Australian Government

BIOREGIONAL ASSESSMENTS

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

Water balance assessment for the Hunter subregion

Product 2.5 for the Hunter 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 https://www.environment.gov.au/water/coal-and-coal-seam-gas/office-of-water-science.

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Authorship is listed in relative order of contribution.

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Cover photograph

Oblique view west of Muswellbrook showing Bengalla coal storage (left foreground) with irrigated agriculture and riparian vegetation either side of the Hunter River and Mount Arthur coal mine in the distance (right background), NSW, 2014

© Google earth (2015), Sinclair Knight Merz Imagery date 16 December 2008. Position 32°17′58′′ S, 150°48′51′′ E, elevation 136 m, eye altitude 1.59 km

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This technical product was reviewed by several groups:

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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.

Currency of scientific results

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

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

Introduction

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

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

The IESC has been involved in the development of *Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources* (the BA methodology; Barrett et al., 2013) and has endorsed it. The BA methodology specifies how BAs should be undertaken. Broadly, a BA comprises five components of activity, as illustrated in Figure 1. Each BA 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.

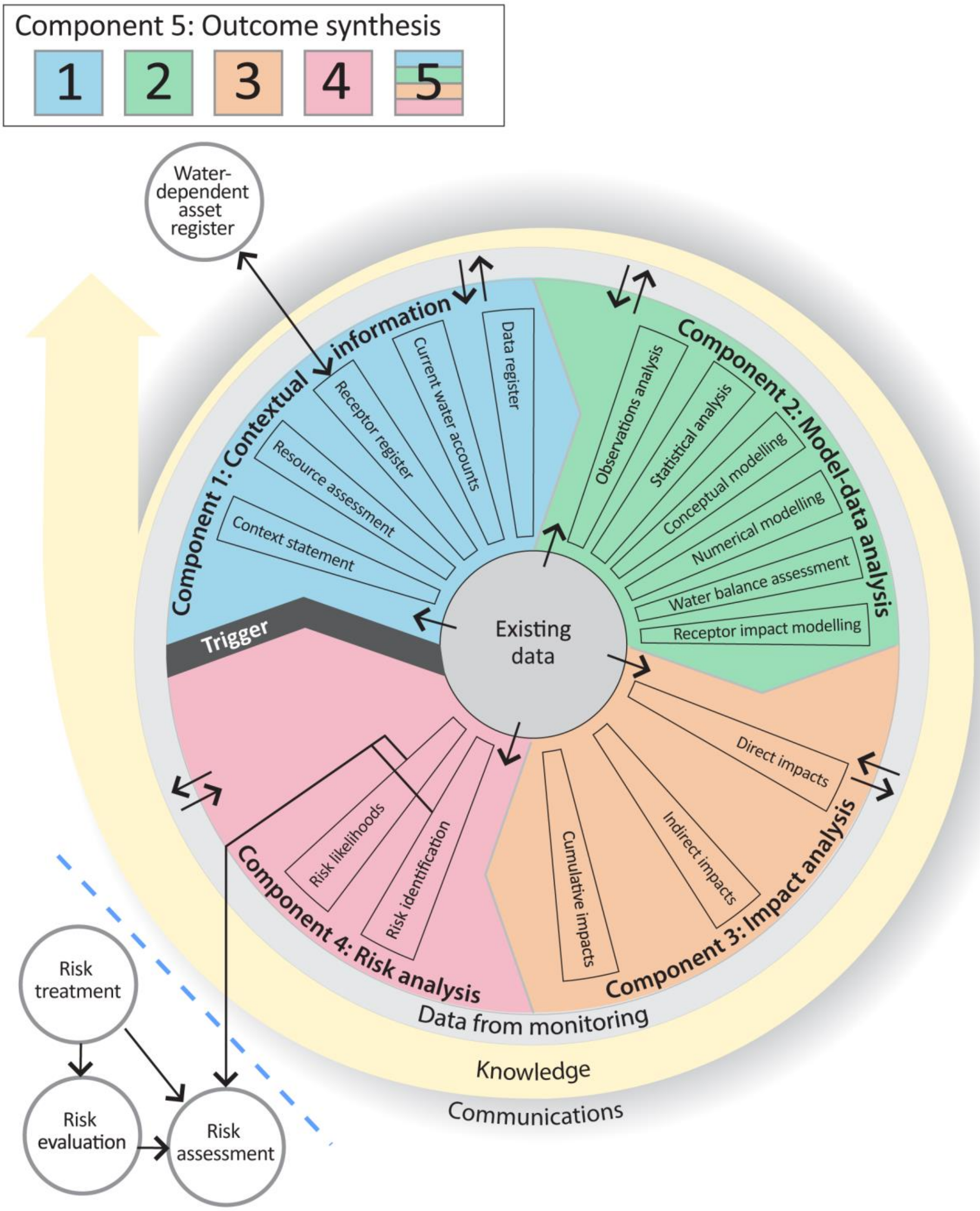

Figure 1 Schematic diagram of the bioregional assessment methodology

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.

