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

Water balance assessment for the Gloucester subregion

Product 2.5 for the Gloucester subregion from the Northern Sydney 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 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 http://www.environment.gov.au/coal-seam-gas-mining/.

Bureau of Meteorology

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/.

CSIRO

Australia is founding its future on science and innovation. Its national science agency, CSIRO, is a powerhouse of ideas, technologies and skills for building prosperity, growth, health and sustainability. It serves governments, industries, business and communities across the nation. For more information, visit http://www.csiro.au.

Geoscience Australia

Geoscience Australia is Australia's national geoscience agency and exists to apply geoscience to Australia's most important challenges. Geoscience Australia provides geoscientific advice and information to the Australian Government to support current priorities. These include contributing to responsible resource development; cleaner and low emission energy technologies; community safety; and improving marine planning and protection. The outcome of Geoscience Australia's work is an enhanced potential for the Australian community to obtain economic, social and environmental benefits through the application of first class research and information. For more information, visit http://www.ga.gov.au.

ISBN-PDF 978-1-925315-19-6

Citation

Herron NF, Crosbie RS, Viney NR, Peeters LJM and Zhang YQ (2018) Water balance assessment for the Gloucester subregion. Product 2.5 for the Gloucester subregion from the Northern Sydney Basin Bioregional Assessment. Department of the Environment and Energy, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia. http://data.bioregionalassessments.gov.au/product/NSB/GLO/2.5.

Authorship is listed in relative order of contribution.

Copyright

Disclaimer

Cover photograph

View of the Gloucester valley NSW with the Barrington River and associated riparian vegetation in the foreground and the township Gloucester in the distance looking south from the Kia Ora Lookout, 2013

Credit: Heinz Buettikofer, CSIRO

Australian Government
Department of the Environment and Energy
Bureau of Meteorology
Geoscience Australia

CSIRO

v20180226

Contents

Figures

Tables

Contributors to the Technical Programme

The following individuals have contributed to the Technical Programme, the part of the Bioregional Assessment Programme that undertakes bioregional assessments.

Role or team	Contributor(s)
Assistant Secretary	Department of the Environment and Energy: Matthew Whitfort
Programme Director	Department of the Environment and Energy: Anthony Swirepik
Technical Programme Director	Bureau of Meteorology: Julie Burke
Projects Director	CSIRO: David Post
Principal Science Advisor	Department of the Environment and Energy: Peter Baker
Science Directors	CSIRO: Brent Henderson Geoscience Australia: Steven Lewis
Integration	Bureau of Meteorology: Richard Mount (Integration Leader) CSIRO: Becky Schmidt
Programme management	Bureau of Meteorology: Louise Minty CSIRO: Paul Hardisty, Warwick McDonald Geoscience Australia: Stuart Minchin
Project Leaders	CSIRO: Alexander Herr, Kate Holland, Tim McVicar, David Rassam Geoscience Australia: Tim Evans Bureau of Meteorology: Natasha Herron
Assets and receptors	Bureau of Meteorology: Richard Mount (Discipline Leader) Department of the Environment and Energy: Glenn Johnstone, Wasantha Perera, Jin Wang
Bioregional Assessment Information Platform	Bureau of Meteorology: Lakshmi Devanathan (Team Leader), Derek Chen, Trevor Christie-Taylor, Melita Dahl, Angus MacAulay, Christine Panton, Paul Sheahan, Kellie Stuart, Carl Sudholz CSIRO: Peter Fitch, Ashley Sommer Geoscience Australia: Neal Evans
Communications	Bureau of Meteorology: Karen de Plater CSIRO: Helen Beringen, Chris Gerbing Department of the Environment and Energy: Amanda Forman, John Higgins, Lea Locke, Milica Milanja Geoscience Australia: Michelle McGranahan
Coordination	Bureau of Meteorology: Julie Burke, Eliane Prideaux, Sarah van Rooyen CSIRO: Ruth Palmer Department of the Environment and Energy: Anisa Coric, James Hill, Bronwyn McMaster, Emily Turner
Ecology	CSIRO: Anthony O'Grady (Discipline Leader), Caroline Bruce, Tanya Doody, Brendan Ebner, Craig MacFarlane, Patrick Mitchell, Justine Murray, Chris Pavey, Jodie Pritchard, Nat Raisbeck-Brown, Ashley Sparrow
Geology	CSIRO: Deepak Adhikary, Emanuelle Frery, Mike Gresham, Jane Hodgkinson, Zhejun Pan, Matthias Raiber, Regina Sander, Paul Wilkes Geoscience Australia: Steven Lewis (Discipline Leader)

Role or team	Contributor(s)
Geographic information systems	CSIRO: Jody Bruce, Debbie Crawford, Daniel Gonzalez, Mike Gresham, Steve Marvanek, Arthur Read Geoscience Australia: Adrian Dehelean, Joe Bell
Groundwater modelling	CSIRO: Russell Crosbie (Discipline Leader), Tao Cui, Warrick Dawes, Lei Gao, Sreekanth Janardhanan, Luk Peeters, Praveen Kumar Rachakonda, Wolfgang Schmid, Saeed Torkzaban, Chris Turnadge, Andy Wilkins, Binzhong Zhou
Hydrogeology	Geoscience Australia: Tim Ransley (Discipline Leader), Chris Harris-Pascal, Jessica Northey, Emily Slatter
Information management	Bureau of Meteorology: Belinda Allison (Team Leader) CSIRO: Qifeng Bai, Simon Cox, Phil Davies, Mick Hartcher, Geoff Hodgson, Brad Lane, Ben Leighton, David Lemon, Trevor Pickett, Shane Seaton, Ramneek Singh, Matt Stenson Geoscience Australia: Matti Peljo
Products	CSIRO: Becky Schmidt (Products Manager), Maryam Ahmad, Clare Brandon, Heinz Buettikofer, Sonja Chandler, Simon Gallant, Karin Hosking, Allison Johnston, Maryanne McKay, Linda Merrin, Joely Taylor, Sally Tetreault-Campbell, Catherine Ticehurst Geoscience Australia: Penny Kilgour, Kathryn Owen
Risk and uncertainty	CSIRO: Simon Barry (Discipline Leader), Jeffrey Dambacher, Jess Ford, Keith Hayes, Geoff Hosack, Adrian Ickowicz, Warren Jin, Yang Liu, Dan Pagendam
Surface water hydrology	CSIRO: Neil Viney (Discipline Leader), Santosh Aryal, Mat Gilfedder, Fazlul Karim, Lingtao Li, Dave McJannet, Jorge Luis Peña-Arancibia, Xiaogang Shi, Tom Van Niel, Jai Vaze, Bill Wang, Ang Yang, Yongqiang Zhang

Acknowledgements

This technical product was reviewed by several groups:

- Discipline Leaders: Russell Crosbie (groundwater modelling)
- Senior Science Leaders: Senior Science Leaders: David Post (Projects Director), Steven Lewis (Science Director, Geoscience Australia), Brent Henderson (Science Director, CSIRO), Becky Schmidt (Products Manager)
- Technical Assurance Reference Group: Chaired by Peter Baker (Principal Science Advisor, Department of the Environment and Energy), this group comprises officials from the NSW, Queensland, South Australian and Victorian governments.
- Independent reviewers: Francis Chiew (CSIRO) Dirk Mallants (CSIRO).

Currency of scientific results

The modelling results contained in this product were completed in July 2015 using the best available data, models and approaches available at that time. The product content was completed in May 2016.

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 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.

