Australian Government

BIOREGIONAL ASSESSMENTS

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

Water balance assessment for the Clarence-Moreton bioregion

Product 2.5 from the Clarence-Moreton Bioregional Assessment

31 January 2017

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 Office of Water Science, within 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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The Bureau of Meteorology is Australia's national weather, climate and water agency. Under the *Water Act 2007*, the Bureau is responsible for compiling and disseminating Australia's water information. The Bureau is committed to increasing access to water information to support informed decision making about the management of water resources. For more information, visit http://www.bom.gov.au/water/.

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Authorship is listed in relative order of contribution.

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Rainforest waterfall in Border Ranges National Park, NSW, 2008

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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.

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 will be 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, will undertake 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.

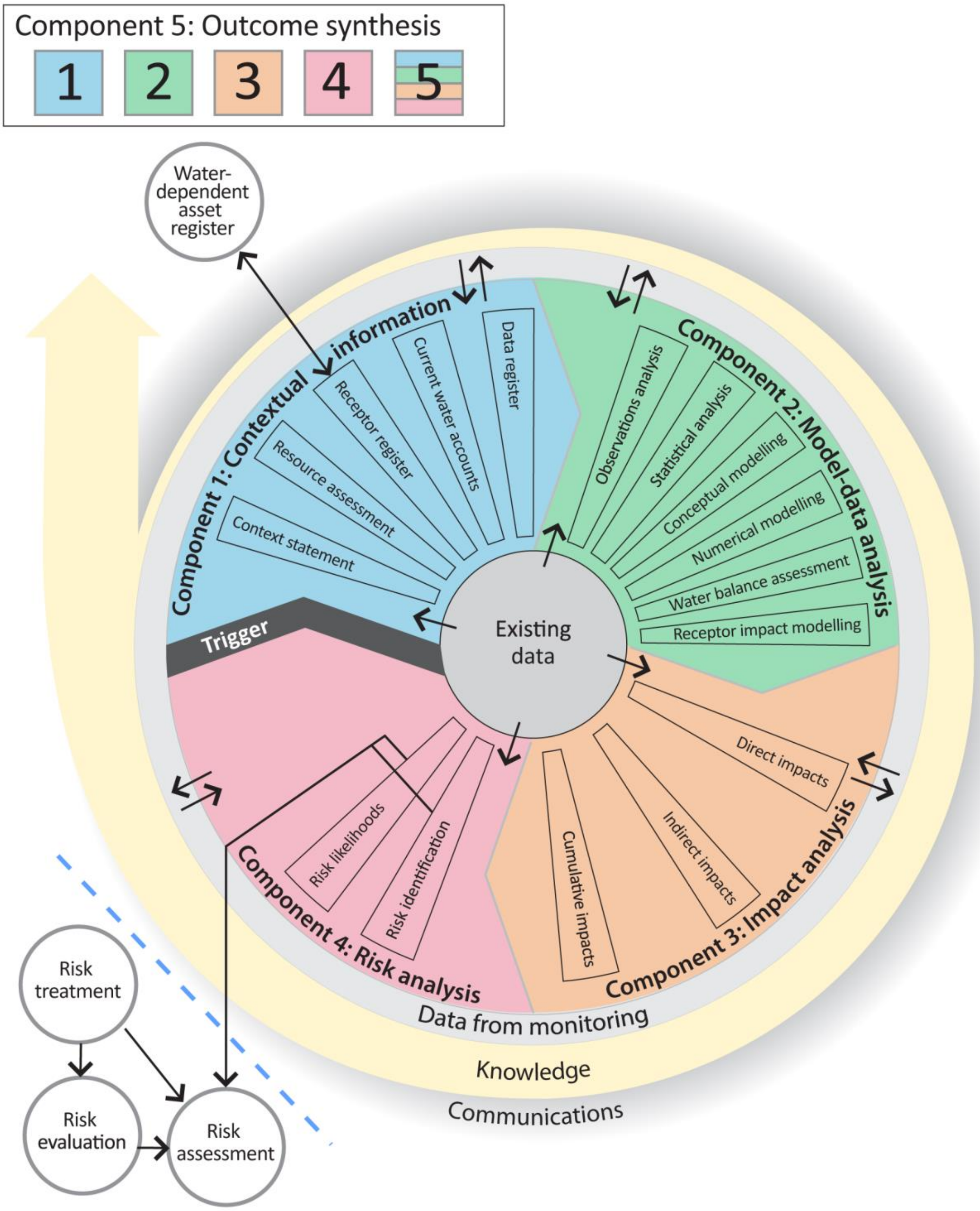

Figure 1 Schematic diagram of the bioregional assessment methodology

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 – in this case an explanation will be supplied in the technical products of that BA. Ultimately the Programme anticipates publishing a consolidated 'operational BA methodology' with fully worked examples based on the experience and lessons learned through applying the methods to 13 bioregions and subregions.

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.

