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

Water balance assessment for the Galilee subregion

Product 2.5 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

The Bioregional Assessment Programme

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

The Programme is funded by the Australian Government Department of the Environment and Energy. The Department of the Environment and Energy, Bureau of Meteorology, CSIRO and Geoscience Australia are collaborating to undertake bioregional assessments. For more information, visit http://www.bioregionalassessments.gov.au.

Department of the Environment and Energy

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

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Artesian Spring Wetland at Doongmabulla Nature Refuge, Queensland, 2013

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Currency of scientific results

The modelling results contained in this product were completed in March 2016 using the best available data, models and approaches available at that time. The product content was completed in December 2017.

All products in the model-data analysis, impact and risk analysis, and outcome synthesis (see Figure 1) were published as a suite when completed.

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.

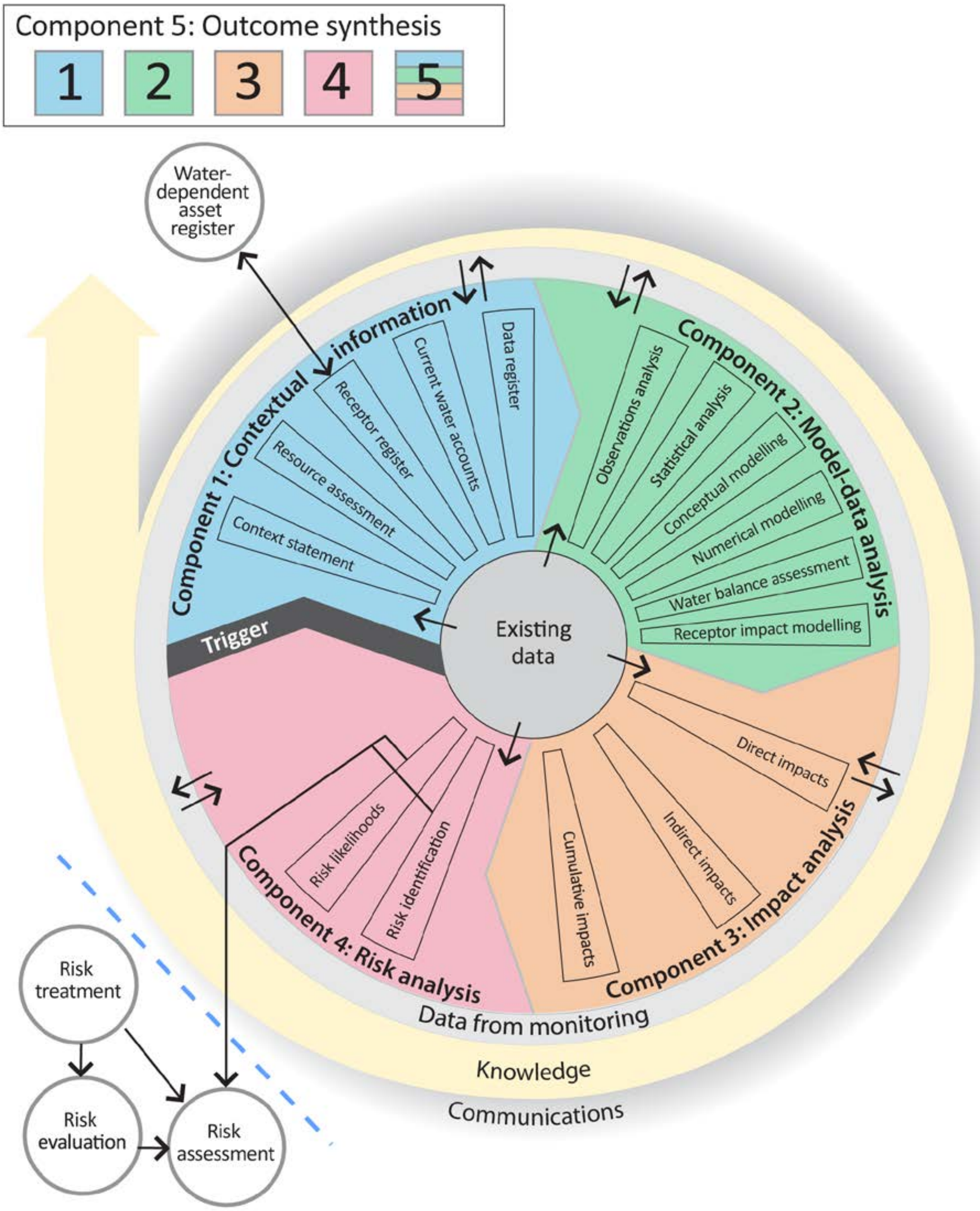

Figure 1 Schematic diagram of the bioregional assessment methodology

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.

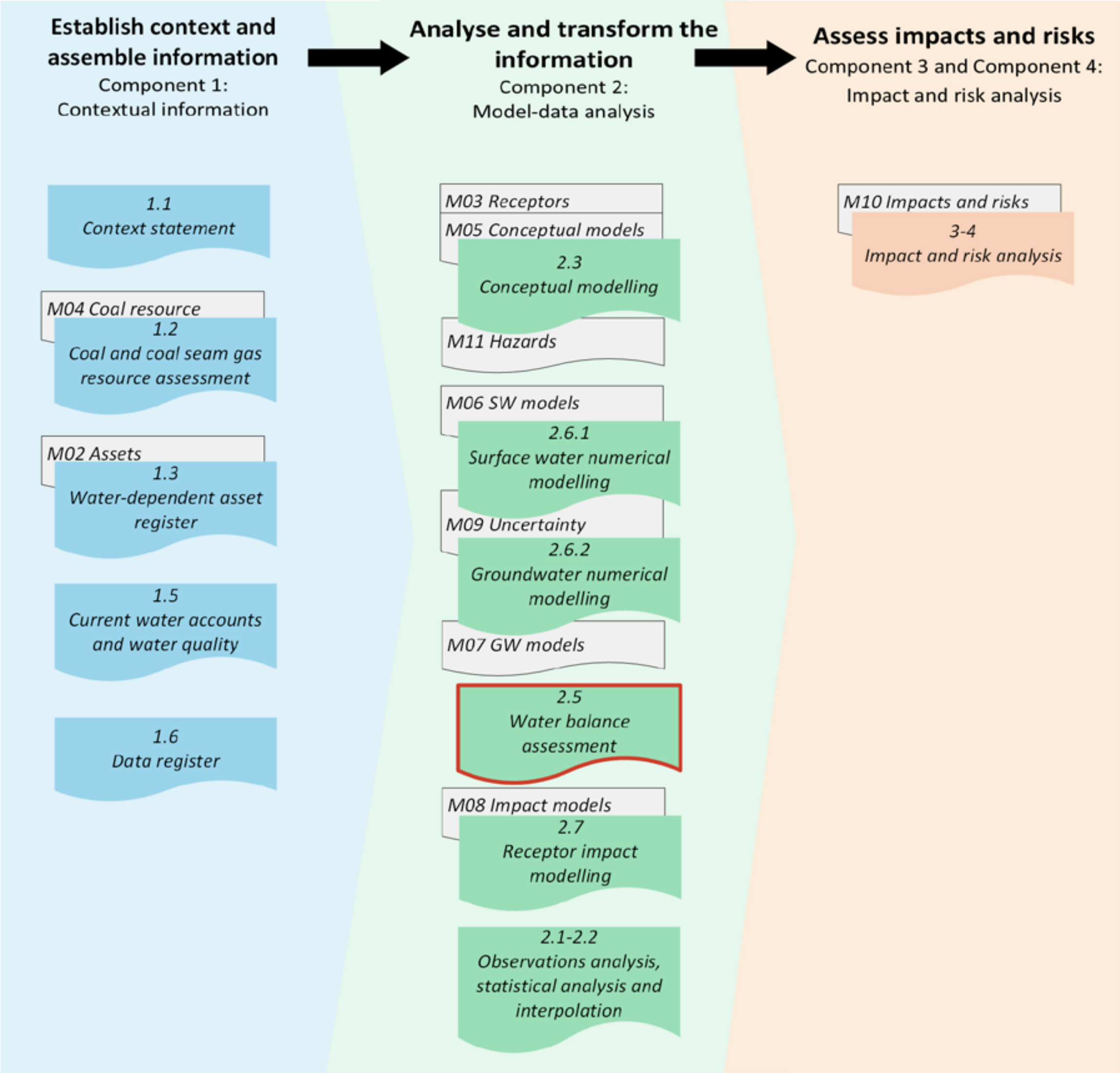

Figure 2 Technical products and submethodologies associated with each component of a bioregional assessment

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 20 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 20 June 2018, http://www.iesc.environment.gov.au/publications/information-guidelines-independent-expert-scientific-committee-advice-coal-seam-gas.