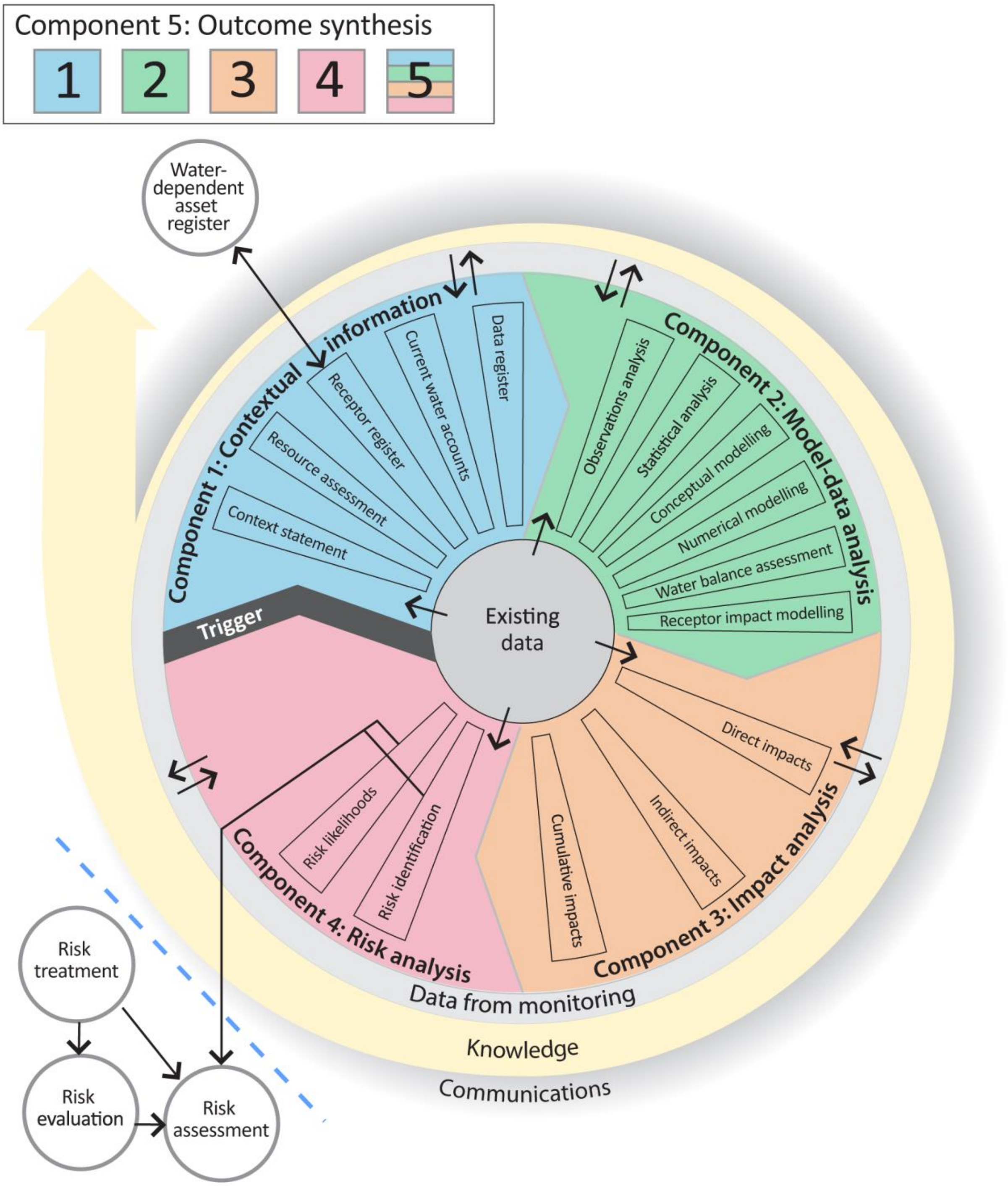

Figure 1 Schematic diagram of the bioregional assessment methodology

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) to, in the first instance, 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.

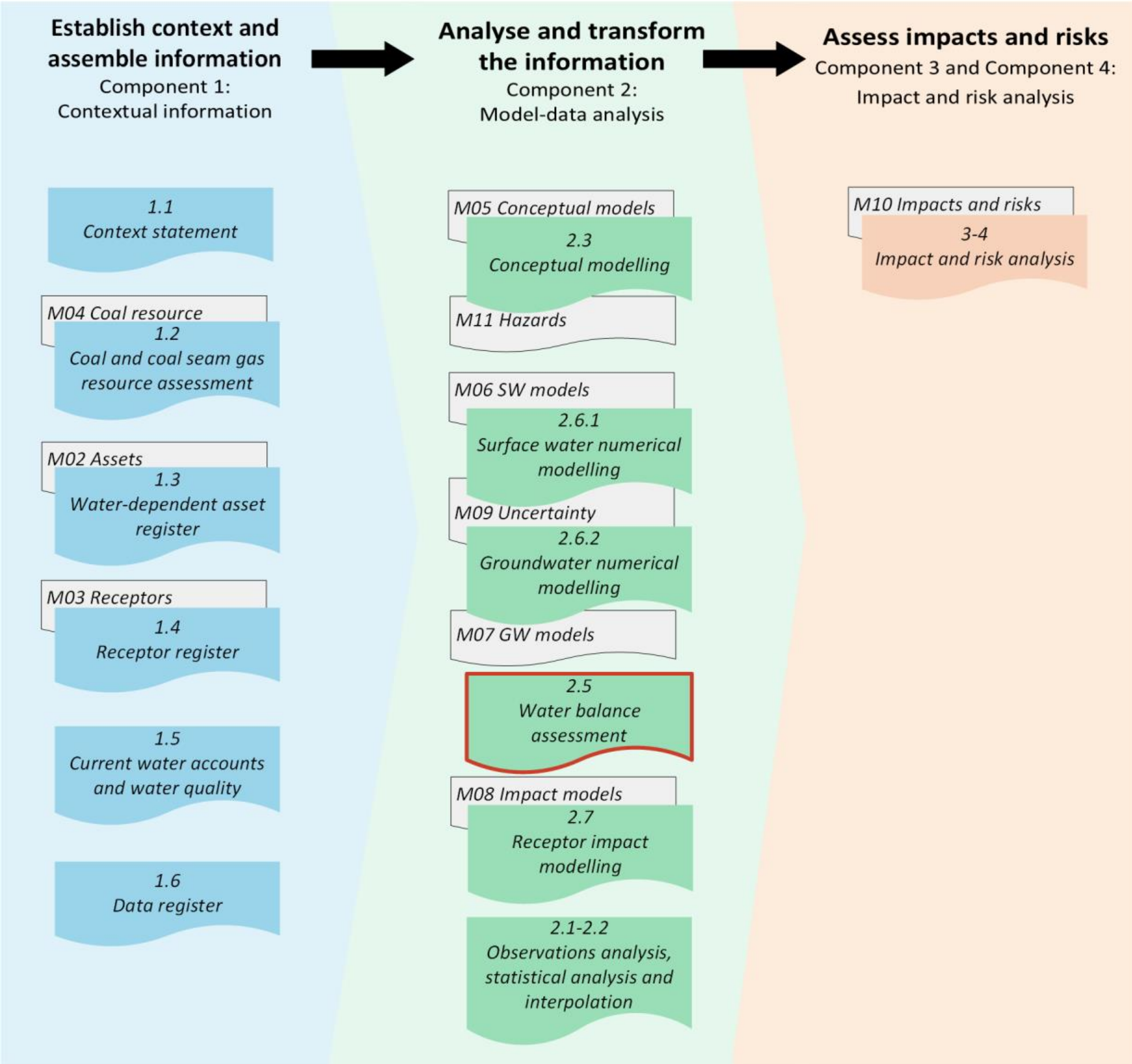

Figure 2 Technical products and submethodologies associated with each component of a bioregional assessment

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 Gloucester subregion

For each subregion in the Northern Sydney 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 products 2.6.1 (surface water modelling) and 2.6.2 (groundwater 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 Gloucester 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 Gloucester 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 Gloucester subregion	3-4	Impact and risk analysis	5.2.1, 2.5.4, 5.3	PDF, HTML
Component 5: Outcome synthesis for the Gloucester 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 Northern Sydney 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 151.0° East for the Northern Sydney Basin bioregion and two standard parallels of –18.0° and –36.0°.
- Visit http://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 26 February 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 26 February 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 Gloucester subregion

This product presents mean annual water balances for the Gloucester 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 (ACRD) – 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 can 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).