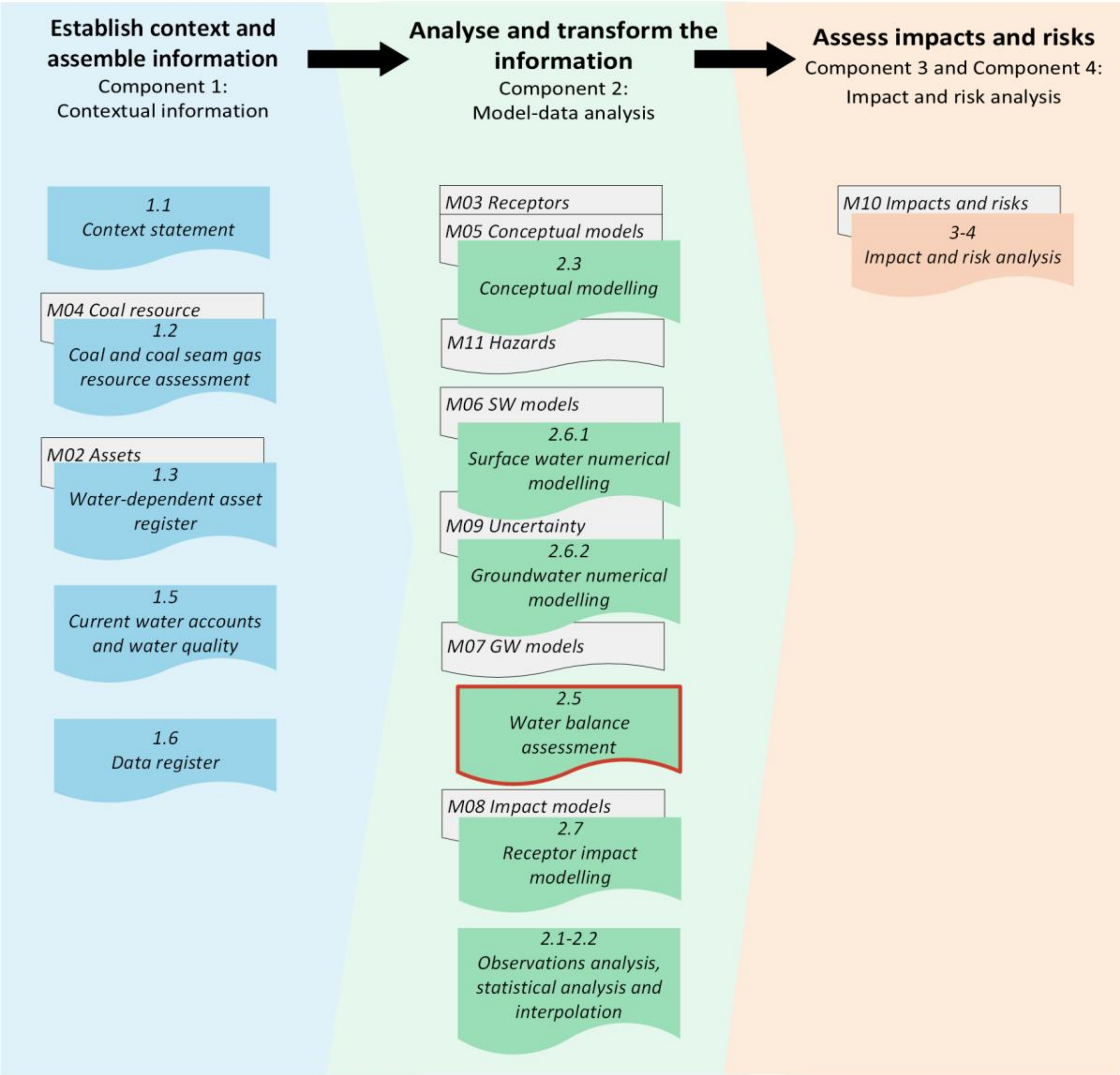

Figure 2 Technical products and submethodologies associated with each component of a bioregional assessment

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 Clarence-Moreton bioregion

For the Clarence-Moreton 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 Clarence-Moreton bioregion	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 Clarence-Moreton bioregion	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	Not produced
Component 3 and Component 4: Impact and risk analysis for the Clarence-Moreton bioregion	3-4	Impact and risk analysis	5.2.1, 2.5.4, 5.3	Not produced
Component 5: Outcome synthesis for the Clarence-Moreton bioregion	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 Clarence-Moreton 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.
- 'Not produced' indicates that the product was not developed. A webpage explains why and points to relevant submethodologies (Table 1).

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 151.0° East for the Clarence-Moreton bioregion and two standard parallels of –18.0° and –36.0°.
- Contact bioregionalassessments@bom.gov.au to access metadata (including copyright, attribution and licensing information) for all datasets cited or used to make figures in this product. At a later date, this information, as well as all unencumbered datasets, will be published online.
- 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 15 March 2017, 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 15 March 2017, http://www.iesc.environment.gov.au/publications/information-guidelines-independent-expert-scientific-committee-advice-coal-seam-gas.

2.5 Water balance assessment for the Clarence-Moreton bioregion

This product presents mean annual water balances for the Clarence-Moreton bioregion 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 absolute 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).