2.5 Water balance assessment for the Galilee subregion

This product presents mean annual water balances for the Galilee subregion using results from product 2.6.1 (surface water numerical modelling) and product 2.6.2 (groundwater numerical modelling). The water balances are reported over three 30-year periods, namely 2013 to 2042, 2043 to 2072 and 2073 to 2102, during which modelled global temperature increases of 1.0, 1.5 and 2.0 °C, respectively, have been assumed.

Water balances are reported for the two potential futures considered in a bioregional assessment:

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

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

This product reports results for only those developments in the baseline and CRDP that have been modelled.

Surface water balance terms will generally include rainfall, surface water outflow, licensed extraction and a residual term. Groundwater balance terms will generally include recharge, evapotranspiration, baseflow and change in storage. The exact set of water balance terms reported can vary from region to region.

The water balance reported here summarises volumetric changes and does not represent impacts on flow regime changes which may be more significant than changes in average flow volumes in some cases. For more details see product 2.6.1 (surface water numerical modelling) and product 2.6.2 (groundwater numerical modelling).

Impacts of flow volume and regime changes are considered in product 3-4 (impact and risk analysis).

2.5.1 Methods

Summary

Surface water model nodes used in water balance reporting are selected to quantify hydrological changes due to proposed coal resource development over the minimum possible area that incorporates all hydrologically connected cumulative changes.

In the Galilee subregion, changes in surface water from coal mines accumulate along a hydrologically connected stream network (Sandy Creek–Native Companion Creek–Belyando River). The cumulative changes to surface water occur primarily in the Belyando river basin, which forms part of the headwaters of the Burdekin river basin.

For the estimation of total changes, a single model node was selected on the Belyando River (node 53) that captures the cumulative changes on surface water in the Galilee subregion due to the seven coal resource developments in the coal resource development pathway (CRDP) that can be modelled.

Unlike cellular numerical groundwater models, the analytic element model is not capable of producing a water balance, therefore, a conceptual groundwater balance method was developed using an accounting approach to estimate the groundwater balance for the portion of the Burdekin river basin that occurs within the Galilee subregion. The approach taken is a modified version of the water cycle report defined for the Water Accounting Stocktake project undertaken by the inter-jurisdictional National Water Initiative Committee (SKM, 2006). While this relatively simple approach to the groundwater balance does not produce stochastic outputs, it is considered fit for purpose for this BA as it will flag if there is potential for groundwater pumping by coal mining operations to cause changes to a major component of the groundwater balance, as well as identify possible data gaps.

Many of the modelled coal resource developments include an estimate of extra water that is required from sources external to the mine area. External water required for mine sites is not included in water balance estimates presented in this product as the location of the external water offtakes and the licensed amounts are yet to be finalised.

2.5.1.1 Spatial and temporal extent of the water balance

2.5.1.1.1 Surface water balance

Proposed coal resource developments in the Galilee subregion that have been modelled occur in the north-flowing Belyando river basin, which comprises a part of the Burdekin river basin. The coal seam gas (CSG) and coal projects in the coal resource development pathway (CRDP) are the sum of those in the baseline and in the additional coal resource development (ACRD). The coal projects included in the additional coal resource development are: South Galilee, China First, Kevin's Corner, Alpha, Carmichael, China Stone and Hyde Park. Because there are no coal resource developments in the baseline for the Galilee subregion, the CRDP includes only the proposed CSG and coal projects in the ACRD. There are a total of 17 proposed coal resource developments in the Galilee subregion including 14 coal mines and three CSG projects. Only seven of them (i.e. South

Galilee, China First, Alpha, Kevin's Corner, Carmichael, China Stone and Hyde Park) have sufficient data to include in surface water modelling (Figure 3). These coal resource developments are detailed in Section 1.2.3 of companion product 1.2 for the Galilee subregion (Lewis et al., 2014) and Section 2.3.4 of companion product 2.3 for the Galilee subregion (Evans et al., 2018b). Model nodes for reporting water balance have been selected to quantify the cumulative hydrological changes of coal resource development over the minimum possible area that they are all hydrologically connected and for which model outputs have been generated. In this case, surface water numerical model node 53 (Figure 3) is the upstream-most location where resultant changes of the seven modelled mines are found. The catchment of model node 53 represents a proportion of Belyando river basin intended to quantify the 'maximum' changes from all hydrologically connected mines in the CRDP, rather than the maximum changes around individual mines or small groupings of some mines.

Water balances for the baseline and CRDP at model node 53 have been extracted from the landscape water balance model (Australian Water Resources Assessment landscape model (AWRA-L)) for three 30-year periods (2013–2042, 2043–2072 and 2073–2102), which align with modelled temperature increases of 1.0, 1.5 and 2.0 °C under a future climate projection from the Geophysical Fluid Dynamics Laboratory (GFDL) model GFDL2.0 of global climate models (GCMs). These three time periods were generated from the 30-year historical sequence from 1983 to 2012 by modifying the historical sequence to reflect a warming trend. Thus the variability in the historical sequence is preserved, but the effect of droughts and floods does not confound the comparison between time periods. The time to maximum change will be different for different hydrological response variables and receptors, which means at the subregion level there is not a single point in time for which a maximum change water balance can be constructed. The water balance terms reported in this product represent the annual averages for each 30-year period.