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

2.5.1 Methods

Summary

Water balance reporting nodes are selected to quantify impacts of coal resource developments over the minimum possible area which incorporates all hydrologically connected cumulative impacts.

Impacts from mines accumulate along two hydrologically disconnected pathways, the north-flowing Avon River and south-flowing Karuah River. Two nodes were selected for analysis: node 6, located on the Avon River; and node 21, located on the Mammy Johnsons River within the Karuah river basin.

The groundwater domain is defined by the alluvial groundwater modelling domain and differs from the surface water modelling domain. Thus separate water balances are reported for surface water and groundwater.

Three reporting periods are used to summarise water balance terms. These are 2013 to 2042, 2043 to 2072, and 2073 to 2102. They have the same variability as in the 1983–2012 historical sequence, but each of the future 30-year climate blocks assume some level of global warming.

Two possible coal resource development futures have been modelled.

In all, 24 water balances are presented.

2.5.1.1 Spatial and temporal extent of the water balances

Coal resource developments in the Gloucester subregion occur in both the north-flowing Avon river basin and the south-flowing Karuah river basin. These coal resource developments are detailed in Section 2.3.4 of companion product 2.3 for the Gloucester subregion (Dawes et al., 2018). In terms of surface water, they are not hydrologically contiguous. While the regional groundwater resources in the Gloucester Basin are continuous, the alluvial groundwater systems of the Avon and Karuah river basins are not in contact with each other (see companion product 1.1 for the Gloucester subregion (McVicar et al., 2014)). Water balance reporting points have been selected to quantify the cumulative hydrologic impacts of coal resource developments over the minimum possible area such that they are all hydrologically connected and for which model outputs had been generated (Figure 3). These are node 6 in the northern river basin and node 21 in the southern river basin. Each of these areas is a subdomain of the subregion intended to quantify the ‘maximum’ impact from all hydrologically connected mines, rather than the maximum impact around individual mines or small groupings of just some mines.

In the Avon river basin to the north, node 6 is the first downstream hydrological node that will reflect cumulative hydrological impacts of coal resource developments from expansions at the open-cut Stratford Coal Mine, the proposed Rocky Hill open-cut mine and AGL’s Stage 1 gas field development (Figure 3(b)). The surface water contributing area for this basin is 256.1 km^2.

The open-cut Duralie Coal Mine, which is the only mining operation within the Karuah river basin (southern part of subregion), is located in the Mammy Johnsons river basin. Node 21, which is located on this river, is the first node downstream of the mine which will reflect the impacts of mining on both surface water and groundwater in the alluvium (Figure 3(c)). The surface water contributing area to node 21 is 308.6 km^2.

Water balances for the baseline coal resource development (baseline) and coal resource development pathway (CRDP) at nodes 6 and 21 have been extracted from the landscape water balance (Australian Water Resources Assessment Landscape model, AWRA-L) and alluvial groundwater models for three 30-year periods (2013 to 2042; 2043 to 2072; and 2073 to 2102), which assume modelled temperature increases of 1.0, 1.5 and 2.0 °C under a future climate projection from the CSIRO-Mk3.0 global climate model (GCM). 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 impact will be different for different hydrologic response variables and receptors, which means at the subregion level there is not a single point in time for which a maximum impact water balance can be constructed. The water balance terms reported here represent the annual means for each 30-year period. Changes in the other hydrological response variables (i.e. low flow, high flow and flow regime metrics) generated by the modelling cannot be represented as water balances. The effect of the modelled additional coal resource development on these variables is provided in companion product 2.6.1 for the Gloucester subregion (Zhang et al., 2018).

Groundwater modelling in the Gloucester subregion was based on an alluvial aquifer model and a deeper groundwater model (see companion product 2.6.2 for the Gloucester subregion (Peeters et al., 2018)). Since the alluvial aquifer supports the largest proportion of assets in the Gloucester subregion (see companion product 1.3 for the Gloucester subregion (McVicar et al., 2015)), groundwater balance terms are reported for the alluvial aquifer only. The groundwater balance volumes reflect the entire modelled extent of the alluvial aquifer. The alluvial aquifer in the Avon river basin covers 36.1 km^2 and in the Karuah river basin covers 26 km^2.

Licensed extractions for non-mining uses were assumed not to differ between the two modelled futures and were not modelled. Licensed extractions of groundwater for coal seam gas (CSG) and dewatering of coal mines are modelled in the deeper groundwater model and their potential impact on the water balance in the alluvial aquifer is accounted for in the upward flow from deeper groundwater water balance term.

The water balances for surface water and groundwater are summarised separately because the spatial domains represented in the water balances differ and the reported numbers cannot be combined into a single water balance.

Figure 4 summarises the water balance terms reported for (a) the surface water balances and (b) the groundwater balances. The surface water figure shows that evapotranspiration, leakage and change in storage are reported as a single residual term in the surface water balances.