2.5.1 Methods

Summary

The groundwater balance analysis was conducted for the entire groundwater model domain, which covers an area of 8230 km^2. The groundwater balances comprise recharge, boundary flux, discharge to surface water, mining pumping, non-mining groundwater extractions, and change in storage water balance terms. The surface water balance analysis covers an area of 2942 km^2 and is reported at four locations: the Richmond River above Casino, the Richmond River above Kyogle, Shannon Brook above Yorklea and Eden Creek. The surface water balances comprise rainfall, surface water outflow, and losses (including evapotranspiration and water extractions). The groundwater and surface water balances are reported for three 30-year periods (2013 to 2042, 2043 to 2072 and 2073 to 2102) for both the baseline and the coal resource development pathway (CRDP). The analysis was carried out based on 30 model realisations chosen from a total of 3877 successful simulations conducted for the sensitivity analysis reported in companion product 2.6.2 (groundwater numerical modelling) for the Clarence Moreton bioregion (Cui et al., 2016).

The water balance assessment presents a quantitative water balance for the Clarence-Moreton bioregion for both the baseline and the coal resource development pathway (CRDP). It was conducted under the guidance of companion submethodology M07 (Crosbie et al., 2016). The water balance components were derived from the outputs of the surface water modelling and the groundwater modelling that are reported in companion products 2.6.1 and 2.6.2 for the Clarence-Moreton bioregion (Gilfedder et al., 2016; Cui et al., 2016), respectively. See Section 2.6.1.5 and Section 2.6.2.8 in these products for caveats and limitations associated with the information.

2.5.1.1 Spatial and temporal extent of the water balances

The Jeebropilly Mine west of Ipswich, Queensland is the only coal mine in the baseline coal resource development (baseline) for the Clarence-Moreton bioregion. In addition to this coal mine, the CRDP includes only one additional coal resource development (ACRD), which is named as West Casino Gas Project in companion product 2.3 (conceptual modelling) for the Clarence-Moreton bioregion (Raiber et al., 2016) (Figure 3). The West Casino Gas Project occurs in the central part of the Richmond river basin, while the Jeebropilly Mine is distant and hydrologically disconnected from the CSG project as described in companion product 2.3 for the Clarence-Moreton bioregion (Raiber et al., 2016). Thus, the water balance analysis, surface water modelling, and groundwater modelling was only carried out for the Richmond river basin area.

A groundwater model has been developed to assess the potential impacts of the West Casino Gas Project on the groundwater system and associated groundwater-dependent ecosystems in companion product 2.6.2 for the Clarence-Moreton bioregion (Cui et al., 2016). This water balance analysis is based on the groundwater modelling results. The groundwater balance analysis was conducted for the entire groundwater model domain in order to capture any possible changes in water balance due to the West Casino Gas Project. The groundwater model covers an area of 8230 km^2 and mostly follows the boundaries of the Richmond river basin with deviations in some areas as outlined in companion product 2.3 (conceptual modelling) for the Clarence-Moreton bioregion (Raiber et al., 2016). The groundwater model boundary is shown in Figure 3. A more detailed description of the groundwater model is found in companion product 2.6.2 for the Clarence-Moreton bioregion (Cui et al., 2016).

A surface water Australian Water Resources Assessment landscape model (AWRA-L) has been developed to assess the potential impacts of the West Casino Gas Project on the surface water system (see companion product 2.6.1 for the Clarence-Moreton bioregion (Gilfedder et al., 2016)). The surface water balance analysis is reported at three locations which are either in or very close to the West Casino Gas Project: Eden Creek (model node CLM002), Shannon Brook above Yorklea (model node CLM007), and Richmond River above Casino (model node CLM008) (Figure 3). It is also reported for the Richmond River above Kyogle (model node CLM014) to ensure that any groundwater impacts propagating north along the Richmond river valley are estimated. A more detailed description of the surface water model is found in companion product 2.6.1 for the Clarence-Moreton bioregion (Gilfedder et al., 2016).

The water balances are reported for three 30-year periods (2013 to 2042, 2043 to 2072 and 2073 to 2102) for both the baseline and CRDP. These three periods align with temperature increases of 1.0, 1.5 and 2.0 °C from current, under a future climate projection derived from the CSIRO-Mk3.0 global climate model (GCM) (Viney, 2016). Only a single future climate time series was used during the modelling for water balance analysis. The climate time series was generated by concatenating the 30-year series (1983–2012) three times, and scaled by a median climate change projection.

The time to maximum hydrological change will be different for different water balance terms such as surface water outflow and storage change, which means that at the bioregion level there is not a single point in time for which a maximum change on water balance can be constructed. Thus, the water balance changes are not reported as a maximum and its associated occurring time.