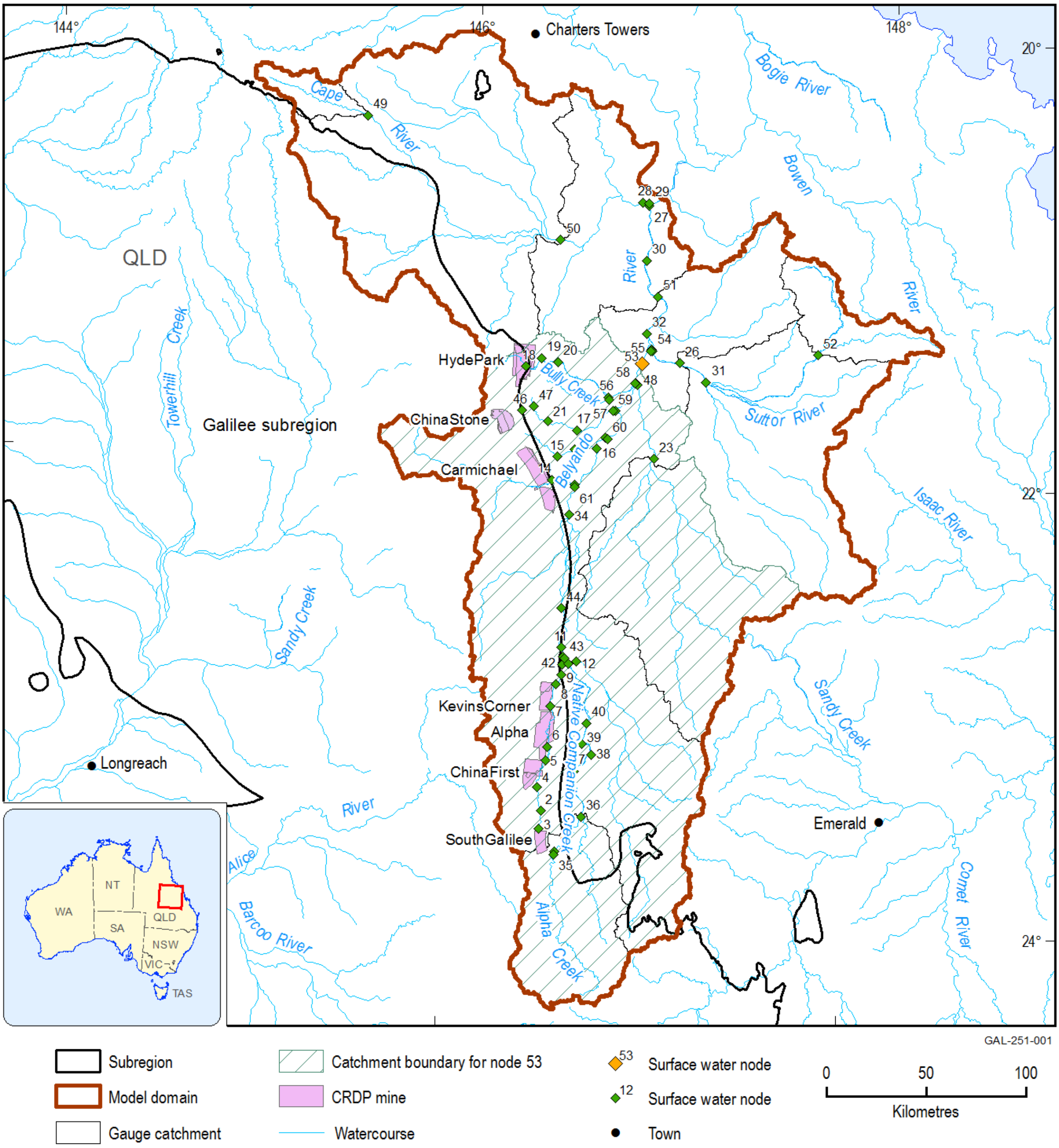

Figure 3 Location and upstream catchment of water balance reporting for node 53, and extent of the seven mines included in the coal resource development pathway (CRDP) for the Galilee subregion

Data: Bioregional Assessment Programme (Dataset 1, Dataset 2); Bureau of Meteorology (Dataset 3)

2.5.1.1.2 Conceptual groundwater balance

Unlike other bioregional assessment groundwater modelling approaches, the groundwater analytic element model outlined in companion product 2.6.2 for the Galilee subregion (Peeters et al., 2018) was not designed to estimate historical and future water balances. The main focus of the groundwater analytic element model was to simulate changes in water fluxes due to groundwater pumping as part of coal mine development. Also, it does not include information for some key groundwater balance components such as recharge. Section 2.6.2.9 in Peeters et al. (2018) details the limitations of the groundwater analytic element model approach.

A water balance was produced as an output as part of the Galilee Basin hydrogeological model (GBH), which is a regional numerical groundwater model that encompasses the whole of the Galilee subregion (Turvey et al., 2015). However, this water balance is not suitable for the purposes of the bioregional assessment for the following reasons:

- It encompasses the whole of the Galilee subregion, and not just that part of the Burdekin river basin (specifically the Belyando river basin) that lies within the Galilee subregion where changes to groundwater are likely to occur.
- The area used to define the groundwater water balance for this product needs to have some congruence with areas where the surface water modelling (in companion product 2.6.1 (Karim et al., 2018)) and groundwater modelling (in companion product 2.6.2 (Peeters et al., 2018)) predicts change.
- The GBH model is a complex regional groundwater model produced in a very short time period and within a limited budget. Upon completion, a number of limitations and issues have been identified by the contractors – HydroSimulations – and reviewers from Queensland Government, Office of Water Science and relevant project and discipline leads from the bioregional assessment (Peeters et al., 2018). Some of the known issues would also affect the water balance that was output from the GBH numerical model.
- The GBH numerical model does not have stochastic outputs. It is a deterministic model that includes a water balance summary as an output.

As an alternative, a conceptual groundwater balance was developed in order to compare baseline conditions (pre-mining) with a period 30 years in the future that assumes full development of the seven coal mines in the modelled CRDP. This conceptualised groundwater balance focuses on the portion of the Galilee subregion that falls within the Burdekin river basin (Figure 3). Because of the lack of data, it is not possible to model the water balance for the same three future time periods to the same degree as was undertaken for the surface water balance (Section 2.5.1.1.1).

The approach taken is a modified version of the water cycle report defined for the Water Accounting Stocktake project undertaken by the inter-jurisdictional National Water Initiative Committee (SKM, 2006). While this is a relatively simple modelling approach that does not produce stochastic outputs for uncertainty analysis, it is considered fit for purpose for this BA as it can flag if there is potential for groundwater pumping by coal mining operations to cause changes to a major component of the groundwater balance, as well as identify possible data gaps.

The conceptual groundwater balance consists of several components. These are:

- inputs – rainfall and surface water recharge
- outputs – bore water use, mine dewatering, groundwater discharge to rivers and springs (baseflow), diffuse evapotranspiration and groundwater flow out of the modelling area.

Baseflow can be derived from a number of processes (for further detail see Section 2.1.5.2 in companion product 2.1-2.2 for the Galilee subregion (Evans et al., 2018a)). However, for the purposes of the conceptual water balance, baseflow is assumed to be derived through fully saturated groundwater discharge from an aquifer to surface drainage. This may provide a theoretical upper estimate of the potential fluxes of groundwater that may occur between river reach and an underlying aquifer.

The conceptual groundwater balance assumes that prior to the drilling of groundwater bores, the groundwater system was in a steady-state condition with inputs equal to outputs. Thus prior to development of coal and CSG resources in the region:

Rainfall recharge + surface water recharge = Evapotranspiration + baseflow + spring discharge + groundwater flow out of the modelling area.

Therefore values, around which there are low levels of confidence, such as evapotranspiration and groundwater flow out of the modelling area, are determined by balancing the above equation with parameters around which there may be higher levels of confidence such as groundwater recharge, spring discharge and baseflow.

Because the conceptual groundwater balance is based on published estimates of water balance components, it is not possible to report using the three 30-year time periods as used in the surface water balance (Section 2.5.1.1.1) and other bioregional assessments. The groundwater balance was undertaken to compare the results under the baseline (a future where no coal resource developments occur) to results under the modelled CRDP (a future where additional coal resource developments occur). Section 2.3.4 of companion product 2.3 (Evans et al., 2018b) provides more detail on the modelled CRDP for the Galilee subregion.

Full references for each item in the groundwater balance along with estimates of data currency and reliability are available in Bioregional Assessment Programme (Dataset 1).

2.5.1.2 Water balance uncertainty

Water balances represent a long-term mean averaged over a yearly period. Changes in water components such as groundwater discharge may appear small when compared to other fluxes (e.g. groundwater recharge) but may cause significant changes in indices such as number of zero-flow days in surface water systems. Further information on specific components of water balance, such as baseflow, is outlined in Karim et al. (2018).

2.5.1.2.1 Surface water

The water balance terms summarised in this product are a different set of model outputs to the hydrological response variables generated at model nodes, which were reported in companion product 2.6.1 (Karim et al., 2018) for the Galilee subregion. To estimate the uncertainty of the water balance terms, the posterior parameter distributions for the model chain are sampled a limited number of times to calculate the water balance components. From a set of 347 model runs that met the acceptance criteria for the uncertainty analysis reported in companion product 2.6.1 (Karim et al., 2018) for the Galilee subregion, a total of 30 runs were selected to assess the uncertainty in the components of the water balance. The sample size of 30 was used because it is commonly considered as the threshold sample size separating small-sample statistics from large-sample statistics (Davis, 2002). Although the 30 samples will not provide the rigorous uncertainty analysis presented in companion product 2.6.1 (Karim et al., 2018) for the Galilee subregion, it is expected to provide a statistically significant estimate of the 10th, 50th and 90th percentiles of the various water balance components.

2.5.1.2.2 Groundwater

There are likely to be significant uncertainties associated with most components of the groundwater balance presented in Section 2.5.2.1.2 (e.g. evapotranspiration (ET), recharge, groundwater flow out of modelling area, spring discharge). These uncertainties have not been quantified as the approach taken does not have stochastic outputs. There is likely to be a greater level of confidence around components such as bore water use as an estimate can be made of water usage. However, bore water use, by volume, is one of the smaller components of the water balance.