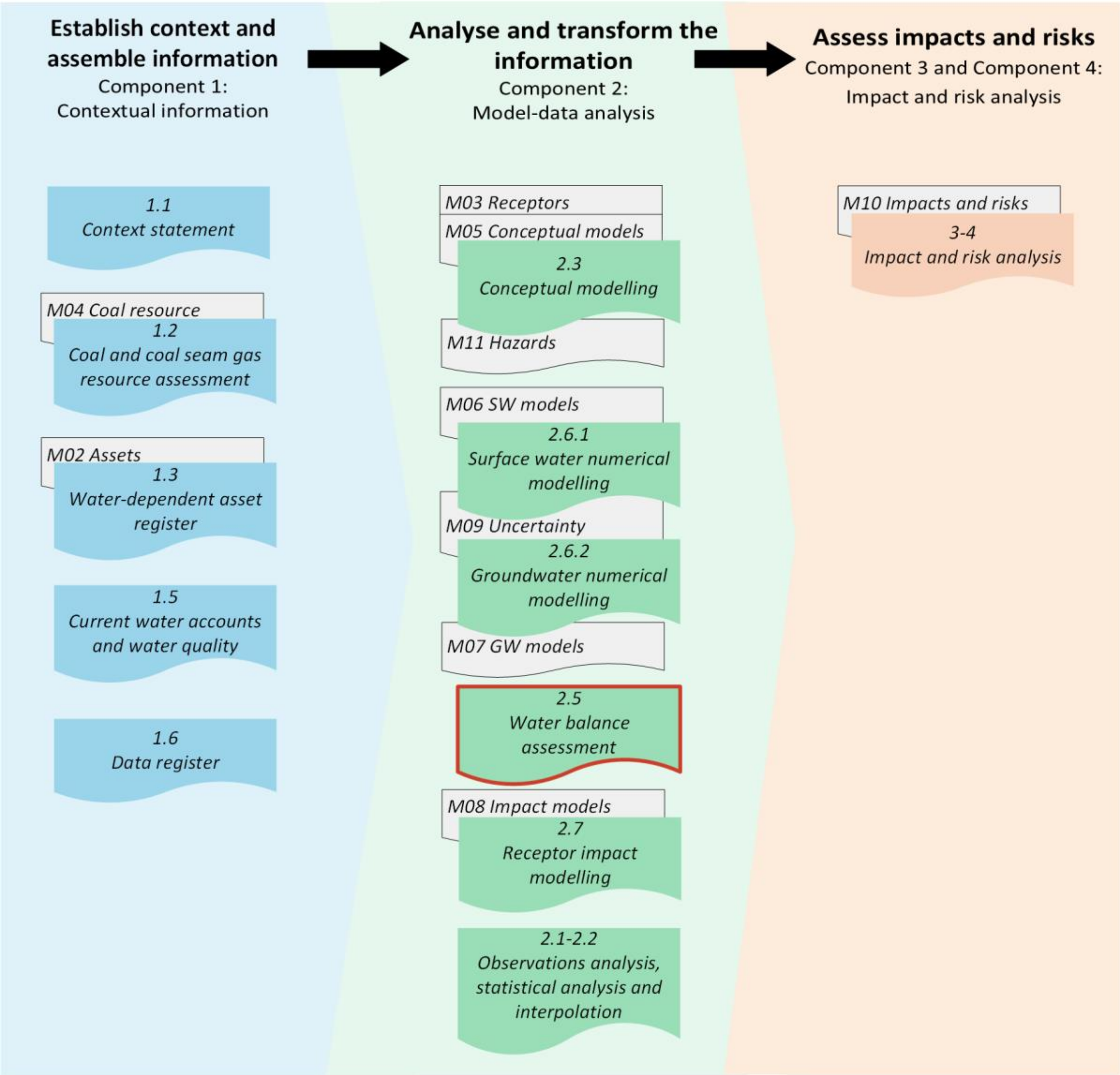

Figure 2 Technical products and submethodologies associated with each component of a bioregional assessment

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 Hunter 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 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 Hunter 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 Hunter 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 Hunter subregion	3-4	Impact and risk analysis	5.2.1, 2.5.4, 5.3	PDF, HTML
Component 5: Outcome synthesis for the Hunter 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 2 March 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 2 March 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 Hunter subregion

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

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

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

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

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

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

The water balance reported here summarises volumetric changes and does not represent impacts on flow regime changes which may be more significant than changes in 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 balances are presented for the Hunter subregion and subdomains of the subregion for the reporting periods: 2013 to 2042, 2043 to 2072, and 2073 to 2102. Each of the future 30-year reporting periods includes some level of global warming, with the same variability as in the 1983 to 2012 historical sequence. For each time period, results from the baseline and coal resource development pathway (CRDP) are presented.

One set of water balances is reported for the entire Hunter subregion from the groundwater modelling. It comprises recharge, evapotranspiration, non-mining groundwater extractions, mine pumping, surface water – groundwater flux, boundary flux and change in storage water balance terms.

Two sets of surface water balances are provided at model nodes in the Hunter river basin, selected to quantify hydrological changes due to additional coal resource development over the minimum possible area which incorporates all hydrologically connected cumulative impacts to node 41 (stream gauge 210006) on the Goulburn River and node 6 (stream gauge 210001) on the Hunter River. The surface water balances comprise rainfall, streamflow, licensed river extractions, mine discharges to the river and a balancing term (residuals).

The groundwater water balances are based on 229 of the 1450 groundwater model simulations that showed closest agreement to watertable level and streamflow observation data.

The surface water balances are based on 300 of the 3000 surface water simulations that showed the best agreement with annual streamflow observation data.

2.5.1.1 Spatial and temporal extent of the water balances

A water balance provides a summary of the inflows, outflows and change in storage for a defined area and period of time. A crude water balance was provided in Section 2.3.2.4 of companion product 2.3 for the Hunter subregion (Dawes et al., 2018), which included estimates of rainfall, recharge, baseflow and a residual term for the Hunter subregion, based on observation data and various approximation methods. Results from the numerical modelling reported in companion product 2.6.1 (surface water modelling; Zhang et al., 2018) and companion product 2.6.2 (groundwater modelling; Herron et al., 2018) for the Hunter subregion are reported as water balances in this product to provide accessible summaries of the effect of coal resource development on key variables of the regional water balance. The coal resource development pathway (CRDP) in the Hunter subregion comprises open-cut and underground coal mines only. Coal seam gas (CSG) development is not currently part of the CRDP for the Hunter subregion.

In the Hunter subregion, groundwater and surface water have been modelled largely independently, but come together in the river model via a surface water – groundwater flux along a river network common to both models. Given this, separate groundwater and surface water balance domains are defined for the Hunter subregion, with some overlap in the surface water balances. Figure 3 summarises the water balance terms reported for (a) groundwater balances and (b) surface water balances. The water balance equations can be written for:

a. Groundwater as: $Re = ET + Ex_L + Ex_M + Q_{bf} + B + \Delta S$

where Re denotes recharge, ET is evapotranspiration, Ex_L and Ex_M are licensed and mining extractions, respectively, Q_{bf} is surface water – groundwater flow, B is boundary flow, ΔS is change in storage; and

b. Surface water: $P + M = Q + Ex + Res$

where P is rainfall and M is mine water discharge, both inputs to the system, and Q is streamflow, Ex is extractions from the river and Res is a residual term, which includes evapotranspiration, leakage and change in storage. Streamflow, Q, includes the surface water – groundwater flux, Q_{bf}, from the groundwater model.

