlying or encasing palaeovalley sediments).

bioregion: a geographic land area within which coal seam gas (CSG) and/or coal mining developments are taking place, or could take place, and for which bioregional assessments (BAs) are conducted bioregional assessment: a scientific analysis of the ecology, hydrology, geology and hydrogeology of a bioregion, with explicit assessment of the potential direct, indirect and cumulative impacts of coal seam gas and coal mining development on water resources. The central purpose of bioregional assessments is to analyse the impacts and risks associated with changes to water-dependent assets that arise in response to current and future pathways of coal seam gas and coal mining development.

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

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

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

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

conceptual model: abstraction or simplification of reality

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

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

consequence: synonym of impact

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

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

dataset: a collection of data in files, in databases or delivered by services that comprise a related set of information. Datasets may be spatial (e.g. a shape file or geodatabase or a Web Feature Service) or aspatial (e.g. an Access database, a list of people or a model configuration file).

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

derived dataset: a dataset that has been created by the Bioregional Assessment Programme

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.

direct impact: for the purposes of bioregional assessments, a change in water resources and water-dependent assets resulting from coal seam gas and coal mining developments without intervening agents or pathways

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

dmax: maximum difference in drawdown, obtained by choosing the maximum of the time series of differences between two futures. For example, to calculate the difference in drawdown between the coal resource development pathway (CRDP) and baseline, use the equations dmax = max (dCRDP(t) – dbaseline(t)) where d is drawdown, or dmax = max (hbaseline(t) – hCRDP(t)) where h is groundwater level and t is time.

dmaxRef: maximum difference in drawdown under the baseline future or under the coal resource development pathway future relative to the reference period (1983 to 2012). This is typically reported as the maximum change due to additional coal resource development.

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.

ecosystem function: the biological, geochemical and physical processes and components that take place or occur within an ecosystem. It refers to the structural components of an ecosystem (e.g. vegetation, water, soil, atmosphere and biota) and how they interact with each other, within ecosystems and across ecosystems.

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

EventsR2.0: the mean annual number of events with a peak daily flow exceeding the threshold (the peak daily flow in flood events with a return period of 2.0 years as defined from modelled baseline flow in the reference period (1983 to 2012)). This metric is designed to be approximately representative of the number of overbank flow events in future 30-year periods. This is typically reported as the maximum change due to additional coal resource development.

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

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

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

Galilee subregion: The Galilee subregion is part of the Lake Eyre Basin bioregion and is entirely within Queensland. It extends westwards across the Great Dividing Range and into the Lake Eyre drainage basin. The subregion is sparsely populated, with most people living in towns and localities including Charleville, Barcaldine, Blackall and Hughenden. The subregion encompasses the headwaters of several major waterways including the Cooper Creek and the Diamantina, Belyando, Cape, Thomson, Barcoo, Flinders, Bulloo, and Warrego rivers. In addition to the river systems, the subregion has numerous wetlands, springs, waterholes and lakes, including the nationally important lakes Buchanan and Galilee. Some of these are home to diverse and unique plants and animals, many of which are listed as rare or threatened under Queensland and Commonwealth legislation. Native vegetation consists largely of grasslands in the west and open eucalyptus woodlands in the east. Cattle and sheep grazing on native pasture is the main land use and groundwater is of great importance.

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

goaf: that part of a mine from which the coal has been partially or wholly removed; the waste left in old workings

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).

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

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

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

inflow: surface water runoff and deep drainage to groundwater (groundwater recharge) and transfers into the water system (both surface water and groundwater) for a defined area

interquartile range (IQR): the interquartile range in daily flow (ML/day); that is, the difference between the daily flow rate at the 75th percentile and at the 25th percentile. This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102).

Lake Eyre Basin bioregion: The Lake Eyre Basin bioregion covers an area of about 1.31 million square kilometres of central and north-eastern Australia, which is almost one-sixth of the country. It extends across parts of Queensland, SA, NSW and the NT and incorporates the whole of the Lake Eyre drainage basin. The bioregion was selected for assessment because of the likelihood of coal seam gas and coal mining development and the potential for water-dependent impacts on the environment and other industries that use water such as agriculture.