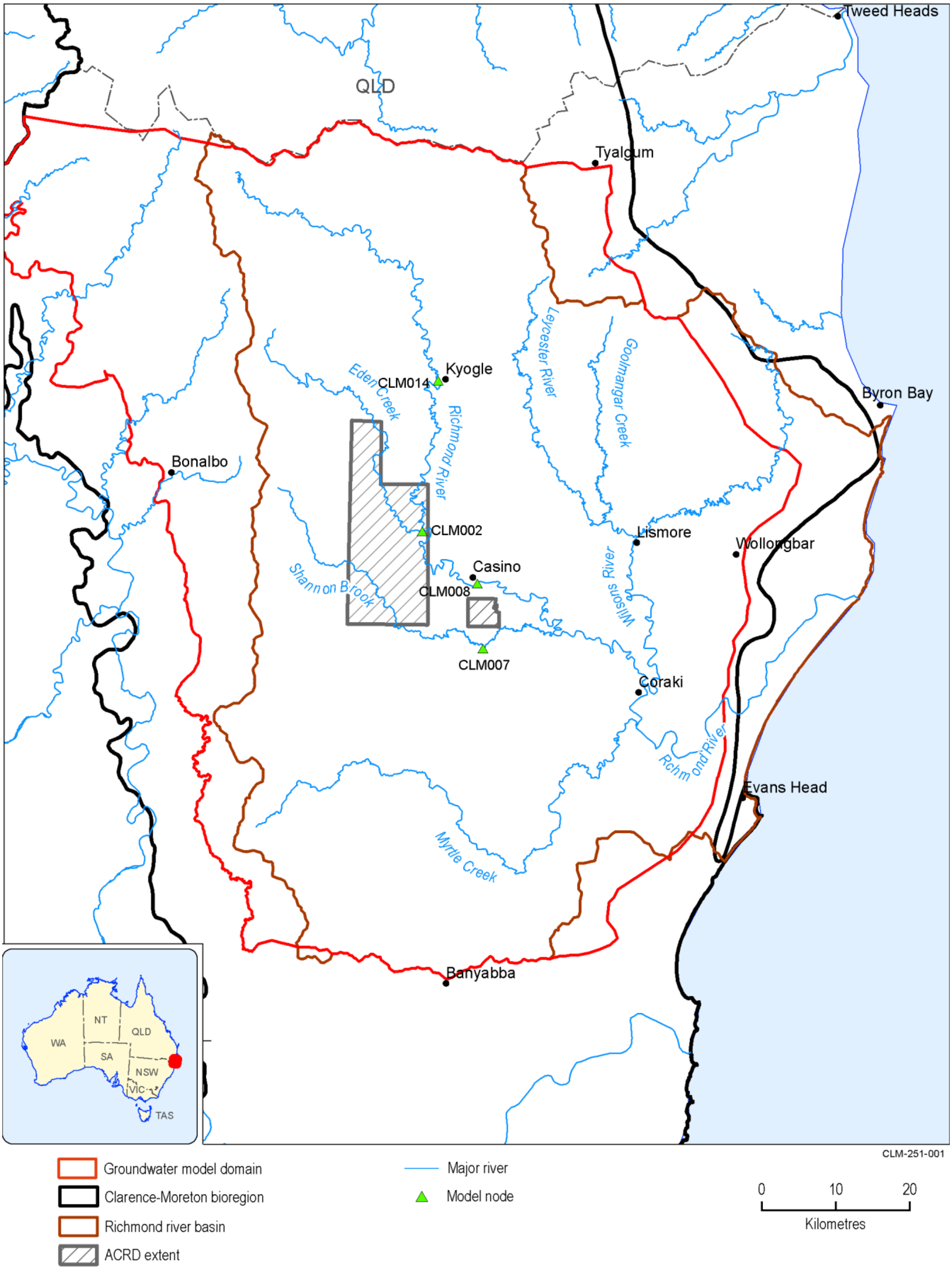

Figure 3 Location of model nodes for surface water balance terms for the Clarence-Moreton bioregion

ACRD = additional coal resource development

Data: Bioregional Assessment Programme (Dataset 1)

2.5.1.2 Water balance uncertainty

The components of the water balance are not included in the uncertainty analysis reported in companion product 2.6.1 (Gilfedder et al., 2016) and 2.6.2 (Cui et al., 2016) for the Clarence-Moreton bioregion. The water balance analysis was carried out based on 30 model simulations selected from a total of 3877 simulations conducted for the sensitivity analysis reported in companion product 2.6.2 (groundwater numerical modelling) for the Clarence-Moreton bioregion (Cui et al., 2016). 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). While the 30 samples will not provide the rigorous uncertainty analysis that is presented in companion product 2.6.1 (Gilfedder et al., 2016) and product 2.6.2 (Cui et al., 2016) for the Clarence-Moreton bioregion, it is expected to provide a statistically significant estimate of the 10th, 50th and 90th percentiles of the water balance components. Losses are not able to be included in the estimation of water balance uncertainty because they would not form part of the hydrological response variables used should any impact and risk analysis be conducted.

The selection of suitable simulations and subsequent output analysis involved the following steps:

1. Filter models using the forecast water production. Only models with a median annual water production that is within the range from one-tenth of the forecast volume to ten times the forecast volume were used for further analysis.
2. Compute the head objective function (sum of squared residuals) using the observed heads described in companion product 2.6.2 for the Clarence-Moreton bioregion (Cui et al., 2016).
3. Compute the baseflow objective function (sum of squared residuals) using estimated baseflow at the river stage gauge site near Casino (CLM008) (Figure 3).
4. Rank the models based on the sum of the two normalised components of the objective function described in step 2 and step 3.
5. Conduct a statistical summary analysis using the top 30 models derived in step 4.

The computing approaches for various water balance terms are summarised in Table 3 and Table 4.