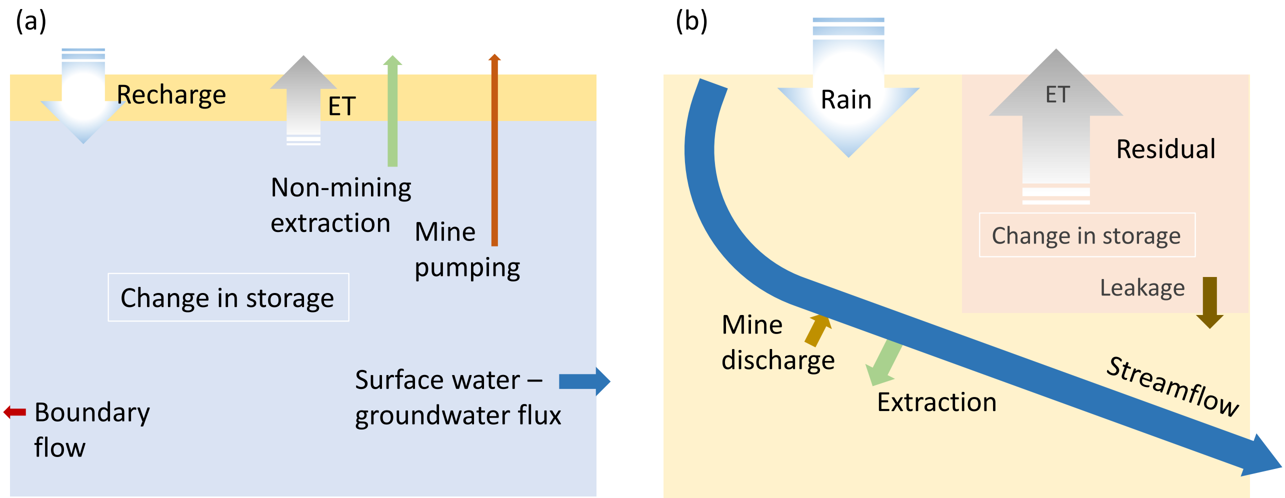

Figure 3 Water balance terms for the Hunter subregion (a) groundwater balances and (b) surface water balances

Groundwater balances are shown in cross-section, whereas surface water balances are shown in plan view.
ET = evapotranspiration

Most of the coal resource developments in the Hunter subregion occur around the Hunter River from Muswellbrook and Singleton, south of Maitland, in the headwaters of the Goulburn River and inland and around Lake Macquarie and Tuggerah Lakes. These coal resource developments are detailed in Section 2.3.4 of Dawes et al. (2018). Five additional coal resource developments were not included in the groundwater modelling: three due to insufficient information to represent them in the model (West Muswellbrook, Wambo and Wilpinjong); and two due to the small scale of the proposed changes (Austar and Mount Arthur). Five additional coal resource developments were not included in the surface water modelling: two due to no significant change in the area of disturbance at the surface (Austar and Wambo); one due to insufficient information to represent in the model (West Muswellbrook); one due to mining under Lake Macquarie (Chain Valley); and one due to lack of surface water – groundwater flux data from the groundwater model (Mandalong). The potential hydrological changes and impacts on assets from additional coal resource developments that were not modelled using surface water and/or groundwater models are discussed in companion product 3-4 (impact and risk analysis) for the Hunter subregion (as listed in Table 2).

Water balance terms have been extracted from the various models for three 30-year periods (2013 to 2042, 2043 to 2072 and 2073 to 2102), which align with modelled temperature increases of 1.0, 1.5 and 2.0 °C under a future climate projection from the Japanese Meteorological Research Institute 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 water balance terms reported here represent the annual means for each 30-year period. These are not directly comparable to the hydrological response variables reported in Herron et al. (2018) and Zhang et al. (2018), which were based on the maximum difference between the CRDP and baseline time-series for each hydrological response variable over the simulation period, but are derived from the same sets of model simulations.

The groundwater modelling domain for the Hunter subregion encompasses an area greater than the subregion (Figure 4). As described in Herron et al. (2018), the groundwater model represents groundwater in the Hunter subregion as a whole-of-subregion aquifer, overlain by alluvial aquifers along the Hunter River and its tributaries and along the streams that drain the Macquarie-Tuggerah lakes basin (see companion product 1.1 for the Hunter subregion (McVicar et al., 2015)). A groundwater balance can be generated for the entire Hunter subregion, which comprises an inflow from recharge, outflows from evapotranspiration, mine and non-mine groundwater extractions, discharges to streamflow (baseflow) and boundary flows, and change in storage (Figure 3(a)). Boundary flows occur at the edges of the model domain and reflect inflows to or outflows from the subregion. The reported volumes are for an area of 34,000 km^2. Groundwater balances for subdomains of the Hunter subregion are not presented because the model was not configured to do this.

The high connectivity between alluvial aquifers and streams in the Hunter river basin means they are managed conjunctively. It is here that exchanges between groundwater and surface water predominantly occur. The groundwater model provides the change in surface water – groundwater fluxes to the Australian Water Resources Assessment river model (AWRA-R), hence this groundwater term is included in the surface water balances. No other groundwater fluxes (e.g. from seeps or springs) are represented in the surface water balances as they are not modelled.

Surface water balances can be reported for subdomains of a subregion because, if surface water – groundwater fluxes are assumed to be generated within the same contributing area as the surface flows, surface water catchments can be treated as relatively closed basins (with respect to inflows) with clearly defined outflow points. Surface water balance terms for the Hunter subdomains are rainfall, river diversions and mine discharges and river outflows, and were obtained from the AWRA landscape model (AWRA-L), AWRA-R and groundwater modelling.

Surface water balance reporting points were selected to quantify the cumulative hydrological changes due to coal resource development over the minimum possible area that they are all hydrologically connected and for which model outputs were generated. Thus these reporting areas summarise the ‘maximum’ impact on streamflow from the main groupings of hydrologically connected mines, rather than the maximum impact around individual mines.

Two areas were defined in the Hunter river basin (Figure 4) – the contributing areas to:

1. node 41 (stream gauge 210006) on the Goulburn River, which is just downstream of the tributaries that drain the most eastern mine in the western group, Bylong mine. This node represents the cumulative changes of the Ulan West, Moolarben, Wilpinjong and Bylong additional coal resource developments (but excludes changes to baseflow from Wilpinjong mine, which was not represented in the groundwater modelling). The surface water contributing area for this basin is 3400 km^2
2. node 6 (stream gauge 210001) on the Hunter River, just downstream of Singleton. This node represents the cumulative changes from the Goulburn River coal mines, as well as the additional coal resource developments in the Hunter River basin upstream of this point: the open-cut mines at Ashton, Bengalla, Bulga, Drayton South, Liddell, Mount Arthur, Mount Owen, Mount Pleasant and Mount Thorley-Warkworth; and underground mine at Mount Arthur (but excludes changes to baseflow from West Muswellbrook open-cut and Wambo underground; and reductions in surface runoff from West Muswellbrook mine). The surface water contributing area for this basin is 16,485 km^2.