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

length of low-flow spell (LLFS): the length (days) of the longest low-flow spell each year. This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102).

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 to additional 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 spells (LFS): the number of low-flow spells 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). A spell is defined as a period of contiguous days of flow below the 10th percentile threshold.

low-flow days (averaged over 30 years) (LQD): 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: flood condition where water flows beyond and sub-parallel to the main channel of a river, but within the bounding floodplain

P99: the daily flow rate at the 99th percentile (ML/day). This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102).

percentile: a specific type of quantile where the range of a distribution or set of runs is divided into 100 contiguous intervals, each with probability 0.01. An individual percentile may be used to indicate the value below which a given percentage or proportion of observations in a group of observations fall. For example, the 95th percentile is the value below which 95% of the observations may be found.

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.

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

preliminary assessment extent: the geographic area associated with a subregion or bioregion in which the potential water-related impact of coal resource development on assets is assessed. The PAE is estimated at the beginning of a bioregional assessment, and is updated to the 'assessment extent' on the basis of information from Component 1: Contextual information and Component 2: Model-data analysis.

probability distribution: the probability distribution of a random variable specifies the chance that the variable takes a value in any subset of the real numbers. It allows statements such as 'There is a probability of x that the variable is between a and b'.

quantile: a set of values of a variate that divide the range of a probability distribution into contiguous intervals with equal probabilities (e.g. 20 intervals with probability 0.05, or 100 intervals with probability 0.01). Within bioregional assessments, probability distributions are approximated using a number of runs or realisations.

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

return period: An event has a return period (or recurrence interval) of T years if its magnitude is equalled or exceeded once on average every T years. The reciprocal of the return period is the exceedance probability of the event, that is, the probability that the event is equalled or exceeded in any one year. For example, a flood with a return period of 10 years has a 0.1 or 10% chance of being exceeded in any one year and a flood with a return period of 50 years has a 0.02 or 2% chance of being exceeded in any one year. The actual number of years between floods of any given size varies a lot because of climatic variability.

riparian: An area or zone within or along the banks of a stream or adjacent to a watercourse or wetland; relating to a riverbank and its environment, particularly to the vegetation.

risk: the effect of uncertainty on objectives

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

severity: magnitude of an impact

source dataset: a pre-existing dataset sourced from outside the Bioregional Assessment Programme (including from Programme partner organisations) or a dataset created by the Programme based on analyses conducted by the Programme for use in the bioregional assessments (BAs)

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

stratigraphy: stratified (layered) rocks

stressor: chemical or biological agent, environmental condition or external stimulus that might contribute to an impact mode subcrop: 1 - A subsurface outcrop, e.g. where a formation intersects a subsurface plane such as an unconformity. 2 - In mining, any near-surface development of a rock or orebody, usually beneath superficial material.

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 nine 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.

tenement: a defined area of land granted by a relevant government authority under prescribed legislative conditions to permit various activities associated with the exploration, development and mining of a specific mineral or energy resource, such as coal. Administration and granting of tenements is usually undertaken by state and territory governments, with various types related to the expected level and style of exploration and mining. Tenements are important mechanisms to maintain standards and safeguards relating to environmental factors and other land uses, including native title.

tmaxRef: the year that the maximum difference in drawdown relative to the reference period (1983 to 2012) (dmaxRef) occurs

transparency: a key requirement for the Bioregional Assessment Programme, achieved by providing the methods and unencumbered models, data and software to the public so that experts outside of the Assessment team can understand how a bioregional assessment was undertaken and update it using different models, data or software 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.

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

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-dependent asset register: a simple and authoritative listing of the assets within the preliminary assessment extent (PAE) that are potentially subject to water-related impacts

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)

water use: the volume of water diverted from a stream, extracted from groundwater, or transferred to another area for use. It is not representative of 'on-farm' or 'town' use; rather it represents the volume taken from the environment.