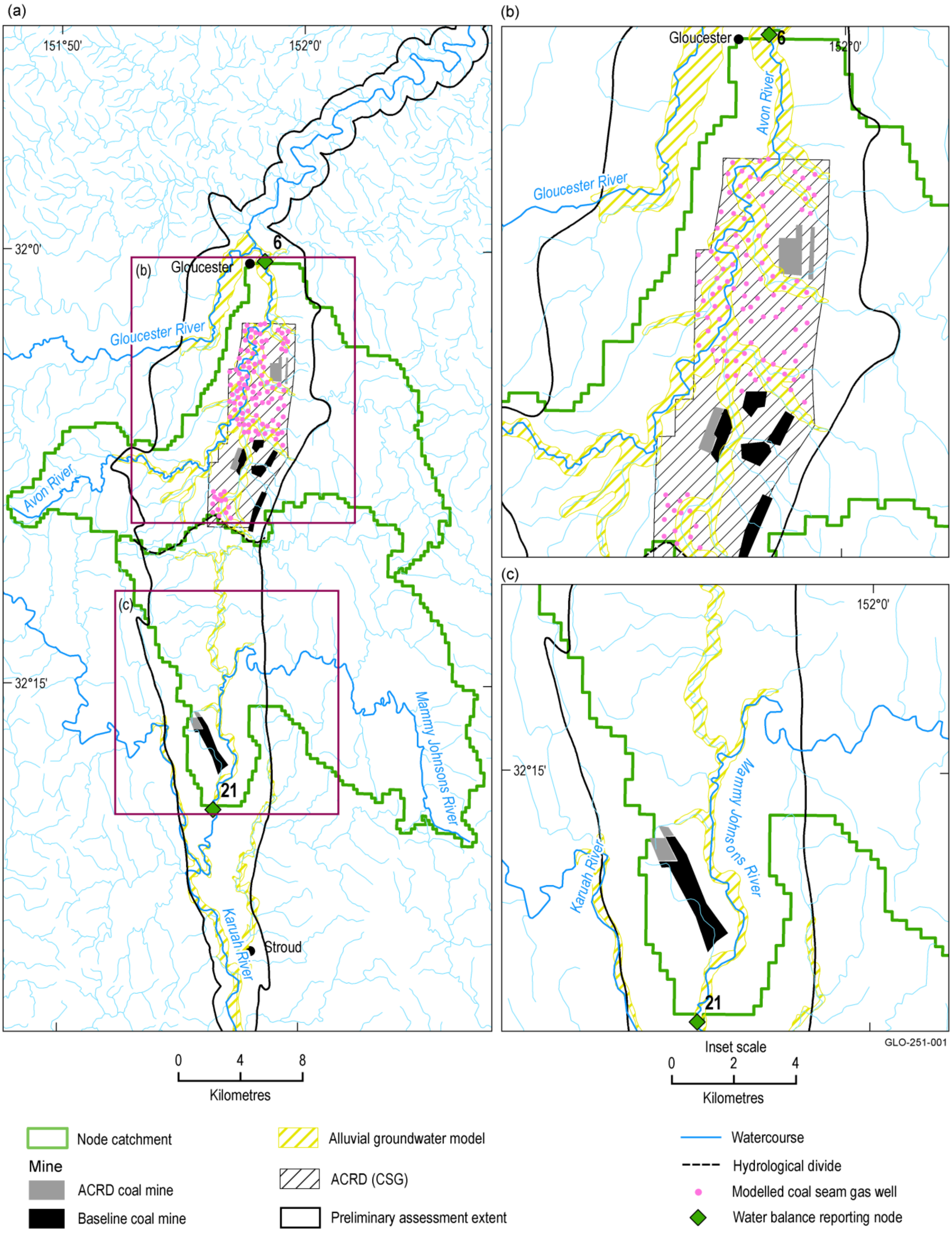

Figure 3 Location of water balance reporting nodes (green diamonds) (a) for the Gloucester subregion, (b) for developments in the Avon river basin and (c) for developments in the Mammy Johnsons river basin

ACRD = additional coal resource development
Data: CSIRO Land and Water (Dataset 1); Bureau of Meteorology (Dataset 2, Dataset 3); AGL (Dataset 4); CSIRO (Dataset 5); Bioregional Assessment Programme (Dataset 6)

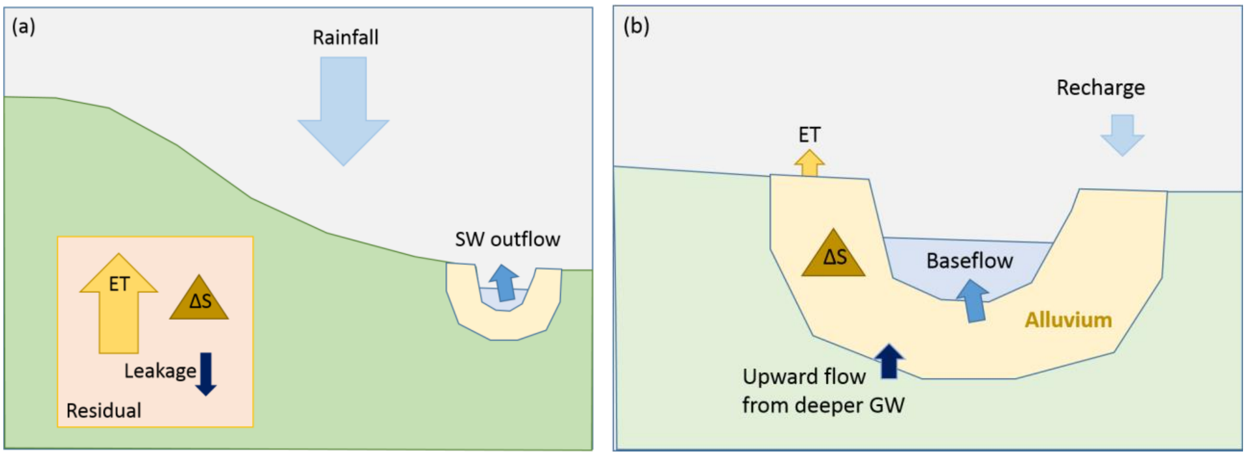

Figure 4 Water balance terms for (a) the surface water and (b) groundwater balances

2.5.1.2 Water balance uncertainty

The water balance terms summarised here are a different set of model outputs to the hydrological response variables generated at receptor locations, which were reported in companion product 2.6.1 (Zhang et al., 2018) and companion product 2.6.2 (Peeters et al., 2018) for the Gloucester subregion. To estimate the uncertainty of the water balance terms, the posterior parameter distributions for the model chain (Section 2.6.2.8 and Section 2.6.1.6) are sampled a limited number of times to calculate the water balance components. For this product, 30 unique parameter combinations were randomly selected from the subset of the 10,000 parameter combinations that had acceptable values of the objective function. While this small number of samples will not provide the rigorous uncertainty analysis presented in companion product 2.6.1 (Zhang et al., 2018) and companion product 2.6.2 (Peeters et al., 2018) for the Gloucester subregion, they will provide a credible estimate of the 10th, 50th and 90th percentiles of the water balance components.

References

Dawes WR, Macfarlane C, McVicar TR, Wilkes PG, Rachakonda PK, Henderson BL, Ford JH, Hayes KR, O'Grady AP, Marvanek SP and Schmidt RK (2018) Conceptual modelling for the Gloucester subregion. Product 2.3 for the Gloucester subregion from the Northern Sydney Basin Bioregional Assessment. Department of the Environment and Energy, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia. http://data.bioregionalassessments.gov.au/product/NSB/GLO/2.3.

McVicar T, Langhi L, Barron OV, Rachakonda PK, Zhang YQ, Dawes WR, Macfarlane C, Holland KL, Wilkes PG, Raisbeck-Brown N, Marvanek SP, Li LT and Van Niel TG (2014) Context statement for the Gloucester subregion. Product 1.1 from the Northern Sydney Basin Bioregional Assessment. Department of the Environment, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia. Viewed 26 April 2016, http://data.bioregionalassessments.gov.au/product/NSB/GLO/1.1.

McVicar TR, Macfarlane C, McNamara JM, Marston FM, Mount RE, Raisbeck-Brown N, Wang J, Moran BT, Moore B, Holland KL, Marvanek SP, Li LT, Zhang YQ and Barron OV (2015) Description of the water-dependent asset register for the Gloucester subregion. Product 1.3 for the Gloucester subregion from the Northern Sydney Basin Bioregional Assessment. Department of the Environment, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia. Viewed 23 December 2015, http://data.bioregionalassessments.gov.au/product/NSB/GLO/1.3.

Peeters LJM, Dawes WR, Rachakonda PR, Pagendam DE, Singh RM, Pickett TW, Frery E, Marvanek SP and McVicar TR (2018) Groundwater numerical modelling for the Gloucester subregion. Product 2.6.2 for the Gloucester subregion from the Northern Sydney Basin Bioregional Assessment. Department of the Environment and Energy, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia. http://data.bioregionalassessments.gov.au/product/NSB/GLO/2.6.2.