From a surface water perspective, the Macquarie-Tuggerah lakes basin is not hydrologically contiguous with the Hunter river basin, nor are the individual subcatchments hydrologically connected, although some drain to the same coastal lakes. This basin contains three additional coal resource developments: Mandalong and Chain Valley, which were not included in the surface water modelling, and did not have surface water – groundwater fluxes calculated by the groundwater model; and Wallarah 2, which had surface water changes quantified using AWRA-L and groundwater fluxes to the Wyong River generated at two model nodes. Due to the incompleteness of the numerical modelling of the Mandalong and Chain Valley additional coal resource developments, a surface water balance is not presented for this area.

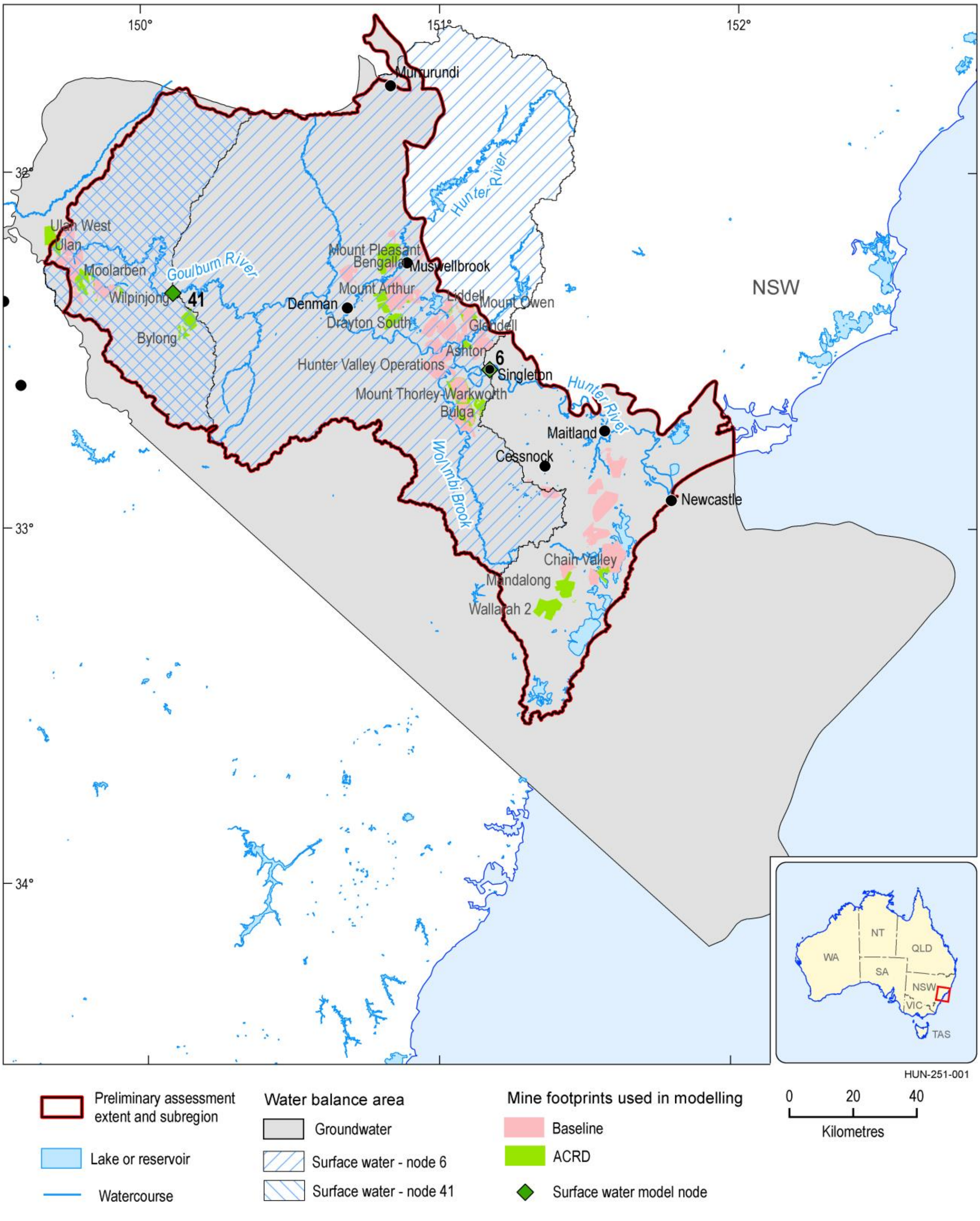

Figure 4 Reporting areas for groundwater and surface water balances

baseline = baseline coal resource development, ACRD = additional coal resource development
Footprints represent the maximum impacted area at the surface and include both groundwater and surface water footprints.
Footprints of the coal resource development pathway (CRDP) equal the union of footprints for baseline and ACRD.
Data: Bioregional Assessment Programme (Dataset 1, Dataset 2, Dataset 3, Dataset 4, Dataset 5)

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 model nodes, which are reported in companion product 2.6.1 (surface water numerical modelling; Zhang et al., 2018) and companion product 2.6.2 (groundwater numerical modelling; Herron et al., 2018) for the Hunter subregion. The range, as represented by the 10th and 90th percentile values for each groundwater balance term, summarises the results of 229 of the 1450 original simulations of the groundwater model. This subset of model simulations was chosen through the uncertainty analysis described in Section 2.6.2.8 of Herron et al. (2018). The chosen 229 groundwater simulations are those in which the watertable level and streamflow meet observation data most closely.

The range, as represented by the 10th and 90th percentile values for each surface water balance term reflects the top 10% of the original 3000 model simulations, evaluated against annual streamflow observations at 17 Hunter subregion gauges. The gauges chosen for evaluating model performance had at least 25 years of daily data and included unregulated and regulated parts of the river system.

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Datasets

Dataset 1 Bioregional Assessment Programme (2016) Hunter Groundwater Model extent. Bioregional Assessment Derived Dataset. Viewed 11 August 2016, http://data.bioregionalassessments.gov.au/dataset/6d4a8c97-f7ea-4840-9de9-af6f7b18b8d6.

Dataset 2 Bioregional Assessment Programme (2016) HUN AWRA-R simulation nodes v01. Bioregional Assessment Derived Dataset. Viewed 11 August 2016, http://data.bioregionalassessments.gov.au/dataset/fda20928-d486-49d2-b362-e860c1918b06.