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).

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).

Landscape classification

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

- 'Dryland' landscape group: Ecosystems in the 'Dryland' landscape group are not dependent on either surface water or groundwater.
  - 'Dryland' landscape class: The 'Dryland' landscape class is characterised by ecosystems that are not on the floodplain and are not wetlands nor groundwater dependent. Water requirements are derived from rainfall and local runoff. Vegetation in this landscape class exhibits evidence of mechanical or chemical disturbance.
  - 'Dryland, remnant vegetation' landscape class: The 'Dryland, remnant vegetation' landscape class comprises ecosystems that are not on the floodplain and are not wetlands nor groundwater dependent. Water comes from rainfall and local runoff. Vegetation in this landscape class retains many of the structural and floristic attributes of similar undisturbed communities.
- 'Floodplain, non-wetland' landscape group: Ecosystems in the 'Floodplain, non-wetland' landscape group are alluvial plains that are not elsewhere classified as wetlands.
  - 'Floodplain disconnected non-wetland' landscape class: The 'Floodplain disconnected non-wetland' landscape class is characterised by ecosystems on alluvial floodplains subject to periodic inundation. Vegetation is typically (but not exclusively) dominated by *Eucalyptus* or *Acacia* woodlands or open woodlands, with no evidence of groundwater dependence. This landscape class excludes floodplain riverine, palustrine and lacustrine wetlands. Vegetation in this landscape class exhibits evidence of mechanical or chemical disturbance.
  - 'Floodplain disconnected non-wetland, remnant vegetation'' landscape class: The 'Floodplain disconnected non-wetland, remnant vegetation' landscape class is characterised by ecosystems on alluvial floodplains subject to periodic inundation. Vegetation is typically (but not exclusively) dominated by *Eucalyptus* or *Acacia* woodlands or open woodlands, with no evidence of groundwater dependence. This landscape class excludes floodplain palustrine and lacustrine wetlands. Vegetation in this landscape class retains many of the structural and floristic attributes of similar undisturbed communities.
- 'Floodplain, wetland GDE' landscape group: Wetlands in the 'Floodplain, wetland GDE' landscape group are groundwater-dependent wetlands on alluvial plains overlying unweathered sandstone geologies associated with local or regional watertables.
  - 'Wetland GDE' landscape class: The 'Wetland GDE' landscape class is characterised by palustrine or lacustrine wetlands occurring on floodplains. Water regimes are defined by surface water and groundwater inputs. Vegetation in this landscape class may exhibit evidence of mechanical or chemical disturbance.

  - 'Wetland GDE, remnant vegetation' landscape class: The 'Wetland GDE, remnant vegetation' landscape class is characterised by palustrine or lacustrine wetlands occurring on floodplains. The water regime is defined by surface water and groundwater inputs. Vegetation in this landscape class retains many of the structural and floristic attributes of similar undisturbed communities.
- 'Floodplain, disconnected wetland' landscape group: Wetlands in the 'Floodplain, disconnected wetland' landscape group are on alluvial plains overlying bedrock other than unweathered sandstone, dominated by surface water regimes.
  - 'Floodplain disconnected saline wetland' landscape class: The 'Floodplain, disconnected saline wetland' landscape class is characterised by disturbed palustrine or lacustrine wetlands occurring on alluvial floodplains. These are areas of permanent or periodic/intermittent inundation with static or flowing water that is brackish to saline (>3000 mg/L total dissolved solids). Water regimes are dominated by surface water inputs and there is no evidence of interaction with groundwater. Vegetation in this landscape class may exhibit evidence of mechanical or chemical disturbance.
  - 'Floodplain disconnected saline wetland, remnant vegetation' landscape class: The 'Floodplain disconnected saline wetland, remnant vegetation' landscape class is characterised by undisturbed palustrine or lacustrine wetlands occurring on alluvial floodplains. These are areas of permanent or periodic/intermittent inundation with static or flowing water that is brackish to saline (>3000 mg/L total dissolved solids). Water regimes are dominated by surface water inputs and there is no evidence of interaction with groundwater. Vegetation in this landscape class retains many of the structural and floristic attributes of similar undisturbed communities.
  - 'Floodplain disconnected wetland' landscape class: The 'Floodplain disconnected wetland' landscape class is characterised by disturbed palustrine or lacustrine wetlands occurring on alluvial floodplains. These are areas of permanent or periodic/intermittent inundation with static or flowing water that is fresh (<3000 mg/L total dissolved solids). Water regimes are dominated by surface water inputs and there is no evidence of interaction with groundwater. Vegetation in this landscape class may exhibit evidence of mechanical or chemical disturbance.
  - 'Floodplain disconnected wetland, remnant vegetation' landscape class: The 'Floodplain disconnected wetland, remnant vegetation' landscape class is characterised by undisturbed palustrine or lacustrine wetlands occurring on alluvial floodplains. These are areas of permanent or periodic/intermittent inundation with static or flowing water that is fresh (<3000 mg/L total dissolved solids). Water regimes are dominated by surface water inputs and there is no evidence of interaction with groundwater. Vegetation in this landscape class retains many of the structural and floristic attributes of similar undisturbed communities.