In environmental impact statement (EIS) documentation for six of the seven mines included as additional coal resource developments it is reported that there will be a requirement for water to be sourced external to mine site areas. The external water volumes have not been incorporated in the water balance estimates presented here, as the sources and final volumes for external water were yet to be determined as of February 2016.

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Datasets

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2.5.2 Water balances

Summary

The hydrological changes from proposed coal resource developments in the Galilee subregion are presented in the following ways: surface water – in terms of net changes in surface water flow over three time periods (2013 to 2042, 2043 to 2072 and 2073 to 2102); groundwater – a conceptual groundwater balance at 2012 (pre-development) and then at 30 years in the future (when proposed mines are in production).

The Galilee subregion coal resource development pathway (CRDP) consists of 17 proposed coal and coal seam gas (CSG) resource development projects (see companion product 2.3 for the Galilee subregion (Evans et al., 2018a)) of which only 7 were considered to have enough available information for inclusion in the additional coal resource development (i.e coal mining projects included in the modelling).

The model area for both water balances is that portion of the Galilee subregion that lies within the Burdekin river basin, specifically the Belyando river basin. The Belyando River is a tributary to the Burdekin River. All seven coal mining projects included in the modelled CRDP are situated within in the headwaters of the Belyando river basin.

The surface water balance is presented at a specific location on the Belyando River (node 53) that captures resultant changes in streamflow of the seven modelled coal mining projects in the Galilee subregion, while the groundwater results are presented for the portion of the Belyando River basin included in the modelling area.

For the surface water balance, the major difference noted between the baseline and modelled CRDP is the decrease in surface water outflow. This is due to interception of surface runoff on the mine sites rather than a decrease in baseflow discharge due to groundwater extraction. This change in flow magnitude between the baseline and modelled CRDP futures is less than 1% at model node 53 on the Belyando River, and is within the uncertainty of the predicted surface water flow.

The conceptual groundwater balance primarily focuses on the major components of the groundwater system: recharge, discharge, storage, and changes to storage through groundwater usage. While this represents a relatively simple approach with non-stochastic outputs it does demonstrate that 30 years into the future, the seven coal mining operations in the Galilee subregion will substantially increase the volume of groundwater extracted (primarily due to mine dewatering). This increase in groundwater usage may be the equivalent of up to 66% of estimated groundwater recharge. This represents a substantial change in the groundwater balance in comparison to the pre-mining situation. Future work should focus on improving the understanding of recharge processes in the Galilee Basin, as well as improved volumetric estimates of the components of the water balance.

Most of the pumped groundwater will be used within the coal projects as part of the mine water management system. However, from mine environmental impact statement (EIS)

documentation it is apparent that additional water will also need to be sourced external to the mine areas for operational purposes. As of April 2016, the amount and sources of external water are yet to be finalised. This represents a largely unknown but additional factor for the groundwater and surface water balances.

2.5.2.1 Belyando river basin

2.5.2.1.1 Model Node 53 – Belyando River surface water balance

Surface water balances at surface water model node 53 (Figure 3 of Section 2.5.1) on the Belyando River are provided in Table 3 for time period 2013 to 2042, Table 4 for 2043 to 2072 and Table 5 for 2073 to 2102. The surface water balance applies to an area of 35,326 km^2 on the Belyando river basin, which represents a proportion of the river basin upstream of node 53. Rainfall inputs over the three time periods reflect changes due to a varying climate signal as described in Section 2.5.1.1.

Each table presents the difference in results under the CRDP and the baseline. The difference in results is attributable to only the additional coal resource developments (i.e. the seven coal projects in the CRDP that can be modelled), as the climate signal is identical for baseline and CRDP. The differences between corresponding values over the three reporting periods encompass both the effects of climate and the coal resource development.

The climate change signal exhibits as an overall decrease in mean annual rainfall. Any rainfall that does occur is also increasingly concentrated into the summer rainfall period. The decrease in mean annual rainfall is about 2% and 4% for the period 2043 to 2072 and 2073 to 2102 respectively compared to the 2013 to 2042 period. Surface water outflow, however, shows an increasing trend of approximately 1% and 2% for the same time period which is equivalent to approximately 21 and 42 GL/year respectively. The explanation for this contrasting behaviour between mean annual rainfall and streamflow is that the increase in summer rainfall coincides with the season when most of the streamflow occurs (see companion product 1.1 for the Galilee subregion (Evans et al., 2014)).

The major difference in the surface water balance between the baseline and the seven coal projects modelled from the CRDP is in the surface water outflow. This has a maximum difference of 13 GL/year in the 2013 to 2042 period (Table 3), with decreasing differences in the subsequent two 30-year periods (Table 4, Table 5). Most of this difference can be attributed to interception of surface runoff rather than groundwater extraction because for all three periods of time the changes in baseflow are very small. The decrease in surface water outflow is reflected in an increase in the water balance losses term. Most of the water lost is from evapotranspiration, although leakage of water from open-cut mines and mine water storages may account for a small component. The decrease in surface water outflow under the CRDP is less than 1% of the baseline surface water outflow and within the uncertainty of the predicted surface water outflow (as shown by the range of surface water outflow estimates at the 10th, 50th and 90th percentiles for the three respective reporting periods in Table 3 (2013 to 2042), Table 4 (2043 to 2072) and Table 5 (2073 to 2102)).

Table 3 Mean annual surface water balance at model node 53 on the Belyando River for 2013 to 2042 in the Galilee subregion

Water balance term	Under the baseline[a] (GL/y)	Under the coal resource development pathway[a] (GL/y)	Difference
Rainfall	19,363	19,363	0
Surface water outflow	2,057 (1,308; 4,024)	2,044 (1,300; 3,992)	–13
Losses (e.g. ET, leakage)	17,306 (15,339;18,055)	17,319 (15,371;18,063)	13
Change in storage	0	0	0

[a]For some (but not all) terms, three numbers are provided. The first number is the median, and the 10th and 90th percentile numbers follow in brackets.
baseline = baseline coal resource development, ET = evapotranspiration
The coal seam gas and coal projects in the coal resource development pathway (CRDP) are the sum of those in the baseline and in the additional coal resource development (ACRD). Because there are no coal resource developments in the baseline for the Galilee subregion, the CRDP includes only the proposed coal seam gas and coal projects in the ACRD. Results are presented for seven coal projects that had sufficient data to have been included in numerical hydrological modelling.
Data: Bioregional Assessment Programme (Dataset 1, Dataset 2)

Table 4 Mean annual surface water balance at model node 53 on the Belyando River for 2043 to 2072 in the Galilee subregion

Water balance term	Under the baseline[a] (GL/y)	Under the coal resource development pathway[a] (GL/y)	Difference
Rainfall	18,998	18,998	0
Surface water outflow	2078 (1,319; 3969)	2,067 (1,314; 3,945)	–11
Losses (e.g. ET, leakage)	16,920 (15,029; 17,679)	16,931 (15,053; 17,684)	11
Change in storage	0	0	0

[a]For some (but not all) terms, three numbers are provided. The first number is the median, and the 10th and 90th percentile numbers follow in brackets.
Baseline = baseline coal resource development, ET = evapotranspiration
The coal seam gas and coal projects in the coal development resource pathway (CRDP) are the sum of those in the baseline and in the additional coal resource development (ACRD). Because there are no coal resource developments in the baseline for the Galilee subregion, the CRDP includes only the proposed coal seam gas and coal projects in the ACRD. Results are presented for seven coal projects that had sufficient data to have been included in numerical hydrological modelling.
Data: Bioregional Assessment Programme (Dataset 1, Dataset 2)

Table 5 Mean annual surface water balance at model node 53 on the Belyando River for 2073 to 2102 in the Galilee subregion

Water balance term	Under the baseline[a] (GL/y)	Under the coal resource development pathway[a] (GL/y)	Difference
Rainfall	18,634	18,634	0
Surface water outflow	2,099 (1,341; 3,969)	2,094 (1,338; 3,960)	-5
Losses (e.g. ET, leakage)	16,535 (14,665; 17,293)	16,540 (14,674; 17,296)	5
Change in storage	0	0	0