Table 3 Computing approaches of water balance terms in the surface water model for the Clarence-Moreton bioregion

Water balance term	Computing approach
Rainfall	Measured rainfall modified using scaling factors from global climate models (GCMs)
Surface water outflow	From AWRA-L model
Licensed extractions	AWRA-L does not model extractions
CSG produced water	Any discharge to streams is subject to stringent control and could not be included in the AWRA-L model since timing and volume is not known.
Losses	Rainfall minus surface water outflow. This includes evapotranspiration, and would also include water extractions since AWRA-L does not model them explicitly

AWRA-L is the Australian Water Resources Assessment landscape model

Table 4 Computing approaches of water balance terms in the groundwater model for the Clarence-Moreton bioregion

Water balance term	Computing approach
Recharge (diffuse)	From the Recharge Package of MODFLOW
Recharge (streams)	From the River Package of MODFLOW
GHB boundary	From the General-Head Boundary Package of MODFLOW
Discharge (surface water)	The perennial streams were explicitly simulated in the groundwater model using the River Package of MODFLOW. Other surface water features, such as local intermittent streams and swamps, were lumped together and implicitly simulated using the Drain Package of MODFLOW. Thus, discharge to the surface water represents the sum of the discharge components of these two packages.
Non-CSG bores	From the MNW2 Package of MODFLOW that was implemented in accordance with the licensed extractions.
CSG wells	The CSG water pumping process was simulated by the Drain Package of MODFLOW. Thus, the water balance term is from the component representing CSG wells in the Drain Package.
Storage change	Directly from the storage component in MODFLOW water balance output

CSG = coal seam gas

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2.5.2 The water balances

Summary

The surface water balance analysis is reported at four model nodes: the Richmond River above Casino, the Richmond River above Kyogle, Shannon Brook above Yorklea and Eden Creek. It is reported for three consecutive 30-year periods, each with different rainfall inputs to reflect modelled varying climate signal. The median change at all four model nodes was essentially zero (less than 0.05 GL total) in surface water balance for each of the 30-year periods (2013 to 2042, 2043 to 2072 and 2073 to 2102). There are insignificant changes in baseflow during the three 30-year periods.

Based on the current groundwater model conceptualisation, groundwater storage exhibits a future decline even without the impacts of the West Casino Gas Project, although the median annual reduction is well below 0.5% of the corresponding median annual recharge for all the three reporting periods. This can be a result of climate change, extraction for irrigation and other usage. Water usage by the West Casino Gas Project mainly occurs between 2013 and 2042 with a median mean annual pumping of 328 ML/year. An additional 321 ML/year reduction in groundwater storage occurs due to the West Casino Gas Project from 2013 to 2042. A very small impact is also seen in the discharge component to surface water to compensate for coal seam gas (CSG) water production. No other impact can be identified for the other water balance components.

2.5.2.1 Water balance based on the AWRA-L model

Surface water balances are reported for three consecutive 30-year periods, each with different rainfall inputs to reflect a temporally trended climate signal. Licensed extractions from surface water for non-mining uses are not reported because they are unable to be represented in the Australian Water Resources Assessment landscape model (AWRA-L). Such extraction can be modelled using the Australian Water Resources Assessment river model (AWRA-R), however in the absence of significant regulation and consumptive water use, AWRA-R has not been used in this study. The impact of licensed extractions of groundwater for CSG is reflected in changes in the upward flow from the deeper groundwater system as modelled in the groundwater model. The impact of the additional coal resource development (the West Casino Gas Project), calculated as difference between the coal resource development pathway (CRDP) and the baseline (presented in Table 5 to Table 9), reflects the impacts of CSG development only, as the climate signal is identical in both modelling runs. The changes in corresponding values over the three reporting periods encompass the effects of both climate and the coal resource development. Note that the values in the difference column are calculated individually for each of the 30 model runs, and the summary differences presented (i.e. median of the differences, not difference of the medians). The median, 10th and 90th percentile of water balance components derived from the selected 30 AWRA-L model runs are presented in this section.

This section provides summaries of the total water balance calculated at four surface water locations in the Richmond river basin for each of the three 30-year periods. These locations are:

- Eden Creek above its confluence with the Richmond River (model node CLM002)
- Shannon Brook above Yorklea (model node CLM007)
- Richmond River above Casino (model node CLM008)
- Richmond River above Kyogle (model node CLM014).

The effect of climate change in the water balance for the Richmond river basin is very small given the projected climate signal in the current model. There is a decreasing trend in the rainfall which translates into a decreasing trend in the surface water outflow and groundwater recharge. However, the magnitude of the change is very small with less than 2% decrease in rainfall and surface water outflow and slightly more than 1% decrease in groundwater recharge when the 2073 to 2102 period is compared to the 2013 to 2042 period for the baseline.

2.5.2.1.1 Water balance for Eden Creek (model node CLM002)

The catchment area above model node CLM002 is 696 km^2 and is within the West Casino Gas Project extent. The difference in the modelled water balance between the CRDP and the baseline at Eden Creek is in the total surface water outflow over each of the three 30-year periods (Table 5). Note that differences of less than 0.05 GL will appear as 0.0 GL in the table (0.05 GL over 30-year period is less than 2 ML/year).