Dataset 3 Bioregional Assessment Programme (2016) HUN AWRA-R nested calibration catchments v01. Bioregional Assessment Derived Dataset. Viewed 11 August 2016, http://data.bioregionalassessments.gov.au/dataset/e17e87dd-8839-462d-8bb3-b45037b7bb16.

Dataset 4 Bioregional Assessment Programme (2016) HUN SW modelling total mine footprint v01. Bioregional Assessment Derived Dataset. Viewed 11 August 2016, http://data.bioregionalassessments.gov.au/dataset/b78597ba-4781-4b95-80c3-d6c11cb2e595.

Dataset 5 Bioregional Assessment Programme (2016) HUN Mine footprints for GW modelling v01. Bioregional Assessment Derived Dataset. Viewed 11 August 2016, http://data.bioregionalassessments.gov.au/dataset/93f99710-e84a-41c0-9c4f-4da9712c3263.

2.5.2 Water balances

Summary

Hydrological changes due to coal mining in the Hunter subregion are summarised in the form of water balances. Separate summaries are provided for groundwater and surface water; however, the streamflow term in the surface water balances includes a contribution from the groundwater model.

The groundwater balance covers the entire groundwater modelling domain. The key water balance term for the mining impact is the mine pumping volume. The reported values are based on mean annual extraction rates over each 30-year period and were inputs to the simulations. Between 2013 and 2042, the increase in the median 30-year mean annual pumping rate due to the additional coal resource development was 8.5 GL/year, a 46% increase on the baseline rate of 18.6 GL/year. Between 2043 and 2072, all baseline developments had ceased, but there was a comparatively small change in the rate of pumping (i.e. 30-year mean of 1.1 GL/year) for the additional coal resource development. The modelled surface water – groundwater flux response to mine water pumping and hydraulic enhancement is a decreasing trend over the three 30-year periods. The additional coal resource development results in reductions of the median groundwater contribution to streamflow of 0.1 GL/year in the 2013 to 2042 period, 0.9 GL/year difference between 2043 and 2072 and 1.2 GL/year between 2073 and 2102. These are equivalent to reductions of 0.2%, 1.8% and 2.4% relative to the baseline fluxes. The trend reflects the lagged response of the surface water – groundwater flux to mine pumping.

The changes due to the additional coal resource development upstream of node 41 on the Goulburn River flows are reductions of 0.5 GL/year between 2013 and 2042 and 0.2 GL/year for the 2043 to 2072 and 2073 to 2102 periods. At node 6 on the Hunter River, the median reductions in mean annual streamflow due to the additional coal resource development are 10.3 GL/year (2013–2042), 7.3 GL/year (2043–2072) and 4.5 GL/year (2073–2102). Surface water changes are correlated with mine footprint area, which reaches a maximum between 2013 and 2042. Following the cessation of mining, the lagged groundwater response to mining and the gradual rehabilitation of open-cut mines and enduring impacts on surface runoff from final voids and above longwall mines, mean the impacts on streamflow of coal resource development are sustained beyond the life of the mines. In the Goulburn River, the changes to streamflow due to the additional coal resource development are 1.0% to 0.4% of the baseline streamflow; in the Hunter River at Singleton, it varies from 2.4% to 1.1% of baseline streamflow over the reporting periods.

2.5.2.1 Groundwater balance for the groundwater modelling domain

Groundwater balances for the Hunter subregion modelling domain (Figure 5) are provided in Table 3 for 2013 to 2042, 2043 to 2072 and 2073 to 2102. Water balance terms represent the mean annual volume in GL/year for each 30-year period across the entire groundwater modelling domain, an area of 34,000 km^2. The median, 10th and 90th percentile values for each variable of the baseline and coal resource development pathway (CRDP) set of simulations are reported, whereas the difference reflects the change attributable to the additional coal resource development, obtained from subtracting the median baseline value from the median CRDP value. Figure 5 summarises the difference in the median values of each groundwater balance variable for the three 30-year periods.

The dominant water balance terms are recharge and evapotranspiration. The recharge term in the baseline and CRDP simulations varies across the three periods due to changes in rainfall and evapotranspiration from the increases in temperature assumed in the modelling to reflect global warming (see submethodology M06 for surface water modelling (Viney, 2016)). However, the difference between the baseline and CRDP recharge in each 30-year period is predicted to be zero because the groundwater model does not account for changes in recharge that might arise as a result of mine subsidence or excavation of open-cut pits.

Evapotranspiration, on the other hand, is influenced by not just atmospheric conditions, but also the position of the watertable relative to the evapotranspiration extinction depth (a parameter in the model which approximates the maximum rooting depth below which vegetation and atmospheric processes cannot extract water). Since the hydrological change due to the additional coal resource development is through pumping-induced drawdown of the watertable around the mining operations, there is a difference between the CRDP and baseline simulations in each of the 30-year periods, which reflects changes in the area of watertable above the evapotranspiration extinction depth. While, intuitively, one might expect increasing drawdown to increase the area of watertable below the evapotranspiration extinction depth, model results indicate small increases in evapotranspiration under the CRDP. This is because the modelled redistribution of the watertable reflects the combined effects of hydraulic enhancement and landscape position and, as illustrated in Section 2.6.2.7 of companion product 2.6.2 for the Hunter subregion (Herron et al., 2018b), can lead to localised areas of higher watertable. It must be noted that these increases in the median 30-year mean annual evapotranspiration range from 0.5 to 2.1 GL/year, less than a 1% increase in all periods and much smaller than the difference in the 10th and 90th percentiles for the baseline for all periods.

Table 3 Groundwater balance for Hunter subregion groundwater model domain for 2013 to 2042, 2043 to 2072 and 2073 to 2102