- 'Floodplain, terrestrial GDE' landscape group: Ecosystems in the 'Floodplain, terrestrial GDE' landscape group are characterised by groundwater-dependent terrestrial vegetation communities associated with alluvial groundwater systems.
  - 'Terrestrial GDE' landscape class: The 'Terrestrial GDE' landscape class is characterised by terrestrial vegetation on alluvial floodplains overlying unweathered sandstone bedrock. These communities will typically be dominated by *Eucalyptus* and/or *Acacia* with a variable dependence on groundwater to support structure and function. Vegetation in this landscape class may exhibit evidence of mechanical or chemical disturbance.
  - 'Terrestrial GDE, remnant vegetation' landscape class: The 'Terrestrial GDE, remnant vegetation' landscape class is characterised by terrestrial vegetation on alluvial floodplains overlying unweathered sandstone bedrock. These communities will typically be dominated by *Eucalyptus* and/or *Acacia* with a variable dependence on groundwater to support structure and function. Vegetation in this landscape class retains many of the structural and floristic attributes of similar undisturbed communities.
- 'Non-floodplain, wetland GDE' landscape group: The 'Non-floodplain, wetland GDE' landscape group is characterised by groundwater-dependent wetlands that do not occur on floodplains.
  - 'Non-floodplain wetland GDE' landscape class: The 'Non-floodplain wetland GDE' landscape class is characterised by disturbed palustrine or lacustrine wetlands that occur in upland environments not occurring on floodplains. Water regimes are supported by the surface or subsurface expression of groundwater. Vegetation in this landscape class may exhibit evidence of mechanical or chemical disturbance.
  - 'Non-floodplain wetland GDE, remnant vegetation' landscape class: The 'Non-floodplain wetland GDE, remnant vegetation' landscape class is characterised by undisturbed palustrine or lacustrine wetlands that occur in upland environments not on floodplains. Water regimes are supported by the surface or subsurface expression of groundwater. Vegetation in this landscape class retains many of the structural and floristic attributes of similar undisturbed communities.
- 'Non-floodplain disconnected wetland' landscape group: The 'Non-floodplain disconnected wetland' landscape group is characterised by wetlands not connected to streams or groundwater features.
  - 'Non-floodplain disconnected wetland' landscape class: The 'Non-floodplain disconnected wetland' landscape class includes temporary palustrine or lacustrine wetlands off floodplains and is not associated with streams or groundwater features. Water regimes are not supported by groundwater and these may include gilgai wetlands. Vegetation in this landscape class may exhibit evidence of mechanical or chemical disturbance.
  - 'Non-floodplain disconnected wetland, remnant vegetation' landscape class: The 'Non-floodplain disconnected wetland, remnant vegetation' landscape class includes temporary palustrine or lacustrine wetlands off floodplains and is not associated with streams or groundwater features. Water regimes are not supported by groundwater and these may include gilgai wetlands. Vegetation in this landscape class retains many of the structural and floristic attributes of similar undisturbed communities.