Rachakonda PK, Zhang YQ, Peña-Arancibia JL and Marvanek SP (2015) Current water accounts and water quality for the Gloucester subregion. Product 1.5 for the Gloucester subregion from the Northern Sydney Basin Bioregional Assessment. Department of the Environment, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia. Viewed 26 April 2016, http://data.bioregionalassessments.gov.au/product/NSB/GLO/1.5.

Zhang YQ, Viney NR, Peeters LJM, Wang B, Yang A, Li LT, McVicar TR, Marvanek SP, Rachakonda PK, Shi XG, Pagendam DE and Singh RM (2018) Surface water numerical modelling for the Gloucester subregion. Product 2.6.1 for the Gloucester subregion from the Northern Sydney Basin Bioregional Assessment. Department of the Environment and Energy, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia. http://data.bioregionalassessments.gov.au/product/NSB/GLO/2.6.1.

Datasets

Dataset 1 CSIRO Land and Water (2015) GLO Receptors 20150518. Bioregional Assessment Derived Dataset. Viewed 15 July 2015, http://data.bioregionalassessments.gov.au/dataset/20a12f38-0413-4a91-9ef2-be95ab89f625.

Dataset 2 Bureau of Meteorology (2013) National Surface Water sites Hydstra. Bioregional Assessment Source Dataset. Viewed 15 July 2015, http://data.bioregionalassessments.gov.au/dataset/f7edc5e5-93ee-4527-bed5-a118b4017623.

Dataset 3 Bureau of Meteorology, Climate and Water Division (2011) Geofabric Surface Cartography, v2.1. Bioregional Assessment Source Dataset. Viewed 15 July 2015, http://data.bioregionalassessments.gov.au/dataset/5342c4ba-f094-4ac5-a65d-071ff5c642bc.

Dataset 4 AGL (2014) AGL Gloucester Gas Project AECOM report location map features. Bioregional Assessment Source Dataset. Viewed 15 July 2015, http://data.bioregionalassessments.gov.au/dataset/7fca4f35-6e4e-4d37-bbae-1c1029a93a40.

Dataset 5 CSIRO (2014) BA_SYD_GLO_AGL_Avon_Wards_River_alluvium_extent_v1. Bioregional Assessment Source Dataset. Viewed 15 July 2015, http://data.bioregionalassessments.gov.au/dataset/4484f125-8401-4324-a8a4-42fd1828e485.

Dataset 6 Bioregional Assessment Programme (2014) Gloucester digitised coal mine boundaries. Bioregional Assessment Source Dataset. Viewed 15 July 2015, http://data.bioregionalassessments.gov.au/dataset/be85b60f-49dd-485c-bb85-11d45de9792d.

2.5.2 Water balances

Summary

The cumulative impacts of coal and coal seam gas (CSG) developments in the Gloucester subregion are presented in terms of separate groundwater and surface water balances for two locations over three future periods.

In the Avon river basin, the impact of additional coal resource developments at the open-cut Stratford and Rocky Hill coal mines and the AGL CSG development is a reduction in the mean annual surface water outflow of 1105 ML/year between 2013 and 2042. Smaller reductions are predicted for the subsequent two 30-year periods to 2102 (717 and 712 ML/year). This is primarily due to the retention of surface runoff on the mine sites rather than a decrease in baseflow due to groundwater extraction (median baseflow reductions vary from 90 to 81 ML/day over the 90-year period). This change in outflow is less than 2% of the baseline coal resource development (baseline) flow and is within the uncertainty of the predicted surface water outflow.

In the Mammy Johnsons river basin, the period from 2043 to 2072 experiences on average the biggest reduction in surface water outflows (186 ML/year) as a consequence of additional coal resource development (Duralie Coal Mine). This reduction persists through the subsequent 30-year period. These reductions are dominated by the retention of surface runoff on the mine sites rather than the baseline responses due to groundwater extraction. This change in outflow represents less than 0.3% of the baseline flow and is within the uncertainty of the predicted surface water outflow.

The lack of constraint on the magnitude of upward flow of groundwater from deeper layers into the alluvium is identified as a major gap in the ability to estimate the water balance. The prediction interval between 10th and 90th percentiles is very wide, indicating that there is insufficient data to constrain this term in the model. It is therefore not possible to provide a reliable estimate of this water balance term with the current modelling.

2.5.2.1 Node 6 – Avon River

Surface water balances at node 6 (Figure 3(b) of Section 2.5.1) on the Avon River are provided in Table 3 for 2013 to 2042, 2043 to 2072 and 2073 to 2102. Groundwater balances for the alluvial groundwater in the Avon River (Figure 3 of Section 2.5.1) are provided in Table 4 for 2013 to 2042, 2043 to 2072 and 2073 to 2102. The median changes in the water balance terms attributable to the additional coal resource development are illustrated in Figure 5 for surface water and Figure 6 for groundwater. The water balances are summarised separately because, as stated in Section 2.5.1, they apply to different areas. The surface water balance applies to an area of 256.1 km^2, whereas the alluvial groundwater model extent is 36.1 km^2. Rainfall inputs over the three reporting periods reflect changes due to a varying climate signal.

Licensed extractions for non-mining uses are not reported because they were not represented in the model (see Section 2.5.1.1). The impact of licensed extractions of groundwater for coal seam gas (CSG) and dewatering of coal mines are reflected in the upward flow from deeper groundwater water balance term.

Within each table, the impact of the additional coal resource development (ACRD), calculated as the difference between the baseline coal resource development (baseline) and the coal resource development pathway (CRDP), reflects the impacts of mining and CSG development only, as the climate signal is identical in both modelling runs.

The differences between corresponding values over the three reporting periods encompass both the effects of climate and the coal resource development.

The effects of the assumed climate change (see Section 2.5.1.1; also Section 2.6.1.3.3 in companion product 2.6.1 for the Gloucester subregion (Zhang et al., 2018)) on the water balance in the Avon River are very small. There is a decreasing trend in rainfall which flows through to a decreasing trend in the surface water outflow and groundwater recharge. However, the magnitude of the change is very small, with less than 1% 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.

The difference in the surface water balances for the baseline and the CRDP is reported in terms of changes to surface water outflows and a compensatory residual term which reflects the net change due to changes in evapotranspiration, leakage and storage. Median surface water outflows are reduced on average by 1105 ML/year in the 2013 to 2042 period, but recover somewhat in the subsequent two 30-year periods (Table 3) to mean annual reductions of 717 and 712 ML/year. Most of the difference can be attributed to the retention of surface runoff on the mine site rather than to groundwater extraction because the changes in baseflow (discharge to stream) for all three periods (Table 4) are approximately an order of magnitude lower than the changes in surface water outflow (Table 3). The maximum mine footprint areas (i.e. areas where surface drainage is disrupted by mining activities) for the open-cut Stratford and Rocky Hill coal mines occur within the period having the largest surface outflow reductions on average. This is consistent with the conceptualisation of changes to surface runoff being instantaneous, rather than lagged as they are for groundwater responses. The surface water model assumes no disruption to surface drainage from the AGL CSG development.