Table 5 Surface water balance totals at Eden Creek (model node CLM002). Results summarise the range in the 30 groundwater model runs for each of the three climate periods modelled in the Clarence-Moreton bioregion

Period	Water balance term	Total under the baseline (GL)	Total under the coal resource development pathway (GL)	Difference for entire period (GL)
2013 to 2042	Rainfall	22,404	22,404	0
	Surface water outflow	5,600 (4,020; 6,678)	5,600 (4,020; 6,678)	0.0 (0.0; 0.0)
	Licensed extractions	NM	NM	NM
	Losses	16,804	16,804	0
2043 to 2072	Rainfall	22,201	22,201	0
	Surface water outflow	5,563 (3,992; 6,625)	5,563 (3,992; 6,625)	0.0 (0.0; –0.1)
	Licensed extractions	NM	NM	NM
	Losses	16,638	16,638	0
2073 to 2102	Rainfall	21,998	21,998	0
	Surface water outflow	5,527 (3,978; 6,571)	5,527 (3,978; 6,571)	0.0 (0.0; –0.1)
	Licensed extractions	NM	NM	NM
	Losses	16,471	16,471	0

Three numbers are provided for surface water outflow. The first number is the median, and the 10th and 90th percentile numbers follow in brackets.
NM = data not modelled
Data: Bioregional Assessment Programme (Dataset 1, Dataset 2)

2.5.2.1.2 Water balance for Shannon Brook above Yorklea (model node CLM007)

The catchment area above model node CLM007 is 498 km^2 and is within the West Casino Gas Project extent. The difference in the modelled water balance between the CRDP and the baseline for Shannon Brook is the total surface water outflow over each of the three 30-year periods (Table 6). The difference was less than 0.2 GL for all three of the 30-year periods. Note that differences of less than 0.05 GL will appear as 0.0 GL in the table (0.05 GL over 30-year period is less than 2 ML/year).

Table 6 Surface water balance totals at Shannon Brook above Yorklea (model node CLM007). Results summarise the range in the 30 groundwater model runs for each of the three climate periods modelled in the Clarence-Moreton bioregion

Period	Water balance term	Total under the baseline (GL)	Total under the coal resource development pathway (GL)	Difference between CRDP and baseline for entire period (GL)
2013 to 2042	Rainfall	15,977	15,977	0
	Surface water outflow	4,628 (3,361; 5,364)	4,628 (3,361; 5,364)	0.0 (0.0; 0.0)
	Licensed extractions	NM	NM	NM
	Losses	11,349	11,349	0
2043 to 2072	Rainfall	15,828	15,828	0
	Surface water outflow	4,576 (3,333; 5,300)	4,576 (3,333; 5,300)	0.0 (0.0; –0.2)
	Licensed extractions	NM	NM	NM
	Losses	11,252	11,252	0
2073 to 2102	Rainfall	15,679	15,679	0
	Surface water outflow	4,529 (3,314; 5,226)	4,529 (3,314; 5,226)	0.0 (0.0; –0.1)
	Licensed extractions	NM	NM	NM
	Losses	11,150	11,150	0

Three numbers are provided for surface water outflow. The first number is the median, and the 10th and 90th percentile numbers follow in brackets.
NM = data not modelled
Data: Bioregional Assessment Programme (Dataset 1, Dataset 2)

2.5.2.1.3 Water balance for Richmond River above Casino (model node CLM008)

The catchment area above model node CLM008 is 1874 km^2. The difference in the modelled water balance between the CRDP and the baseline for the Richmond River above Casino is in the surface water outflow over each of the three 30-year periods (Table 7). The difference was less than 0.05 GL for all three of the 30-year periods. Note that differences of less than 0.05 GL will appear as 0.0 GL in the table (0.05 GL over 30-year period is less than 2 ML/year).

Table 7 Surface water balance totals at Richmond River above Casino (model node CLM008). Results summarise the range in the 30 groundwater model runs for each of the three climate periods modelled in the Clarence-Moreton bioregion

Period	Water balance term	Total under the baseline (GL)	Total under the coal resource development pathway (GL)	Difference between CRDP and baseline for entire period (GL)
2013 to 2042	Rainfall	63,120	63,120	0
	Surface water outflow	17,284 (11,057; 21,620)	17,284 (11,057; 21,620)	0.0 (0.0; 0.0)
	Licensed extractions	NM	NM	NM
	Losses	45,836	45,836	0
2043 to 2072	Rainfall	62,552	62,552	0
	Surface water outflow	17,122 (10,938; 21,361)	17,122 (10,937; 21,361)	0.0 (0.0; 0.0)
	Licensed extractions	NM	NM	NM
	Losses	45,430	45,430	0
2073 to 2102	Rainfall	61,984	61,984	0
	Surface water outflow	16,983 (10,880; 21,114)	16,983 (10,880; 21,114)	0.0 (0.0; 0.0)
	Licensed extractions	NM	NM	NM
	Losses	45,001	45,001	0

Three numbers are provided for surface water outflow. The first number is the median, and the 10th and 90th percentile numbers follow in brackets.
NM = data not modelled
Data: Bioregional Assessment Programme (Dataset 1, Dataset 2)

2.5.2.1.4 Water balance for Richmond River above Kyogle (model node CLM014)

The catchment area above model node CLM014 is 903 km^2 and is upstream of the West Casino Gas Project extent. It has been included to check if there are any predicted impacts further north along the main Richmond river valley, beyond the West Casino Gas Project extent itself. The comparison of the modelled water balance between the CRDP and the baseline for the surface water outflow from the Richmond River above Kyogle shows that there is almost no difference for the 30-year period 2013 to 2042 (Table 8), and no increase in the subsequent two 30-year periods (Table 8). This indicates that there are no significant modelled changes in baseflow. Note that differences of <0.05 GL will appear as 0.0 GL in the table (0.05 GL over 30-year period is less than 2 ML/year). The results indicate that the groundwater drawdown due to the West Casino Gas Project does not propagate as far upstream as this catchment.