- 'Non-floodplain disconnected saline wetland' landscape class: The 'Non-floodplain disconnected saline wetland' landscape class includes saline wetlands in lower parts of the catchment not dependent on groundwater in a disturbed state. Water regimes may be influenced by tidal or estuarine processes. Vegetation in this landscape class may exhibit evidence of mechanical or chemical disturbance.
- 'Non-floodplain disconnected saline wetland, remnant vegetation' landscape class: The 'Non-floodplain disconnected saline wetland, remnant vegetation' landscape class includes saline wetlands in lower parts of the catchment not dependent on groundwater in a disturbed state. Water regimes may be influenced by tidal or estuarine processes. Vegetation in this landscape class retains many of the structural and floristic attributes of similar undisturbed communities.

* 'Non-floodplain, terrestrial GDE' landscape group: The 'Non-floodplain, terrestrial GDE' landscape group includes terrestrial groundwater-dependent ecosystems (GDEs) not associated with floodplains.
  - 'Non-floodplain, terrestrial GDE' landscape class: The 'Non-floodplain, terrestrial GDE' landscape class is characterised by terrestrial vegetation that does not occur on alluvial floodplain environments. These communities will typically be dominated by *Eucalyptus* and/or *Acacia* with a variable dependence on groundwater to support structure and function. Vegetation in this landscape class may exhibit evidence of mechanical or chemical disturbance.
  - 'Non-floodplain, terrestrial GDE, remnant vegetation' landscape class: The 'Non-floodplain, terrestrial GDE, remnant vegetation' landscape class is characterised by terrestrial vegetation that does not occur on alluvial floodplain environments. These communities will typically be dominated by *Eucalyptus* and/or *Acacia* with a variable dependence on groundwater to support structure and function. Vegetation in this landscape class retains many of the structural and floristic attributes of similar undisturbed communities.
* 'Streams, GDE' landscape group: The 'Streams, GDE' landscape group is characterised by groundwater-dependent rivers and streams, where groundwater contributes to flow and/or ecological function.
  - 'Near-permanent, lowland GDE stream' landscape class: The 'Near-permanent, lowland GDE stream' landscape class is characterised by permanent or intermittent rivers and creeks that occur in lower, generally low-relief parts of the catchment. Riverine wetland groundwater-dependent ecosystems (GDEs) are riverine wetlands that require access to groundwater on a permanent or intermittent basis to meet all or some of their water requirements including maintenance of plant and animal communities, ecological processes and ecological services. These riverine wetlands have gaining or variable gaining/losing groundwater connectivity. The underlying aquifers consist of rock types other than sandstone.