Surface runoff does not return to pre-mining levels during the simulated period because the area of ongoing surface water drainage disruption following rehabilitation of the mine site is around 2 km^2 larger under the CRDP than under the baseline (see Figure 7 in companion product 2.6.1 for the Gloucester subregion (Zhang et al., 2018)) and there is a small but sustained reduction in baseflow. The decrease in surface water outflow is reflected in an increase in the residual water balance term. Most of the residual water is lost as evapotranspiration, although leakage of water from open-cut pits and mine water storages may account for a small component and there would also be a small adjustment in catchment storage. Changes to the individual terms have not been quantified in the modelling. The decrease in surface water outflow under the CRDP is less than 2% of the baseline surface water outflow and within the uncertainty of the predicted surface water outflow. Changes in other hydrologic response variables can be more significant than these changes in mean annual flows (see Section 2.6.1.6 of companion product 2.6.1 (Zhang et al., 2018)).

The conceptual model of groundwater movement adopted for modelling the Avon River groundwater systems is that deeper groundwater flows upward into the alluvium, mixes with locally recharged water from rainfall and then discharges into streams as baseflow. Effects of coal mine dewatering and depressurisation due to CSG extraction will be propagated into the alluvial aquifer through reduced upward flow of deeper groundwater. Whether or not the changes in upward flux will be noticeable in the alluvial aquifer depends on the magnitude of the flux and the degree to which the water balance in the alluvial aquifer is driven by local, shallow processes or by deeper groundwater fluxes. The wide range between the 10th and 90th percentiles of the top 30 model runs (Table 4) indicates that this water balance term is not well constrained in the modelling due to insufficient data to characterise aquifer properties and inter-aquifer connectivity. For each time period the range covers both positive and negative values, which indicates the possibility of a reversal of the groundwater flow direction. However, in all three time periods the median prediction is for less upward flow under the CRDP than under the baseline, with the biggest difference on average between the baseline and the CRDP occurring between 2073 and 2102. The pattern over the 90-year simulation period is consistent with early reductions in upward flow to the alluvium being driven by depressurisation of aquifers near the surface from open-cut mining, followed by a more lagged response to depressurisation of deeper coal seams from CSG extraction, leading to larger reductions in the upward flow of groundwater to the alluvium between 2073 and 2102.

Some modelling artefacts are evident in the water balance results. Notably, differences in baseline and CRDP recharge in the period 2073 to 2102 (Table 4) are due to numerical issues with the model. Drawdown can lead to the drying out of cells at the top of the model, which the model then treats as not contributing recharge. The lower recharge under the CRDP indicates that the magnitude of drawdown is greater than under the baseline and more surface cells have dried out. Thus the reduction in annual baseflow in the third period reflects both the impact of the additional coal resource developments and a smaller recharge, the latter being an artefact of model implementation. Overall the additional coal resource developments are having only small effects on the groundwater balance and the small numerical modelling issues are not materially impacting the results.

Table 3 Mean annual surface water balance at node 6 on the Avon River for 2013 to 2042, 2043 to 2072 and 2073 to 2102 in the Gloucester subregion

Water balance term	Period	Under the baseline (ML/y)	Under the coal resource development pathway (ML/y)	Difference (ML/y)
Rainfall	2013–2042	281,966	281,966	0
	2043–2072	281,198	281,198	0
	2073–2102	280,686	280,686	0
Surface water outflow	2013–2042	63,312 (59,175; 67,586)	62,207 (58,129; 66,386)	–1105
	2043–2072	63,080 (59,074; 67,463)	62,363 (58,383; 66,634)	–717
	2073–2102	62,901 (58,958; 67,284)	62,189 (58,270; 66,450)	–712
Licensed extractions	2013–2042	NM	NM	NM
	2043–2072	NM	NM	NM
	2073–2102	NM	NM	NM
Residual (e.g. ET, leakage, change in storage)	2013–2042	218,654 (214,380; 222,791)	219,759 (215,580; 223,837)	1105
	2043–2072	218,118 (213,735; 222,124)	218,835 (214,564; 222,815)	717
	2073–2102	217,785 (213,402; 221,728)	218,497 (214,236; 222,416)	712

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. NM = data not modelled, ET = evapotranspiration,
Data: Bioregional Assessment Programme (Dataset 1)

Table 4 Mean annual groundwater balance for the alluvial groundwater model extent in the Avon River for 2013 to 2042, 2043 to 2072 and 2073 to 2102 in the Gloucester subregion

Water balance term	Period	Under the baseline (ML/y)	Under the coal resource development pathway (ML/y)	Difference (ML/y)
Recharge	2013–2042	6893 (6067; 8191)	6893 (6067; 8191)	0
	2043–2072	6882 (6053; 8157)	6882 (6017; 8172)	0
	2073–2102	6811 (5846; 7815)	6753 (5652; 7815)	–58
Evapotranspiration	2013–2042	289 (46; 866)	285 (46; 808)	–4
	2043–2072	288 (45; 875)	282 (11; 809)	–6
	2073–2102	288 (45; 843)	281 (11; 803)	–7
Baseflow (discharge to stream)	2013–2042	6929 (6441; 7353)	6848 (5659; 7296)	–81
	2043–2072	6981 (6421; 7370)	6849 (5509; 7270)	–32
	2073–2102	6940 (6210; 7521)	6850 (5288; 7279)	–90
Upward flow from deeper groundwater	2013–2042	392 (–44; 533)	340 (–368; 512)	–52
	2043–2072	385 (–242; 529)	350 (–1053; 473)	–35
	2073–2102	428 (–186; 590)	327 (–1562; 484)	–101
Change in storage	2013–2042	–11 (–180; 3)	–5 (–138; 101)	6
	2043–2072	–4 (–75; 1)	–5 (–73; 1)	–1
	2073–2102	–3 (–68; 197)	–5 (–63; 149)	–2

The first number is the median, and the 10th and 90th percentile numbers follow in brackets.
Data: Bioregional Assessment Programme (Dataset 2)

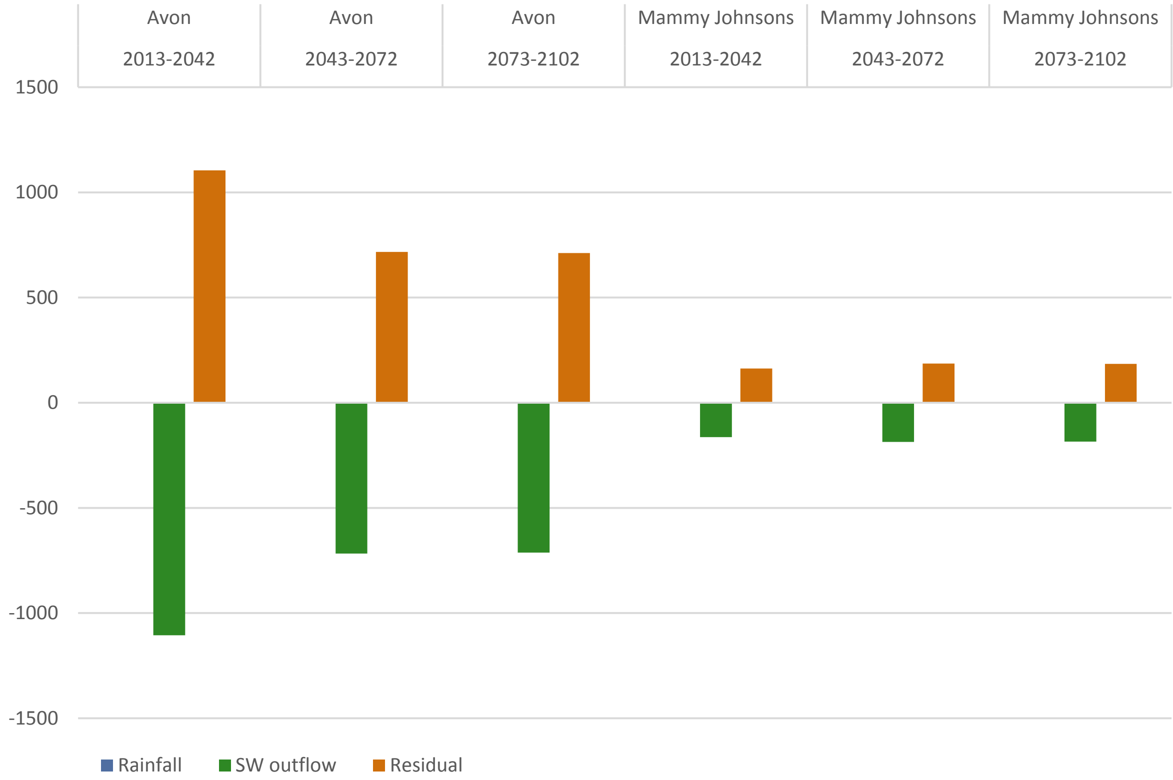

Figure 5 Median changes in surface water balance terms for node 6 (Avon River) and node 21 (Mammy Johnsons River) for the three reporting periods