Water balance term	Period	Under the baseline (GL/y)	Under the coal resource development pathway (GL/y)	Difference (GL/y)
Recharge (Re)	2013 to 2042	362.7 (233.8; 527.0)	362.7 (233.8; 527.0)	0
	2043 to 2072	354.0 (228.2; 514.4)	354.0 (228.2; 514.4)	0
	2073 to 2102	347.1 (223.8; 504.3)	347.1 (223.8; 504.3)	0
Evapotranspiration (ET)	2013 to 2042	277.2 (177.2; 435.0)	279.3 (178.6; 434.0)	2.1
	2043 to 2072	272.6 (174.3; 425.9)	273.1 (173.6; 425.4)	0.5
	2073 to 2102	267.1 (171.0; 417.2)	268.9 (171.7; 417.7)	1.8
Licensed extractions (non-mining uses) (Ex_L)	2013 to 2042	35.8 (35.3; 35.8)	35.8 (35.3; 35.8)	0
	2043 to 2072	35.7 (35.2; 35.8)	35.7 (35.1; 35.8)	0
	2073 to 2102	35.6 (35.0; 35.7)	35.6 (35.0; 35.7)	0
Mine pumping (Ex_M)	2013 to 2042	18.6 (9.8; 24.6)	27.1 (14.2; 35.6)	8.5
	2043 to 2072	0.0 (0.0; 0.0)	1.1 (0.6; 1.5)	1.1
	2073 to 2102	0.0 (0.0; 0.0)	0.0 (0.0; 0.0)	0
Surface water – groundwater flux (Q_{bf})	2013 to 2042	50.6 (16.4; 79.9)	50.5 (15.3; 80.8)	–0.1
	2043 to 2072	50.6 (15.6; 80.9)	49.7 (14.0; 79.6)	–0.9
	2073 to 2102	50.2 (14.8; 79.1)	49.0 (13.5; 78.0)	–1.2
Boundary flow (B)	2013 to 2042	–4.8 (–11.8; 1.4)	–5.4 (–12.3; 1.5)	–0.6
	2043 to 2072	0.6 (–6.6; 5.3)	0.8 (–6.4; 5.6)	0.2
	2073 to 2102	0.3 (–7.0; 5.0)	0.5 (–6.9; 5.3)	0.2
Change in storage (ΔS)	2013 to 2042	–14.7 (–49.7; 6.9)	–24.6 (–60.7; 2.7)	–9.9
	2043 to 2072	–5.5 (–33.5; 9.7)	–6.4 (–33.5; 11.3)	–0.9
	2073 to 2102	–6.1 (–32.7; 10.0)	–6.9 (–32.4; 10.5)	–0.8

Groundwater balance equation: Re = ET + ExL + ExM +Qbf + B + ΔS
The first number is the median, and the 10th and 90th percentile numbers follow in brackets. The difference is between the two median values. Numbers are rounded to one decimal place.
Data: Bioregional Assessment Programme (Dataset 1)

The key water balance term for the mining impact is the mine pumping volume. The reported values are based on the 30-year annual mean extraction rates, which were inputs to the simulations. Between 2013 and 2042, the difference in the median 30-year mean annual pumping rates under the baseline and CRDP was 8.5 GL/year, a 46% increase on the baseline rate of 18.6 GL/year. Between 2043 and 2072, all baseline developments had ceased, thus the comparatively small change in the rate of pumping (1.1 GL/year) was due to the additional coal resource development. In the third period, no mining operations were occurring in the model simulations and there is no difference between the inputs to the baseline and CRDP simulations. The range of values, as represented by the 10th and 90th percentiles, reflects the modelled range using multipliers between 0.5 and 1.5 of the pumping estimates from mine environmental assessment reports (see Section 2.1.6 of companion product 2.1-2.2 for the Hunter subregion (Herron et al., 2018a)).

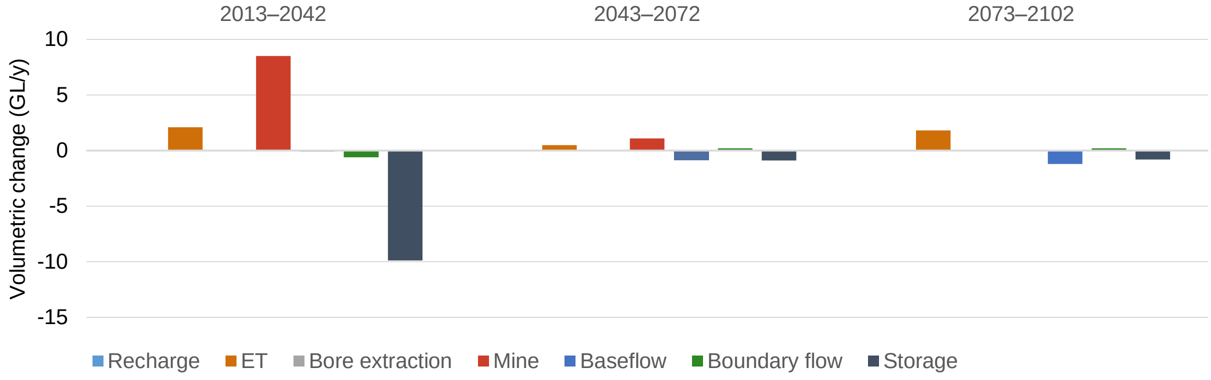

Figure 5 Change in the median value of each groundwater balance term due to the additional coal resource development

ET = evapotranspiration
Data: Bioregional Assessment Programme (Dataset 1)

Licensed extractions (under NSW's *Water Management Act 2000*) for non-mining uses, such as irrigation, stock and domestic, town water supply and industrial uses, were modelled in the groundwater model. It was assumed that extractions were the same under the baseline and CRDP (i.e. changes in mine water use under the CRDP do not affect water use by other licence holders). It was assumed that rates of extraction were at the maximum level permitted under each licence and that there was no increase in licensed entitlements into the future. Thus the non-mining groundwater extractions do not differ between baseline and CRDP in any of the 30-year periods.

Changes in other groundwater balance terms, caused by mine pumping and hydraulic enhancement, are reflected predominantly in the surface water – groundwater flux. This is the net volume of water exchanged between the regional aquifer and the river, calculated as the difference between groundwater flow to the river (i.e. baseflow) and leakage from the river to groundwater. In all three 30-year periods, the median of the 30-year mean annual surface water – groundwater flux under the CRDP is smaller than under baseline, indicating a reduction in baseflow in the river with more intensive coal resource development. Across the range (10th to 90th percentile) of modelled runs, this flux varies from about 30% to 160% of the median, which reflects the variation in modelled pumping rate, as well as the influence of varying hydraulic parameters and depth of the river in the model. The difference in medians attributable to the additional coal resource development varies from a decrease of 0.1 GL/year in the 30-year mean annual surface water – groundwater flux for the 2013 to 2042 period to a 0.9 GL/year decrease for the 2043 to 2072 period to a 1.2 GL/year decrease in the 2073 to 2102 period. This trend of an increasing impact over the three 30-year periods reflects a lagged response to mine pumping, which is at its maximum in the first 30-year period. In percentage terms, the reduction in groundwater flow to the river due to the additional coal resource development represents 0.2%, 1.8% and 2.4% of the groundwater flow to the river under the baseline for the three periods.