Table 8 Surface water balance totals at Richmond River above Kyogle (model node CLM014). Results summarise the range in the 30 groundwater model runs for each of the three climate periods modelled in the Clarence-Moreton bioregion

Period	Water balance term	Total under the baseline (GL)	Total under the coal resource development pathway (GL)	Difference between CRDP and baseline for entire period (GL)
2013 to 2042	Rainfall	31,862	31,862	0
	Surface water outflow	9,827 (5,592; 12,415)	9,827 (5,592; 12,415)	0.0 (0.0; 0.0)
	Licensed extractions	NM	NM	NM
	Losses	22,035	22,035	0
2043 to 2072	Rainfall	31,582	31,582	0
	Surface water outflow	9,762 (5,537; 12,275)	9,762 (5,537; 12,275)	0.0 (0.0; 0.0)
	Licensed extractions	NM	NM	NM
	Losses	21,820	21,820	0
2073 to 2102	Rainfall	31,303	31,303	0
	Surface water outflow	9,684 (5,493; 12,134)	9,684 (5,493; 12,134)	0.0 (0.0; 0.0)
	Licensed extractions	NM	NM	NM
	Losses	21,619	21,619	0

Three numbers are provided for surface water outflow. The first number is the median, and the 10th and 90th percentile numbers follow in brackets.
NM = data not modelled
Data: Bioregional Assessment Programme (Dataset 1, Dataset 2)

2.5.2.2 Water balance based on groundwater model

The water balance is reported for the entire groundwater model domain and is based on the modelling results from the top 30 best-fit models (Bioregional Assessment Programme, Dataset 4). The water balance is summarised in Table 9 for the three reporting periods of 2013 to 2042, 2043 to 2072 and 2073 to 2102, respectively. For each time period the 10th, 50th (median) and 90th percentiles of mean annual values of different water balance components are reported for both the baseline and CRDP. The net impact of the West Casino Gas Project is the difference between the results for the CRDP model and the baseline, and is also reported in the tables. Downwards, upwards and up-down arrows are used to indicate inflow, outflow and inflow/outflow water balance components, respectively.

Based on the current groundwater model conceptualisation, groundwater storage exhibits a future decline even without the impacts of the West Casino Gas Project, although the median annual reduction is well below 0.5% of the corresponding median annual recharge for all the three reporting periods. This can be partly attributed to the climate change signal used in the model; it can also be a result of extraction for irrigation and other usage. Overall, diffuse recharge from precipitation and discharge to surface water systems are the two dominant water balance components for both the baseline and CRDP. Among the 30 sets of modelling results, only the net balance of the General-Head Boundary (GHB) (a package used to simulate head-dependent flux boundaries in MODFLOW) (Harbaugh, 2005) varies from discharge to recharge. This implies that the adopted observations do not constrain the GHB related parameters. Water balance components associated with the GHB boundary are less reliable than other components. Additional observations are required to improve the estimate of flux exchange between the model domain and its surrounding aquifers.

Groundwater extraction due to the West Casino Gas Project mainly occurs between 2013 and 2042 with a median mean annual pumping of 328 ML/year. The median additional mean annual reduction in storage due to the West Casino Gas Project from 2013 to 2042 is 327 ML/year (6.62% of the median mean annual storage change for the baseline). A very minor change is also seen in the discharge component to surface water (Table 9) to compensate for CSG water production. No other changes can be identified for the other water balance components. The water production by the West Casino Gas Project reduces to 58 ML/year (median mean annual extraction) for the second reporting period (Table 9). However, the median mean annual discharge difference grows from 3 to 24 ML/year due to the time lag. The storage change difference is mitigated to some extent through the reduction of discharge component to surface water from 2043 to 2072. The impact on the discharge to the surface water continues until the end of the simulation (Table 9).

The overall change in groundwater balance due to the West Casino Gas Project over the entire model domain is very minor based on the modelling in companion product 2.6.2 for the Clarence-Moreton bioregion (Cui et al., 2016) given the current model conceptualisation. For example, for the first reporting period (2013 to 2042), the median mean annual extraction due to the West Casino Gas Project only corresponds to 0.02% of the median mean annual recharge of the groundwater model domain (Table 9). There, however, can possibly be a more significant change in groundwater water balance components on a local scale close to the CSG development, especially during a dry period when more groundwater is required for other usage such as irrigation. Given the current regional model, a refined model could be developed in order to evaluate the potential impact on a local scale.

Table 9 Mean annual groundwater balance for the entire groundwater model domain for the three reporting periods in the Clarence-Moreton bioregion (ML/year)

[a]The net impact of the additional coal resource development (ACRD) is defined as the difference between results for the coal resource development pathway (CRDP) and the baseline. Note that the difference is calculated individually for each of the 30 model runs because the median under baseline may not correspond to the same realisation with the median under CRDP. The difference column is the summary of individual differences (i.e. median of the differences, not difference of the medians).