Data: Bioregional Assessment Programme (Dataset 1)

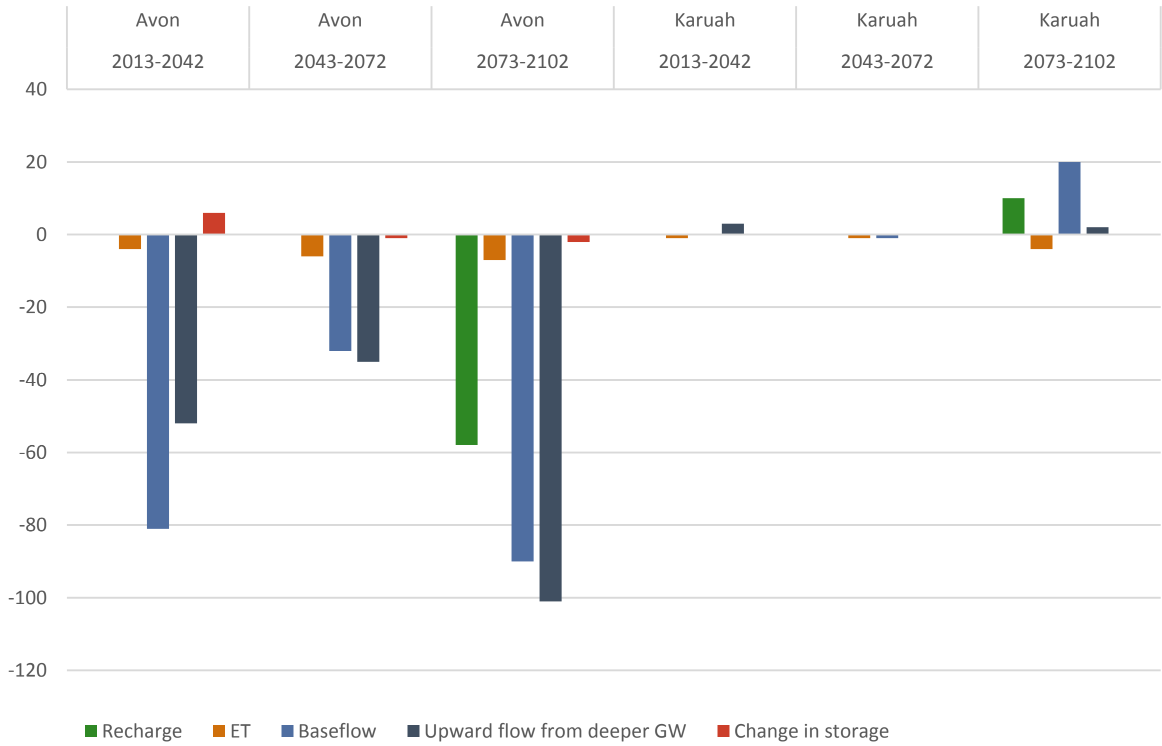

Figure 6 Median changes in groundwater balance terms for the alluvial model groundwater extents of the Avon River and Karuah River for the three reporting periods

Data: Bioregional Assessment Programme (Dataset 2)

2.5.2.2 Node 21 – Mammy Johnsons River

Surface water balances at node 21 (Figure 3(c) of Section 2.5.1) in the Mammy Johnsons River are provided in Table 5 for 2013 to 2042, 2043 to 2072 and 2073 to 2102. Groundwater balances for the alluvial groundwater in the Karuah river basin (Figure 3 of Section 2.5.1) are provided in Table 6 for 2013 to 2042, 2043 to 2072 and 2073 to 2102. The median changes in the water balance terms attributable to the additional coal resource development are illustrated in Figure 5 for surface water and Figure 6 for groundwater. The water balances are summarised separately because, as stated in Section 2.5.1, they apply to different areas. The surface water balance applies to an area of 308.6 km^2, whereas the alluvial groundwater model extent is 26 km^2. Rainfall inputs over the three reporting periods reflect changes due to a varying climate signal.

Licensed extractions for non-mining uses are not reported because they were not represented in the model (see Section 2.5.1.1). The impact of licensed extractions of groundwater for CSG and dewatering of coal mines are reflected in the upward flow from deeper groundwater water balance term.

Within each table, the impact of the ACRD, calculated as the difference between the baseline and the CRDP, reflects the impacts of mining and CSG development only, as the climate signal is identical in both modelling runs.

The differences between corresponding values over the three reporting periods encompass both the effects of climate and the coal resource development.

The effects of climate change on the water balance in the Mammy Johnsons River are very small. There is a decreasing trend in rainfall which flows through to a decreasing trend in the surface water outflow and groundwater recharge. However, the magnitude of the change is very small, with less than 1% decrease in rainfall, less than 2% decrease in surface water outflow and less than 3% decrease in groundwater recharge when the 2073 to 2102 period is compared to the 2013 to 2042 period for the baseline.

The reduction in the median surface water outflow as a consequence of the additional coal resource development is on average greatest (186 ML/year) between 2043 and 2072, and remains at this level through to the end of the simulation in 2102 (Table 5). The majority of this impact is attributed to the retention of surface runoff on-site rather than groundwater extraction because the decrease in baseflow is negligible compared to the decrease in surface water outflow for all three periods of time (Table 6). The surface water impact is sustained over the modelling period at the open-cut Duralie Coal Mine because most of the surface water footprint is due to interception of runoff by small dams, which are assumed to remain in place following the cessation of mining (see Figure 7 in companion product 2.6.1 for the Gloucester subregion (Zhang et al., 2018)). The decrease in surface water outflow is reflected in an increase in the residual term. Most of the water lost is from evapotranspiration, although leakage of water from open-cut pits and mine water storages may account for a small component and there will be a small change in catchment storage. The decrease in the CRDP surface water outflow is 0.3% of the baseline surface water outflow and within the uncertainty of the predicted surface water outflow.

As discussed in Section 2.5.2.1, some modelling artefacts are evident in the water balance results. In the Mammy Johnsons river basin, the CRDP recharge in the period 2073 to 2102 is greater than the baseline recharge (Table 6), which indicates a smaller drawdown under the CRDP, hence fewer surface cells have dried out relative to the baseline. In addition, the location of groundwater pumping under the CRDP has shifted from that for the baseline and this has introduced another modelling artefact, which results in more baseflow under the CRDP than baseline. Thus the increase in annual baseflow under the CRDP in the third period is the net effect of the additional coal resource development and a higher recharge relative to the baseline. Overall, there are negligible changes in the groundwater components of the water balance between the baseline and CRDP for the time periods 2013 to 2042 and 2043 to 2072 (Table 6), and these small numerical modelling issues are not materially impacting the results.