The boundary flow represents the net flux at the general head boundaries of the modelling domain. These boundaries were selected so that they have no impact on the predictions. The differences in boundary flows between the baseline and CRDP are much smaller than the difference in the 10th and 90th percentiles of the baseline indicating that the assumptions about these boundaries are valid. These boundary fluxes might be of concern if the volumes were large, but the volumes are small and therefore largely inconsequential in terms of quantifying the changes on the water balance due to the additional coal resource development.

The change in storage term is typically a balancing term in a water balance, and for a system in equilibrium should be on average zero. In the 2013 to 2042 period, both the baseline and CRDP show decreases in stored water due to pumping of mine water. The difference in stored water between the baseline and CRDP is significant, with almost 10 GL/year (67%) less stored water under the CRDP relative to the baseline. This largely reflects the greater losses from mine pumping under the CRDP. Once groundwater pumping ceases, the changes in storage under the CRDP and baseline are smaller, as is the difference between them.

2.5.2.2 Surface water balances for the Hunter subregion

Surface water balances are provided for two subdomains of the Australian Water Resources Assessment river (AWRA-R) modelling area (Figure 4).

Rainfall was not varied as part of the uncertainty analysis, so only a single rainfall volume is provided for the water balance for each 30-year period. The decreasing mean annual rainfall input over the three 30-year periods reflects the global warming changes assumed in the modelling (see submethodology M06 surface water modelling (Viney, 2016)). In the Hunter subregion, this assumes three seasons with rainfall reductions, with rainfall increases in the summer months (December to February) only.

The streamflow term in the surface water balances includes the surface water – groundwater flux component from the groundwater model. As stated in Section 2.5.1, water balances are reported separately for surface water and groundwater modelling, as they apply to different areas.

These water balances do not account for water that recharges groundwater but is not discharged to the stream. The residual is a balancing term that comprises evapotranspiration, change in storage and leakage from the river.

2.5.2.2.1 Goulburn River subdomain at node 41

Surface water balances at node 41 on the Goulburn River (corresponding to stream gauge 210006 at Kerrabee) are provided in Table 4 for 2013 to 2042, 2043 to 2072 and 2073 to 2102. The contributing area to node 41 is just over 3400 km^2 and includes the additional coal resource developments: Bylong open-cut and underground, Moolarben open-cut and underground, Ulan West underground and Wilpinjong open-cut. The median, 10th and 90th percentile values for each variable of the baseline and CRDP set of simulations are reported. The difference reflects the change attributable to the additional coal resource development, obtained from subtracting the median baseline value from the median CRDP value.

Mine discharges and extractions from the river for economic use were not modelled in the Goulburn River. Extractions from the Goulburn River are low compared to the Hunter Regulated River (see Section 2.5.2.2.2) and would have been modelled the same for the baseline and CRDP, so were not actively pursued. While mine discharges would be expected to change under the CRDP, suitable data were not obtained from which to develop rules for representing discharge behaviour in the model. Furthermore, mining reports indicated that:

- anticipated increases in mine discharge from Ulan West would be to the Talbragar River outside the subregion (Umwelt, 2008)
- Moolarben mine would experience a water deficit for most of its Stage 2 development and not be discharging water to streams; and that it would need to source water from Ulan and Wilpinjong mines to meet demand, thereby reducing discharges to streams from those mines also (Wells Environmental Services and Coffey Natural Systems, 2009)
- the proposed Bylong mine aims to be a nil discharge site (Worley and Parsons, 2016).

Thus mine discharges to the Goulburn River system from additional coal resource development were considered likely to be small.

Table 4 Surface water balance for 2013 to 2042, 2043 to 2072 and 2073 to 2102 at node 41 (Goulburn River)

Water balance term	Period	Under the baseline (GL/y)	Under the coal resource development pathway (GL/y)	Difference (GL/y)
Rainfall (P)	2013 to 2042	2301.9	2301.9	0.0
	2043 to 2072	2287.7	2287.7	0.0
	2073 to 2102	2273.4	2273.4	0.0
Streamflow (Q)	2013 to 2042	50.6 (34.5; 68.5)	50.1 (34.2; 68.1)	–0.5
	2043 to 2072	49.7 (33.6; 67.3)	49.5 (33.4; 67.1)	–0.2
	2073 to 2102	48.2 (32.3; 65.4)	48.0 (32.2; 65.3)	–0.2
Mine discharge (M)	2013 to 2042	NM	NM	NM
	2043 to 2072	NM	NM	NM
	2073 to 2102	NM	NM	NM
Extraction (Ex)	2013 to 2042	NM	NM	NM
	2043 to 2072	NM	NM	NM
	2073 to 2102	NM	NM	NM
Residuals (Res)	2013 to 2042	2251.3 (2233.5; 2267.4)	2251.8 (2233.8; 2267.8)	0.5
	2043 to 2072	2237.9 (2220.4; 2254.0)	2238.2 (2220.6; 2254.3)	0.2
	2073 to 2102	2225.2 (2208.0; 2241.1)	2225.4 (2208.1; 241.2)	0.2

Surface water balance equation: P + M = Q + Ex + Res
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. Numbers are rounded to one decimal place. NM = data not modelled
Data: Bioregional Assessment Programme (Dataset 2)

In all three 30-year periods, the additional coal resource development results in reductions in median streamflow relative to baseline. The biggest impact is registered in the 2013 to 2042 period with a 0.5 GL/year reduction averaged over the 30 years, equivalent to a 1.0% decrease from the median baseline streamflow. This is the main period of mining, during which the maximum mining footprint occurs, relatively limited rehabilitation of open-cut sites is assumed to have occurred and reductions in surface runoff are greatest. By 2072, rehabilitation of open-cut mine sites to just a final void is assumed to have been completed. The difference in the median streamflow reduces to 0.2 GL/year (~0.4% of baseline) in the 2043 to 2072 and 2073 to 2102 periods, reflecting the cessation of mining and gradual rehabilitation of much of the open-cut mine areas.

The persistence of small differences in the median streamflow in the 2073 to 2102 period likely reflects the impacts on the surface water – groundwater flux from drawdowns still propagating through the system from the mine sites, and the fact that in the surface water modelling the reduction in runoff above longwall mines is assumed to be enduring and that open-cut mines generally leave final voids. Thus surface runoff response does not return to a pre-disturbance condition.