[a]For some (but not all) terms, three numbers are provided. The first number is the median, and the 10th and 90th percentile numbers follow in brackets.
baseline = baseline coal resource development, ET = evapotranspiration
The coal seam gas and coal projects in the coal resource development pathway (CRDP) are the sum of those in the baseline and in the additional coal resource development (ACRD). Because there are no coal resource developments in the baseline for the Galilee subregion, the CRDP includes only the proposed coal seam gas and coal projects in the ACRD. Results are presented for seven coal mines that had sufficient data to have been included in numerical hydrological modelling.
Data: Bioregional Assessment Programme (Dataset 1, Dataset 2)

2.5.2.1.2 Conceptual groundwater balance for the portion of the Burdekin river basin that lies within the Galilee subregion

As outlined in Section 2.5.1.1.2, the analytic element groundwater model was not designed to estimate historical and future water balances. Thus, an alternative conceptual groundwater balance was developed in order to compare baseline conditions (no coal resource development) with a period 30 years in the future that assumes the full development of the coal projects in the CRDP for which there are sufficient data for modelling. Furthermore, the conceptual groundwater balance only focuses on the main components of the groundwater balance, including: recharge, discharge, storage, and changes to storage through groundwater use. While this represents a relatively simple approach by aggregating the various components of the groundwater balance, it is considered fit for purpose for this BA as it will highlight the potential for changes to occur to the water balance components through cumulative groundwater pumping for mining operations.

The conceptual groundwater balance is limited to seven coal projects (Hyde Park, Carmichael, Alpha, Kevin's Corner, China First, China Stone, and South Galilee) out of a total 17 coal or coal seam gas developments in the CRDP due to data availability. With the exception of Hyde Park, all of the mine projects listed previously have EIS documentation available. However, due to the variability of existing data it is not possible to model the groundwater balance for the same three future time periods as was the case for the surface water balance (see Section 2.5.1.1.2).

The conceptual groundwater balance (Table 6) focuses on the portion of the Galilee subregion (Figure 4) that falls within the Burdekin river basin. This area was selected for the groundwater balance calculation because the seven coal projects in the CRDP that were modelled are located in the Burdekin river basin (see Section 2.3.4 in companion product 2.3 for the Galilee subregion (Evans et al., 2018a)). It also encompasses the river basin area covered by the surface water balance (Section 2.5.2.1.1) and the area where groundwater drawdown is predicted to occur (for further detail see Section 2.6.2.8 in companion product 2.6.2 for the Galilee subregion (Peeters et al., 2018)).

The groundwater balance consists of inputs (rainfall and surface water recharge) and outputs (bore water use, mine dewatering, discharge to rivers and springs, diffuse evapotranspiration (ET) and groundwater flow out of the modelling area). The conceptual groundwater balance (Table 6 and Figure 5) assumes that prior to drilling of groundwater bores the groundwater system was in a steady-state condition with inputs equal outputs. Thus prior to coal resource development in the region:

Rainfall recharge + surface water recharge = Evapotranspiration + baseflow + spring discharge + groundwater flow out of modelling area.

As outlined in Section 2.5.1, for the purposes of the conceptual water balance, baseflow is assumed to be derived from fully saturated groundwater discharge from an aquifer to surface drainage. This may provide a theoretical upper estimate of the potential fluxes of groundwater that may occur between river reach and an underlying aquifer.

Current groundwater bore use in the modelling region began in the late 1940s and in 2012 it represented approximately 4% of groundwater recharge. Because of the low water use relative to groundwater recharge and the relatively short period of use, the conceptual groundwater balance assumes that at the regional scale, groundwater is considered to be in a quasi-steady-state equilibrium. A groundwater system not in equilibrium can occur where natural discharge exceeds current recharge. This can be the case in large aquifer systems where groundwater has a long residence time or in aquifers with complex flow pathways. This can have implications for the amount of groundwater that is potentially available for abstraction. This assumption can be tested through better understanding of groundwater flow pathways and the use of environmental isotopic tracers.

As can be seen in Table 6, "under the baseline" natural inputs (recharge) are equal to natural outputs (springs, evapotranspiration losses and surface water discharge). The negative change in storage is equal to bore groundwater use.

In the modelled CRDP, natural inputs are again equal to natural outputs with the negative change in storage being due to bore groundwater use and mine water use. In reality, the relatively high mining water use is likely to change (the assumed) quasi-steady-state conditions, which will result in a decrease in groundwater discharge to ET and groundwater flow outside of the modelling area. However, the conceptual groundwater balance is not capable of predicting what these changes may be.

In addition to the combined groundwater balance (Table 6), a separate water balance is also available for the eight major hydrostratigraphic units identified in Section 2.1.3 within the groundwater modelling region (alluvium, Cadna-owie – Hooray aquifer, Hutton Sandstone aquifer, Moolayember Formation aquitard, Clematis Group aquifer, Rewan Group aquitard, upper Permian coal measures partial aquifer, and Joe Joe Group partial aquifer) in Bioregional Assessment Programme (Dataset 1).

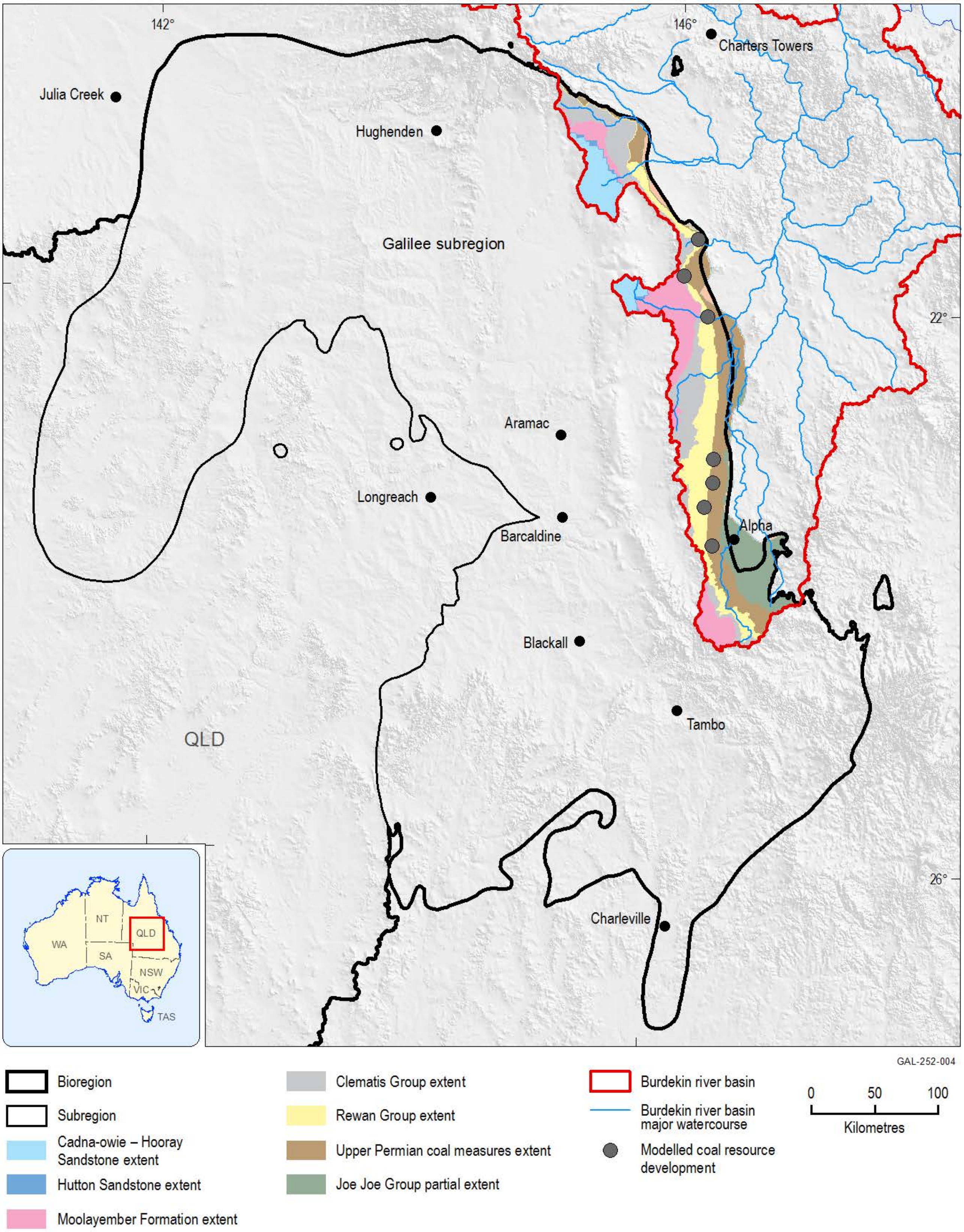

Figure 4 Location of groundwater balance in the Burdekin river basin and an outline of areas used to calculate recharge to separate aquifer systems