   - 'Near-permanent, upland GDE stream' landscape class: The 'Near-permanent, upland GDE stream' landscape class is characterised by permanent or intermittent rivers and creeks that are riverine wetlands in upper parts of the catchment and are wet over 80% of the time. These riverine wetlands require access to groundwater on a permanent or intermittent basis to meet all or some of their water requirements including maintenance of plant and animal communities, ecological processes and ecological services. Flow regimes have gaining or variable gaining/losing groundwater connectivity. Riparian vegetation is likely to be directly (i.e. in direct contact with the aquifer) or indirectly (i.e. via bank recharge) dependent on groundwater. The underlying aquifers consist of rock types other than sandstone.
   - 'Temporary, lowland GDE stream' landscape class: The 'Temporary, lowland GDE stream' landscape class is characterised by ephemeral rivers and creeks that are riverine wetlands in lower, low-relief parts of the catchment and are wet less than 80% of the time. These riverine wetlands require access to groundwater on a permanent or intermittent basis to meet all or some of their water requirements including maintenance of plant and animal communities, ecological processes and ecological services. Flow regimes have variable gaining/losing groundwater connectivity and riparian vegetation is likely to be indirectly dependent (i.e. via bank recharge) on groundwater. The underlying aquifers consist of unweathered sandstones.
   - 'Temporary, upland GDE stream' landscape class: The 'Temporary, upland GDE stream' landscape class is characterised by ephemeral rivers and creeks that are riverine wetlands occurring in upper, generally high-relief parts of the catchment that are wet less than 80% of the time. These riverine wetlands require access to groundwater on a permanent or intermittent basis to meet all or some of their water requirements including maintenance of plant and animal communities, ecological processes and ecological services. Flow regimes have variable gaining/losing groundwater connectivity and the riparian vegetation is likely to be indirectly dependent (i.e. via bank recharge) on groundwater. The underlying aquifers consist of unweathered sandstones.
- 'Streams, non-GDE' landscape group: The 'Streams, non-GDE' landscape group is characterised by riverine wetlands that are not reliant on groundwater inputs to maintain ecological function.
   - 'Near-permanent, estuarine stream' landscape class: The 'Near-permanent, estuarine stream' landscape class is characterised by streams in the lower catchment where marine or oceanic water is diluted by freshwater inputs (>80% of the time). It is an area where the rivers meet the sea and provides habitat for many species. Mangroves and saltmarsh may also be associated with this landscape class.
   - 'Near-permanent, lowland stream' landscape class: The 'Near-permanent, lowland stream' landscape class is characterised by streams in the lower catchment, which are riverine wetlands that occur in low-relief areas of the catchment and are wet more than 80% of the time. These riverine wetlands are characterised by unidirectional flows driven by rainfall, downstream transportation and deposition of sediments and are usually linked directly to floodplain environments.

   - 'Near-permanent, upland stream' landscape class: The 'Near-permanent, upland stream' landscape class is characterised by near-permanent rivers and streams in the upper catchment, which are riverine wetlands that occur in upper areas of the catchment and are wet more than 80% of the time. These riverine wetlands have unidirectional flows driven by rainfall, downstream transportation and deposition of sediments and are usually linked directly to floodplain environments.
   - 'Temporary, estuarine stream' landscape class: The 'Temporary, estuarine stream' landscape class is characterised by temporary estuarine streams, which are riverine wetlands that occur in the lower catchment where marine or oceanic water is diluted by freshwater inputs (<80% of the time). It is an area where the rivers meet the sea and provides habitat for many species. Mangroves and saltmarsh may also be associated with this landscape class.
   - 'Temporary, lowland stream' landscape class: The 'Temporary, lowland stream' landscape class is characterised by intermittent to ephemeral rivers and creeks, which are riverine wetlands in low areas of the catchment that are wet less than 80% of the time. In-channel water levels are dominated by local or upstream rainfall, and water levels may be highly variable. The channel may contain standing water permanently or periodically or may be dry for long periods.
   - 'Temporary, upland stream' landscape class: The 'Temporary, upland stream' landscape class is characterised by intermittent to ephemeral rivers and creeks, which are riverine wetlands in upper catchment areas that are wet less than 80% of the time. In-channel water levels are dominated by local or upstream rainfall, and water levels may be highly variable. The channel may contain standing water permanently or periodically or may be dry for long periods.
- 'Springs' landscape group: The 'Springs' landscape group is characterised by hydrogeological features by which groundwater discharges naturally to the land surface.
   - 'Springs' landscape class: The 'Springs' landscape class includes hydrogeological features by which groundwater discharges naturally to the land surface. It may include springs with permanent or non-permanent wetting regimes, dynamic or static spatial locations, and diffuse or point source spatial locations.

4 Risk analysis for the Galilee subregion

Originally the risk analysis was intended to be reported independently of the impact analysis. Instead it has been combined with the impact analysis as product 3-4 to improve readability. For risk analysis see Section 3 of this product.

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