Period	Water balance term	Under baseline	Under CRDP	Difference[a]
2013 to 2042	↓Recharge (diffuse)	1,600,025 (859,946; 2,621,302)	1,600,025 (859,946; 2,621,302)	0 (0; 0)
	↓Recharge (streams)	11,628 (4,043; 55,712)	11,628 (4,043; 55,712)	0 (0; 1)
	↕GHB	8,592 (–47,758; 117,411)	8,592 (–47,758; 117,411)	0 (0; 0)
	↑Discharge (surface water)	**1,607,220 (920,573; 2,643,897)**	**1,607,215 (920,359; 2,643,851)**	**–3 (–38; 0)**
	↑Non-CSG bores	11,059 (10,678; 11,187)	11,059 (10,677; 11,187)	0 (0; 0)
	↑CSG wells	NA	328 (88; 651)	NA
	Storage change	**–5,161 (–9,271; –2,968)**	**–5,482 (–9,671; –3,130)**	**–327 (–613; –82)**
2043 to 2072	↓Recharge (diffuse)	1,590,460 (854,806; 2,605,634)	1,590,460 (854,806; 2,605,634)	0 (0; 0)
	↓Recharge (streams)	11,659 (4,065; 55,745)	11,660 (4,065; 55,747)	0 (0; 3)
	↕GHB	9,053 (–46,935; 118,597)	9,053 (–46,935; 118,597)	0 (0; 0)
	↑Discharge (surface water)	**1,597,290 (915,104; 2,628,197)**	**1,597,240 (914,749; 2,628,098)**	**–24 (–123; –1)**
	↑Non-CSG bores	11,058 (10,671; 11,186)	11,058 (10,670; 11,186)	0 (0; 0)
	↑CSG wells	NA	58 (16; 121)	NA
	Storage change	**–4,216 (–9,073; –2,437)**	**–4,272 (–9,111; –2,425)**	**–31 (–80; 86)**
2073 to 2102	↓Recharge (diffuse)	1,579,535 (848,934; 2,587,734)	1,579,535 (848,934; 2,587,734)	0 (0; 0)
	↓Recharge (streams)	11,681 (4,083; 55,766)	11,682 (4,083; 55,769)	0 (0; 2)
	↕GHB	9,462 (–46,130; 119,759)	9,462 (–46,130; 119,759)	0 (0; 0)
	↑Discharge (surface water)	**1,587,365 (909,639; 2,612,398)**	**1,587,300 (909,561; 2,612,361)**	**–25 (–83; –2)**
	↑Non-CSG bores	11,055 (10,664; 11,183)	11,055 (10,663; 11,183)	0 (0; 0)
	↑CSG wells	NA	0 (0; 0)	NA
	Storage change	**–4,723 (–10,163; –2,478)**	**–4,721 (–10,158; –2,440)**	**25 (2; 87)**

The first number is the median, and the 10th and 90th percentile numbers follow in brackets. Water balance terms impacted by the West Casino Gas Project are shown in bold.
GHB = general-head boundary
CSG = coal seam gas
NA = data not available
↓: inflow; ↑: outflow; ↕: inflow and outflow
Data: Bioregional Assessment Programme (Dataset 3, Dataset 4)

2.5.2.3 Gaps

Limitations lie in some parameters and the implementation of some stresses, such as localized discharge and evapotranspiration, in the groundwater model. Surface water relevant inputs, such as recharge and river stage, over the three reporting periods only reflect changes due to a single varying climate signal. Thus, the uncertainty in the climate signal is not taken into account in the current analysis. In order to improve model stability and reduce model runtime for a feasible sensitivity analysis, evapotranspiration was not explicitly simulated in the groundwater model. The estimated recharge component may compensate for the ignorance of evapotranspiration to some extent. Only the perennial reaches of the streams within the model domain were simulated directly using the River Package in MODFLOW. This simplification may underestimate stream recharge to the groundwater system. The dual-phase flow process near CSG wells was not modelled in the current project. Previous studies (Moore et al., 2013; Moore et al., 2014; Herckenrath et al., 2015) have shown that the omitting of dual-phase flow overestimates drawdown impact, especially for prediction near CSG wells, depending on hydraulic properties, development plans and simulation time. For example, Moore et al. (2015) reported a drawdown overproduction of 15 m at a distance of 7 km from the well extraction centre at a simulation time of 20 years within the targeted coal seam formation in their model. The Assessment team believe that storage change due to CSG development is also overestimated to some extent, although the impact on water balance analysis was not directly investigated in these studies. In addition, assumptions, limitations and gaps listed in companion products 2.6.1 (surface water numerical modelling) (Gilfedder et al., 2016) and 2.6.2 (groundwater numerical modelling) (Cui et al., 2016) for the Clarence-Moreton bioregion also have an impact on water balance analysis.

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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

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

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.

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.

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.

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).

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.

ecosystem: a dynamic complex of plant, animal, and micro-organism communities and their non-living environment interacting as a functional unit. Note: ecosystems include those that are human-influenced such as rural and urban ecosystems.

effect: for the purposes of Impact Modes and Effects Analysis (IMEA), change in the quantity 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

groundwater: water occurring naturally below ground level (whether in an aquifer or other low permeability material), 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

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 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 recharge: see groundwater recharge

sensitivity: the degree to which the output of a model (numerical or otherwise) responds to uncertainty in a model input

source dataset: a pre-existing dataset sourced from outside the Bioregional Assessment Programme. This includes data sourced from the Programme partner organisations.

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-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)

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’.

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Australian Government

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