Only coal resource developments included in the additional coal resource development are show on the figure
Geological units that underlie the alluvial cover are outlined on the map. Alluvium is not shown.
Data: Bioregional Assessment Programme (Dataset 3, Dataset 4)

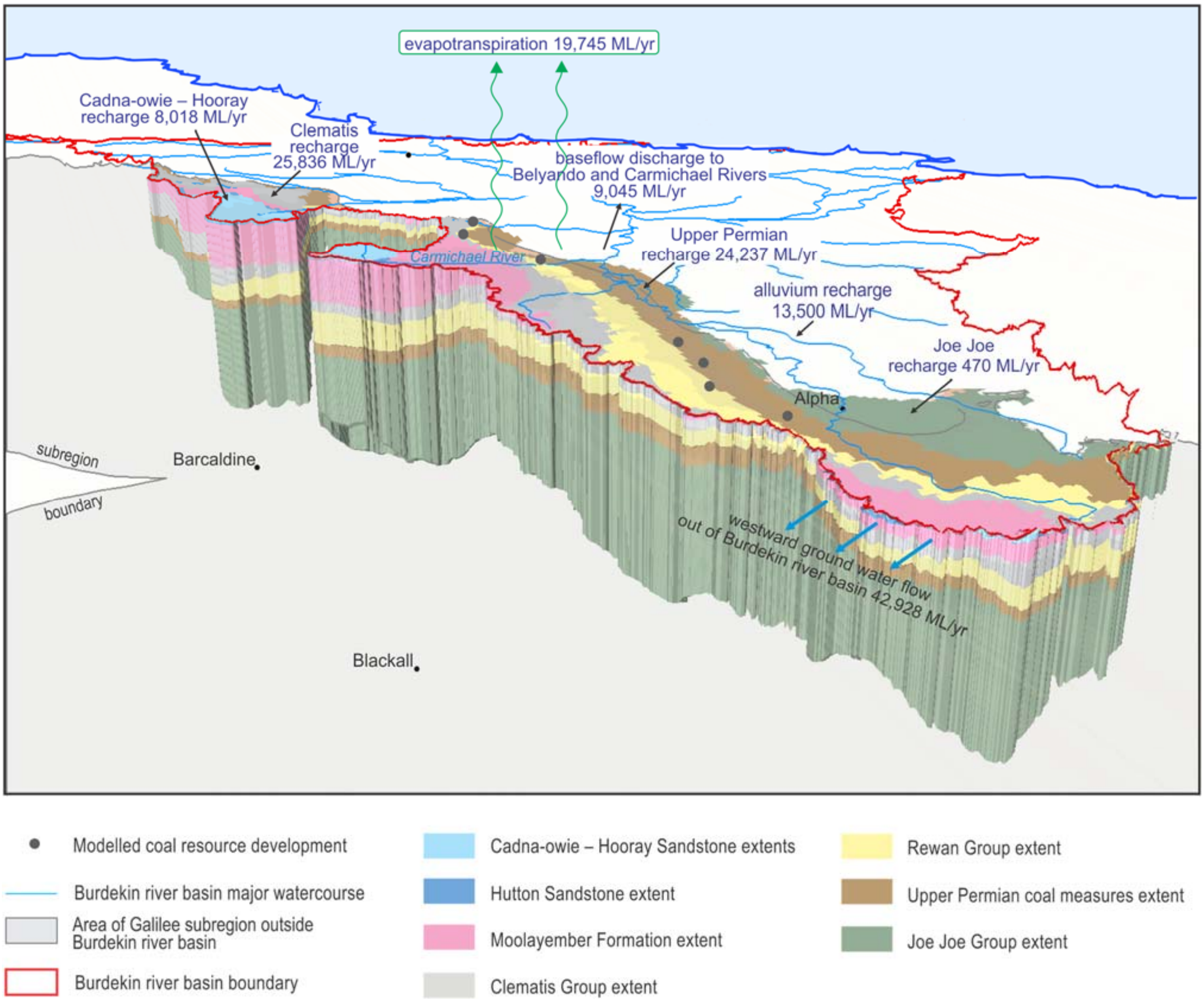

Figure 5 Graphical representation of recharge, evapotranspiration and groundwater outflows from the Burdekin river basin portion of the Galilee subregion

Geological units that underlie the alluvial cover are outlined on the map. Alluvium is not shown.
Data: Bioregional Assessment Programme (Dataset 3)

Table 6 contains the major components of the conceptual groundwater balance. The detailed groundwater balance can be found in Bioregional Assessment Programme (Dataset 1), which also includes data source, currency, a measure of data accuracy and the method used to derive the data. The volumes in Table 6 do not take into account changes to recharge due to future climate variations.

Table 6 Mean annual groundwater balance for the Belyando river basin part of the Galilee Basin at baseline (2012) and during mining (2042)

Water balance term	Inflow or outflow component of the groundwater balance	Under the baseline (ML/y)	Under the modelled coal resource development pathway (ML/y)	Difference
Groundwater recharge	Inflow	72,863	72,863	0
Bore groundwater use	Outflow	2,641	2,737	–96
Mining water use	Outflow	0	48,146	–48,146
Springs	Outflow	1145	1145	0
Losses (e.g. ET, flow out of model area)	Outflow	62,673	62,673	0
Discharge to surface water	Outflow	9,045	9,045	0
Change in groundwater storage	Inflow – Outflow	–2,641	–50,883	–48,242

baseline = baseline coal resource development, ET = evapotranspiration
Change in groundwater storage = inflow components – outflow components
Difference = Baseline – Changes predicted under the modelled coal resource development pathway
Changes predicted under the coal resource development pathway relate only to the seven coal projects for which sufficient data were available for modelling
Table 6 is a conceptualised water balance model. For instance, results from more sophisticated modelling approaches (e.g. Peeters et al. (2018) and GHD Pty Ltd (2013a)) predict varying degrees of impact to the springs and river discharge during mining. No change to spring flow or groundwater outflow was considered as part of the conceptual water balance and baseflow.
Data: Bioregional Assessment Programme (Dataset 5)

In 2012, the change to groundwater storage was due to groundwater extraction by groundwater pumping but bores not associated with coal mine development. The projected changes to groundwater storage in 2042 are primarily due to dewatering due to coal production from the seven coal mining projects included in the modelled CRDP.

The following sections provide further detail on individual components of the conceptual groundwater balance as outlined in Table 6.

Groundwater recharge

Mean groundwater recharge for the Burdekin river basin portion of the Galilee subregion was calculated using the chloride mass balance method as described in Section 2.1.3.2.5 of companion product 2.1-2.2 for the Galilee subregion (Evans et al., 2018b). As such, no distinction is made between rainfall recharge and stream recharge. Recharge represents the main input to the groundwater balance. Unlike the approach taken for the surface water balance (Section 2.5.1.1), no allowance was included for a projected declining rainfall trend.

For the conceptual groundwater model, the groundwater recharge estimates produced by Evans et al. (2018b) were clipped to the conceptual groundwater model boundary. The results (groundwater recharge in mm/year) were multiplied by the area of each aquifer and then converted to ML/year. Total groundwater recharge for the portion of the Belyando river basin that occurs in the Galilee subregion is 72,863 ML/year (Table 7 and Figure 5). Recharge estimates in

Table 7 are independent volumes representing recharge from rainfall only. Recharge was assumed not to vary due to changes in climate.