Even though coal extraction and pumping of mine water are assumed to have finished by 2044, the impacts of groundwater drawdown on surface water – groundwater fluxes continue to work their way through the system over the subsequent two 30-year periods. Table 3 show the reductions in the median 30-year mean surface water – groundwater flux due to the additional coal resource development across the entire groundwater modelling domain increase from 0.1 GL/year in the 2013 to 2042 period to 0.9 GL/year in the 2043 to 2072 period to 1.2 GL/year in the 2073 to 2102 period.

2.5.2.2.2 Hunter River subdomain at node 6

Surface water balances at node 6 on the Hunter River (corresponding to stream gauge 210001 at Singleton) are provided in Table 5 for 2013 to 2042, 2043 to 2072 and 2073 to 2102. The contributing area to node 6 is about 16,485 km^2 and includes, in addition to the additional coal resource developments in the contributing area to node 41 (Section 2.5.2.2.1), the open-cut mines at Ashton, Bengalla, Bulga, Drayton South, Liddell, Mount Arthur, Mount Owen, Mount Pleasant and Mount Thorley-Warkworth; and underground mines at Mount Arthur and Wambo. The median, 10th and 90th percentile values for each variable of the baseline and CRDP set of simulations are reported. The difference reflects the change attributable to the additional coal resource development, obtained from subtracting the baseline value from the CRDP value.

Table 5 Surface water balance for 2013 to 2042, 2043 to 2072 and 2073 to 2102 at node 6 (Hunter River)

Water balance term	Period	Under the baseline (GL/y)	Under the coal resource development pathway (GL/y)	Difference (GL/y)
Rainfall (P)	2013 to 2042	12,059.4	12,059.4	0.0
	2043 to 2072	11,991.8	11,991.8	0.0
	2073 to 2102	11,924.1	11,924.1	0.0
Streamflow (Q)	2013 to 2042	424.5 (318.8; 526.7)	414.2 (311.4; 515.1)	–10.3
	2043 to 2072	421.6 (315.6; 524.8)	414.3 (310.9; 517.1)	–7.3
	2073 to 2102	411.5 (308.8; 515.6)	407.0 (305.6; 509.6)	–4.5
Mine discharge (M)	2013 to 2042	1.3 (1.0; 1.7)	1.3 (1.0; 1.6)	0.0
	2043 to 2072	1.3 (1.0; 1.6)	1.3 (1.0; 1.6)	0.0
	2073 to 2102	1.3 (1.0; 1.6)	1.3 (1.0; 1.6)	0.0
Extraction (Ex)	2013 to 2042	118.2 (94.6; 127.0)	118.2 (94.6; 127.0)	0.0
	2043 to 2072	117.6 (91.2; 126.8)	117.6 (91.2; 126.8)	0.0
	2073 to 2102	115.6 (87.9; 126.5)	115.6 (87.9; 126.5)	0.0
Residuals (Res)	2013 to 2042	11,518.1 (11,407.4; 11,647.0)	11528.3 (11,419.0; 11,654.5)	10.3
	2043 to 2072	11,644.5 (11,439.5; 11,757.6)	11,649.2 (11,446.6; 11,760.6)	7.3
	2073 to 2102	11,398.4 (11,283.7; 11,528.5)	11,402.9 (11,289.6; 11,531.6)	4.5

Surface water balance equation: P + M = Q + Ex + Res
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. Numbers are rounded to one decimal place.
Data: Bioregional Assessment Programme (Dataset 2)

Mine discharges and extractions from the river for economic use were modelled in the Hunter Regulated River. The regulated river is the main source of water to meet the needs of electricity generators, irrigators, mining operations and town water supply along these reaches. Annual discharges by the mines can vary in the model based on flow regime, but the model results suggest the additional coal resource development is not causing a significant change in mine discharges. Extractions from the river also do not vary between the baseline and CRDP because the same management rules are assumed for both. However, the model predicts a decrease in extractions over the 90 years in response to a drying climate, corresponding to reductions in the average annual allocation over time.

The additional coal resource developments are predicted to cause reductions in streamflow at node 6 in all three periods relative to the baseline streamflow. The biggest reduction of 10.3 GL/year occurs in the 2013 to 2042 period and represents a reduction of 2.4% of the median baseline streamflow. The difference between CRDP and baseline decreases to 7.3 GL/year (a 1.7% reduction relative to the baseline) in the 2043 to 2072 period and to 4.5 GL/year (a 1.1% reduction relative to the baseline) between 2073 and 2102.

2.5.2.3 Gaps

The groundwater model was not constructed to permit the generation of sub-domain groundwater balances. The surface water modelling domain overlapped, but did not conform exactly to, the groundwater modelling domain. Generating a single, integrated water balance for the Hunter subregion or for subdomains of the subregion that draws on water balance terms from both models was not possible.

Mine discharges from additional coal resource development were not included in the river modelling. More information needs to be obtained about typical discharge volumes, discharge rules, and water sharing arrangements between Ulan, Moolarben and Wilpinjong mines to represent this in the model.

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Datasets

Dataset 1 Bioregional Assessment Programme (2016) HUN GW Balance v01. Bioregional Assessment Derived Dataset. Viewed 07 December 2016, http://data.bioregionalassessments.gov.au/dataset/7fff53a4-5761-44fb-b768-5c81594cef13.

Dataset 2 Bioregional Assessment Programme (2016) HUN SW Balance v01. Bioregional Assessment Derived Dataset. Viewed 07 December 2016, http://data.bioregionalassessments.gov.au/dataset/f287c125-5365-4568-b187-c987be0ba276.

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).

derived dataset: a dataset that has been created by the Bioregional Assessment Programme

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

diversion: see extraction

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

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

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

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

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

Hunter subregion: Along the coast, the Hunter subregion extends north from the northern edge of Broken Bay on the New South Wales Central Coast to just north of Newcastle. The subregion is bordered in the west and north–west by the Great Dividing Range and in the north by the towns of Scone and Muswellbrook. The Hunter River is the major river in the subregion, rising in the Barrington Tops and Liverpool Ranges and draining south-west to Lake Glenbawn before heading east where it enters the Tasman Sea at Newcastle. The subregion also includes smaller catchments along the central coast, including the Macquarie and Tuggerah lakes catchments.

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

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

recharge: see groundwater recharge

risk: the effect of uncertainty on objectives

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

source dataset: a pre-existing dataset sourced from outside the Bioregional Assessment Programme (including from Programme partner organisations) or a dataset created by the Programme based on analyses conducted by the Programme for use in the bioregional assessments (BAs)

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

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

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

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 use: the volume of water diverted from a stream, extracted from groundwater, or transferred to another area for use. It is not representative of 'on-farm' or 'town' use; rather it represents the volume taken from the environment.

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

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