Table 5 Mean annual surface water balance at node 21 on Mammy Johnsons River for 2013 to 2042, 2043 to 2072 and 2073 to 2102 in the Gloucester subregion

Water balance term	Period	Under the baseline (ML/y)	Under the coal resource development pathway (ML/y)	Difference (ML/y)
Rainfall	2013–2042	350,261	350,261	0
	2043–2072	349,335	349,335	0
	2073–2102	348,101	348,101	0
Surface water outflow	2013–2042	64,855 (58,041; 69,893)	64,692 (57,884; 69,320)	–163
	2043–2072	64,249 (57,494; 69,396)	64,063 (57,314; 68,622)	–186
	2073–2102	63,789 (57,057; 68,990)	63,604 (56,877; 68,156)	–185
Licensed extractions	2013–2042	NM	NM	NM
	2043–2072	NM	NM	NM
	2073–2102	NM	NM	NM
Residual (e.g. ET, leakage, change in storage)	2013–2042	285,406 (280,368; 292,220)	285,569 (280,941; 292,377)	163
	2043–2072	285,086 (279,939; 291,841)	285,272 (280,713; 292,021)	186
	2073–2102	284,312 (279,111; 291,044)	284,497 (279,945; 291,224)	185

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. NM = data not modelled, ET = evapotranspiration
Data: Bioregional Assessment Programme (Dataset 1)

Table 6 Mean annual groundwater balance for the alluvial groundwater model extent in the Karuah river basin for 2013 to 2042, 2043 to 2072 and 2073 to 2102 in the Gloucester subregion

Water balance term	Period	Under the baseline (ML/y)	Under the coal resource development pathway (ML/y)	Difference (ML/y)
Recharge	2013–2042	6000 (5317; 9630)	6000 (5328; 9530)	0
	2043–2072	5989 (5257; 9511)	5989 (5268; 9511)	0
	2073–2102	5840 (5050; 9493)	5850 (5066; 9481)	10
Evapotranspiration	2013–2042	633 (88; 3731)	632 (91; 3769)	–1
	2043–2072	631 (88; 3696)	630 (91; 3744)	–1
	2073–2102	782 (87; 4048)	778 (92; 4028)	–4
Baseflow (discharge to stream)	2013–2042	6403 (5856; 6639)	6403 (5863; 6642)	0
	2043–2072	6392 (5778; 6639)	6391 (5855; 6650)	–1
	2073–2102	6398 (5860; 6696)	6418 (5844; 7134)	20
Upward flow from deeper groundwater	2013–2042	865 (401; 999)	868 (402; 1000)	3
	2043–2072	878 (547; 994)	878 (544; 993)	0
	2073–2102	899 (672; 2140)	901 (742; 2222)	2
Change in storage	2013–2042	1 (1; 7)	1 (1; 7)	0
	2043–2072	1 (0; 6)	1 (0; 2)	0
	2073–2102	0 (–65; 7)	0 (–32; 22)	0

The first number is the median, and the 10th and 90th percentile numbers follow in brackets.
Data: Bioregional Assessment Programme (Dataset 2)

2.5.2.3 Gaps

The limitations on the water balances estimates provided here are a result of the limitations in the numerical modelling. The numerical modelling is described in companion product 2.6.1 for the Gloucester subregion (Zhang et al., 2018) and companion product 2.6.2 for the Gloucester subregion (Peeters et al., 2018) and should be read in conjunction with this product. The groundwater modelling results have exposed some modelling artefacts, which while not materially impacting the overall modelling results, identify areas for improvement.

The most uncertain component of the water balance that has been modelled in the Gloucester subregion is the upward flow from deeper groundwater into the alluvium. This component is the link between the groundwater extraction for CSG and coal mines represented in the deep groundwater model and the change in baseflow simulated by the alluvial groundwater model. The high variability indicates that the observations used to constrain the parameters in the deep groundwater model are inadequate to provide a precise estimate of this component of the water balance.

References

Peeters LJM, Dawes WR, Rachakonda PR, Pagendam DE, Singh RM, Pickett TW, Frery E, Marvanek SP and McVicar TR (2018) Groundwater numerical modelling for the Gloucester subregion. Product 2.6.2 for the Gloucester subregion from the Northern Sydney Basin Bioregional Assessment. Department of the Environment and Energy, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia. http://data.bioregionalassessments.gov.au/product/NSB/GLO/2.6.2.

Zhang YQ, Viney NR, Peeters LJM, Wang B, Yang A, Li LT, McVicar TR, Marvanek SP, Rachakonda PK, Shi XG, Pagendam DE and Singh RM (2018) Surface water numerical modelling for the Gloucester subregion. Product 2.6.1 for the Gloucester subregion from the Northern Sydney Basin Bioregional Assessment. Department of the Environment and Energy, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia. http://data.bioregionalassessments.gov.au/product/NSB/GLO/2.6.1.

Datasets

Dataset 1 Bioregional Assessment Programme (2016) GLO AWRA Model v01. Bioregional Assessment Derived Dataset. Viewed 30 May 2016, http://data.bioregionalassessments.gov.au/dataset/15ca8f9d-84b4-4395-87db-ab4ff15b9f07.

Dataset 2 Bioregional Assessment Programme (2016) GLO_MF_waterbalance v01. Bioregional Assessment Derived Dataset. Viewed 30 May 2016, http://data.bioregionalassessments.gov.au/dataset/2dffc9ac-536e-42e7-89b1-b700ddb87047.

Glossary

The register of terms and definitions used in the Bioregional Assessment Programme is available online at http://environment.data.gov.au/def/ba/glossary (note that terms and definitions are respectively listed under the 'Name' and 'Description' columns in this register). This register is a list of terms, which are the preferred descriptors for concepts. Other properties are included for each term, including licence information, source of definition and date of approval. Semantic relationships (such as hierarchical relationships) are formalised for some terms, as well as linkages to other terms in related vocabularies.

activity: for the purposes of Impact Modes and Effects Analysis (IMEA), a planned event associated with a coal seam gas (CSG) operation or coal mine. For example, activities during the production life-cycle stage in a CSG operation include drilling and coring, ground-based geophysics and surface core testing. Activities are grouped into components, which are grouped into life-cycle stages.

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

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 wells 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

conceptual model: abstraction or simplification of reality connectivity: a descriptive measure of the interaction between water bodies (groundwater and/or surface water)

consequence: synonym of impact

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

dataset: a collection of data in files, 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). In the BA Repository, datasets are guaranteed to have a metadata record in the Metadata Catalogue and to have their components (files, database interface) delivered via the Data Store. In semantic web terms, a BA dataset is defined as a subclass of DCAT Dataset and PROMS Entity and is described in the BA Ontology as a scope note in term record.

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

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

Gloucester subregion: The Gloucester subregion covers an area of about 348 km^2. The Gloucester subregion is defined by the geological Gloucester Basin. It is located just north of the Hunter Valley in NSW, approximately 85 km north-north-east of Newcastle and relative to regional centres is 60 km south-west of Taree and 55 km west of Forster.

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

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

material: pertinent or relevant

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. 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. Sometimes known as a ‘wellbore’.

www.bioregionalassessments.gov.au

Australian Government

Department of the Environment and Energy

Bureau of Meteorology

Geoscience Australia

CSIRO