Table 7 Groundwater recharge

Hydrostratigraphic unit	Groundwater recharge (ML/y)
Alluvium	13,500
Cadna-owie – Hooray Sandstone	8,018
Hutton Sandstone	0
Moolayember Formation	724
Clematis Group	25,836
Rewan Group	78
Upper Permian coal measures	24,237
Joe Joe Group	470
Total	**72,863**

Data: Bioregional Assessment Programme (Dataset 5)

Bore groundwater use

Bore groundwater use is an outflow component from the groundwater balance. As of 2012 there are 353 groundwater bores within the groundwater balance area of which 119 bores had aquifer information. The remaining bores were proportionally assigned to aquifers based on the known aquifer distribution (Table 8 and Figure 5). The existing groundwater bores are used for town water supply, stock and domestic or agricultural purposes.

The vast majority of groundwater bores (344) have no direct groundwater use data and were therefore allocated a nominal value consistent with stock and domestic use of 5 ML/year. Companion product 1.5 for the Galilee subregion (Evans et al., 2015) provides further detail on water allocations and accounting in the Galilee subregion.

Consistent with the relatively low groundwater use (3.6% of groundwater recharge), there is also relatively low growth in the number of groundwater bores. In the decade from 2002 to 2012, an additional four bores were drilled in the region or approximately 1.3% growth per decade. This equates to an increase of approximately 96 ML/year in 2042 or an additional 19 bores. Despite the projected increase in consumption, overall groundwater use based on these figures would still be below 4% of groundwater recharge.

Table 8 Current groundwater extraction as of 2012

Hydrostratigraphic unit	Number of bores	Groundwater extraction (ML/y)
Alluvium	95	988
Cadna-owie – Hooray Sandstone	0	0
Hutton Sandstone	3	15
Moolayember Formation	42	337
Clematis Group	99	694
Rewan Group	27	168
Upper Permian coal measures	42	215
Joe Joe Group	45	225
Total	**353**	**2641**

Data: Bioregional Assessment Programme (Dataset 5)

Mine groundwater use

Groundwater inflows to coal mines and dewatering around mine areas (either open-cut or underground) represent an output from the groundwater balance. It will only occur once mining development commences. As outlined in Table 6, at the time of the baseline estimate (2012) there was no water associated with this component of the groundwater balance as there were no coal projects in operation. This is still the case at the time of writing (March 2016). Note that all groundwater pumped as part of mine development will be utilised at mine site as part of their water management strategies (see Section 2.1.6 in Evans et al. (2018b) and Section 2.3.4.2 in Evans et al. (2018a)).

Table 9 outlines the mine groundwater usage for the seven coal projects included in the modelled CRDP 30 years after development commences. It is estimated that groundwater inflows to mine areas may be the equivalent of up to 66% of the calculated groundwater recharge volume (Table 6).

None of the mine water balances outlined in EIS documentation reference the same time period. As an example, Table 10 outlines the original dewatering figures as reported for the six projects for which an EIS has been submitted to regulatory authorities for consideration. As of April 2016, an EIS had not been submitted for Hyde Park project.

Table 9 Estimated groundwater use by proposed mine derived from groundwater inflows to mine areas

Mine	Mine water use at 2042 from product 2.6.2 (ML/y)
Hyde Park	1,095
China Stone	4,928
Carmichael	5,001
Kevin’s Corner	3,176
Alpha	1,935
China First	22,995
South Galilee	9,016
Total	**48,146**

Data: Peeters et al. (2018), Bioregional Assessment Programme (Dataset 5)

Table 10 Projected mine dewatering volumes (ML/y) throughout production schedule (as outlined in EIS water balance reports)

Years since start of production	4	5	10	15	20	25	30	32	40	56
Hyde Park	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
China Stone	na	5347	na	5551	na	na	na	na	814	na
Carmichael	na	7884	7884	na	7884		7884		7884	7884
Kevin’s Corner	na	4140	4570	na	na	na	5010	na	na	na
Alpha	na	2838	2838	na	2838	na	2838	na	na	na
China First	na	5128	5499	na	na	6005	na	na	na	na
South Galilee	3826		6457		5955			2542		

na = not applicable, NA = data not available (as in the case of Hyde Park).
Data: Evans et al. (2018b), Bioregional Assessment Programme (Dataset 6)

Another water balance related issue, which is beyond the scope of this product, are proposals to obtain water from sources external to the mine development for the six coal mining projects for which an EIS has been submitted. In the EIS documentation, this is termed ‘external water’, which represents water required in addition to that sourced from mine dewatering or rainfall collected on-site.

Estimated volumes and proposed sources for external water requirements are outlined in Table 11. Data presented are sourced from the water balance reports included as part of EIS documentation. In some cases it is not clear whether the external water will be sourced from groundwater or surface water resources, nor if the water will be sourced from either within the Galilee subregion or from elsewhere. Total cumulative external water use for all coal projects could be in the order of an additional 37,657 to 39,320 ML/year (see also Table 11 for further detail).

As of April 2016, the source of external water for the six coal mining projects had yet to be finalised. The cumulative volumes of external water required are substantial, and may represent an increase of approximately 80% over the water that may be obtained through mine dewatering. It should be noted though that this represents the maximum volume that may be required. For instance, if in any given year there was more water available on-site from increased groundwater inflows or wet weather, then it is likely that during those conditions that less external water would be required by mine projects.

Table 11 Proposed external water requirement for mine projects (as outlined in environmental impact statements)

Project	Proposed external water supply amount (ML/y)	Expected life of mine (years)	Total LOM requirement (max) (ML)	Proposed water sources	Reference
China Stone	12,500	50	625,000	From water harvest schemes, from Cape River or Belyando Suttor river system	Hansen Bailey (2013) Chapter 13, p. 25
Carmichael	12,500	56	700,000	Flood water harvester on the Belyando River	GHD (2013b) Table 3-1, p. 19, 21 and 12
Kevin's Corner	2,300–2,952	30	88,560	Unnamed third party supplier	URS (2012) p. 75
Alpha	7,537–8,236	30	247,080	Not stated. 'Out of scope for mine technical reports'	Parsons Brinckerhoff (2011) Table 5-11, p. 60
China First	2,500	25	62,500	Burdekin River	Engeny Water Management (2012) p. 39
South Galilee	320–632	32	20,224	'The external water source is not known and the other external infrastructure solutions require development in conjunction with other proponents of the South Galilee Basin'	AMCI (2014) p. 33, Section 1.7 Scheduling constraints
Total	37,657–39,320		1,743,364		

LOM = life of mine
The reference column outlines the source document for the external water volumes presented in the column 'Proposed external water supply amount'
Data: Bioregional Assessment Programme (Dataset 6)

Springs discharge

Springs represent an outflow component of the groundwater balance. Table 12 and Figure 5 lists the spring complexes included in along with any available estimates of groundwater discharge.

Table 12 Groundwater springs and estimated water use

Name of springs	Likely source aquifer	Groundwater discharge (ML/y)	Reference
Doongmabulla Springs complex	Clematis Group	493	Merrick (2015)
Mellaluka Springs complex	Colinlea Sandstone	631	Fensham et al. (2016)
Albro Springs	Colinlea Sandstone	21	Fensham et al. (2016)
Hector Springs	Dunda beds	NA	Fensham et al. (2016)
Total		**1145**	

NA = Not Available as of February 2016
Data: Bioregional Assessment Programme (Dataset 5)

Other groundwater components (evapotranspiration and groundwater flow into water balance area)

The largest components of natural outflow within the groundwater balance model are evapotranspiration (~26%) and groundwater flow out of the modelling area (~57%).

Due to the lack of information, groundwater flow eastwards towards the margin of the subregion is assumed to discharge as: baseflow to rivers, springs discharge, or as evapotranspiration. Groundwater flow westwards is assumed to flow out of the groundwater balance modelling domain area into other parts of the Galilee Basin.

The volume of groundwater associated with losses as ET or groundwater flow out of the groundwater balance domain are based on the need to balance groundwater recharge as shown in Section 2.5.2.1.2.

The groundwater used by the coal projects included in the modelled CRDP will change quasi-equilibrium conditions resulting in a decrease in both ET and groundwater flow out of the modelling area. However, the conceptual groundwater balance is not capable of making this calculation. Therefore, ET and groundwater flow out of the modelling area are shown as unchanged in the future development pathway.

Evapotranspiration

A significant, albeit difficult to calculate, component of the groundwater balance is diffuse groundwater evapotranspiration (ET). Typically this occurs via transpiration from deep-rooted vegetation and/or direct evaporation of shallow groundwater. Evapotranspiration was not calculated using a specific method; rather it was assumed in the discharge component of the water balance equation that some residual loss (i.e. a loss not attributable to bore discharge, spring discharge or baseflow) is assumed to be due to evapotranspiration (Table 13). The evapotranspiration calculation did not take into account the effects of changes in vegetation cover or type across the conceptual water balance model area.

Table 13 Groundwater discharge as evapotranspiration

Hydrostratigraphic unit	Groundwater evapotranspiration estimate (ML/y)
Alluvium	5,550
Cadna-owie – Hooray Sandstone	8,018
Hutton Sandstone	0
Moolayember Formation	362
Clematis Group	3369
Rewan Group	39
Upper Permian coal measures	9,695
Joe Joe Group	329
Total	**27,362**

Data: Bioregional Assessment Programme (Dataset 5)

Groundwater outflows from the water balance model area

For the baseline (2012) water balance model to be in equilibrium, the overall groundwater inflow volume must equal the groundwater outflow volume (see Table 6). Table 14 details the amount of outflow required to the equation. These volumes may be flowing out of the water balance model area. These numbers could be a measure of how much the model may have underestimated one (or all) of the other outflow components. Alternatively, the recharge (inflow) component is overestimated. This represents a significant unknown for the water balance, in particular for the Clematis Group aquifer and the upper Permian coal measures partial aquifer. As outlined in Section 2.5.2.2, more work is required to refine the estimates for the various water balance components.

The conceptual hydrogeological understanding presented in Section 2.3.2 in companion product 2.3 for the Galilee subregion (Evans et al., 2018a) provides evidence that a major groundwater divide exists in the Galilee Basin groundwater systems, and that this groundwater divide is situated to the west of the Burdekin river basin margin. This groundwater divide does not extend along the whole of the western Burdekin river basin margin. Areas exist where groundwater has potential to flow westwards away from recharges areas into the Galilee basin. These areas occur along the Burdekin river basin margin, south of Alpha (Figure 5).

Only small portions of Eromanga Basin aquifer lie within the Burdekin river basin. For the geological Eromanga Basin, the Burdekin river basin boundary forms a localised groundwater divide within unconfined Eromanga Basin aquifers, directing flow east and west of the topographic divide. Groundwater flow in the alluvium is strongly controlled by local topography and so the Burdekin river boundary would coincide with a groundwater divide in the alluvium; therefore, no inflow occurs from outside the river basin boundary. Table 14 presents an estimate of groundwater flow that occurs into the Burdekin river basin.

Table 14 Groundwater outflow component from the portion of the Burdekin river basin that lies within the Galilee subregion

Geological basin	Hydrostratigraphic unit	Estimate of groundwater outflow (ML/y)
na	Alluvium	0
Eromanga	Cadna-owie – Hooray Sandstone	0
Eromanga	Hutton Sandstone	0
Galilee	Moolayember Formation	362
Galilee	Clematis Group	20,879
Galilee	Rewan Group	39
Galilee	Upper Permian coal measures	13,890
Galilee	Joe Joe Group	141
	Total	**35,311**

na= not applicable
These numbers are used in the 2012 water balance model to balance the outflow component of the water balance equation against the inflow component. Total outflows is the 2012 water balance should equal groundwater inflows + bore discharge
Data: Bioregional Assessment Programme (Dataset 5)

Discharge to surface water

According to the conceptual groundwater balance model (Bioregional Assessment Programme, Dataset 1), total groundwater discharge (Table 15) to the Belyando and Carmichael rivers is 9,045 ML/year.

Table 15 Groundwater discharge to river

River	Aquifer discharging to river baseflow	Estimate of groundwater discharge (ML/y)	Reference
Belyando River	Alluvium	7,950	Evans et al. (2018b)
Carmichael River	Clematis Group/alluvium	1,095	GHD Pty Ltd (2013c)
Total		**9,045**	

Data: Bioregional Assessment Programme (Dataset 5)

2.5.2.2 Gaps

The limitations on the surface water balance estimates provided here are a result of the limitations in the numerical modelling. The surface water numerical modelling is described in companion product 2.6.1 for the Belyando river basin (Karim et al., 2018) and should be read in conjunction with discussion on surface water balance in this product.

The limitations on the conceptual groundwater balance estimates provided in this section are a result of gaps in the understanding of groundwater processes such as the volumes and rate of inter-aquifer flow, evapotranspiration rate, fluxes between surface water and groundwater and the level of detail available in mine EISs on groundwater inflows and external water requirements. The Bioregional Assessment Programme (Dataset 1) includes information on data source and reliability. Other limitations include only using one method to estimate recharge from rainfall and not taking into account the effects of vegetation cover on recharge rates.

The degree and distribution of connectivity between shallow groundwater systems and surface drainage is not well understood in the area covered by the surface water and conceptual groundwater balance (Belyando river basin). This has a bearing on whether there may be an overestimation or underestimation of any surface water – groundwater fluxes, which in turn would have an effect on uncertainty in the water balances, and surface water and groundwater modelling. There is potential that small changes to the groundwater discharge component of the water balance may cause changes to components of the surface water balance, such as low-flow indices and increase in number of zero-flow days. It is difficult to represent such variability in a water balance. Furthermore, as detailed in Bainbridge et al. (2014) and Section 3.3 of companion product 3-4 for the Galilee subregion (Lewis et al., 2018), natural streamflow for the Belyando River and the Burdekin river basin on a whole varies considerably from year to year, which can include long periods of no stream flow. This has a direct bearing on the surface water budget for any given year and to the degree that surface water – groundwater interactions may occur.

The utilisation of more sophisticated analysis methods and other datasets (e.g. remote sensing) to estimate evapotranspiration and recharge may decrease uncertainty for this component of the water balance. As an example, Section 3.5 of companion product 3-4 for the Galilee subregion (Lewis et al., 2018) includes a qualitative interpretation derived from the Landsat archive of Digital Earth Australia (Geoscience Australia, 2017) of aspects of the local hydrology for springs at the Doongmabulla Springs complex. As outlined in Section 3.7 of Lewis et al. (2018), further work utilising the Landsat archive could be undertaken to quantify some of the hydrological processes that are evident in the imagery.

The assumption behind the calculation of the conceptual groundwater balance is that the groundwater flow systems are in equilibrium (Section 2.5.2.1.2). This assumption can be further tested by improving the understanding of groundwater flow pathways and the use of environmental isotopic tracers.

As discussed in detail in Section 2.1.5 of companion product 2.1 for the Galilee subregion (Evans et al., 2018b) the assumption that all baseflow in the Burdekin river basin is derived from fully saturated groundwater discharge and not through other processes, such as interflow, should be tested.

Water allocations from water supplies that are external to mine development areas are yet to be finalised. The amount of external water required will vary from year to year and would depend on factors including: stage of life for the mine development, actual groundwater inflows to mine areas, available rainfall harvested on-site, and amount of water available from surface water systems.

Further discussion on gaps and opportunities for future work are also outlined in Section 3.7 of companion product 3-4 for the Galilee subregion (Lewis et al., 2018). Future iterations could also investigate the water balance post-closure of the mines, and include other factors such as water stored in remanent open-cuts, changes to groundwater recharge and groundwater flow fluxes out of the model area, and changes to recharge rates due to climatic variation.

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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.

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

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.

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.

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.

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

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.

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.

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

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

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).

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

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

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.

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

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

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

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.

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

groundwater system: see water system

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).

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

model chain: a series of linked models where the output of one model becomes an input to another 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.

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.

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

recharge: see groundwater recharge

risk: the effect of uncertainty on objectives

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

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.

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

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

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

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

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

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

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: 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).

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