Australian Government

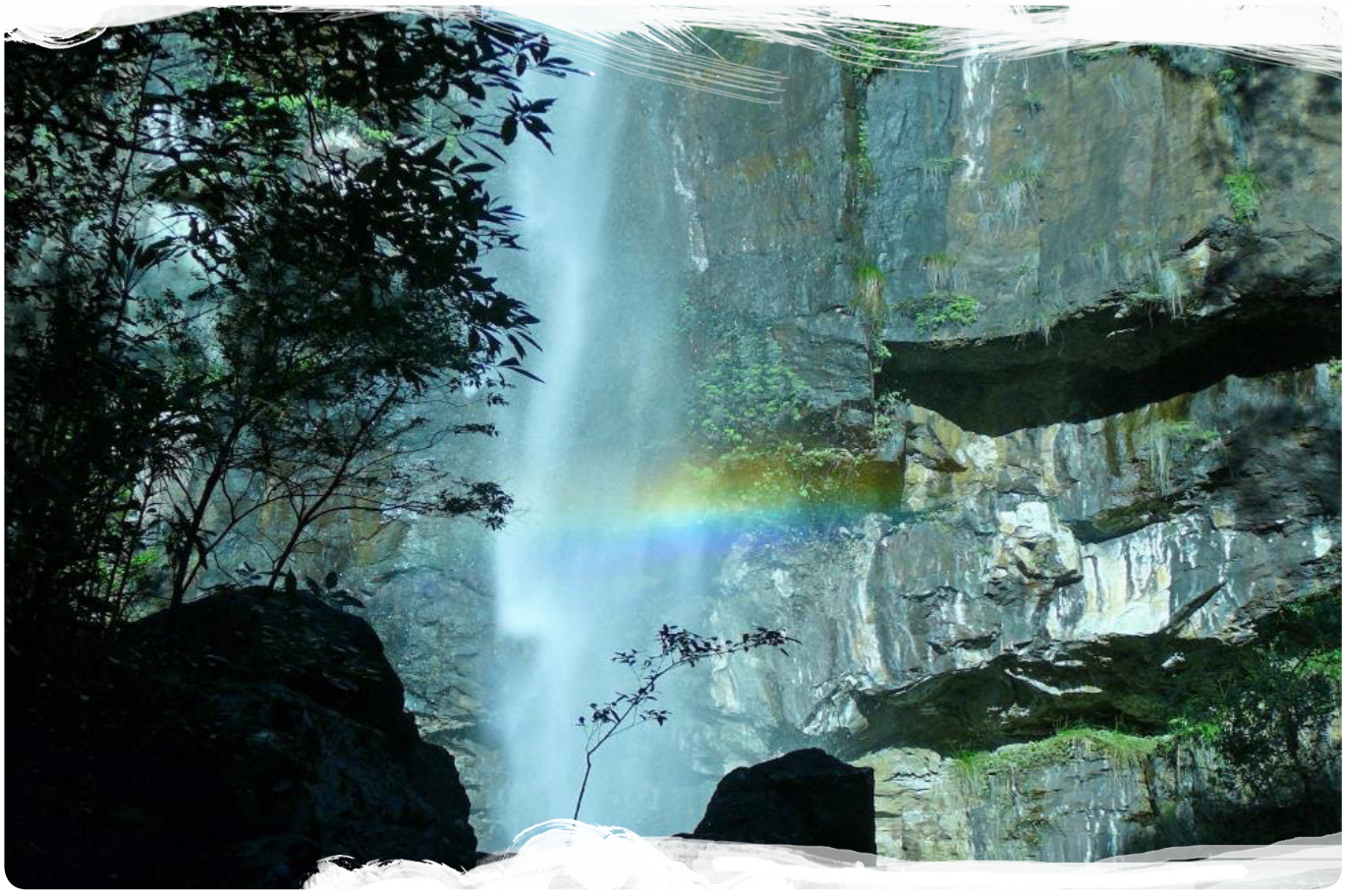
BIOREGIONAL ASSESSMENTS

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

Assessing impacts of coal resource development on water resources in the Clarence-Moreton bioregion: key findings

Product 5: Outcome synthesis from the Clarence-Moreton Bioregional Assessment

26 June 2017



A scientific collaboration between the Department of the Environment and Energy, Bureau of Meteorology, CSIRO and Geoscience Australia

Explore this assessment

Bioregional assessments are independent scientific assessments of the potential cumulative impacts of coal seam gas (CSG) and coal mining developments on water resources and water-dependent assets such as rivers, wetlands and groundwater systems. These regional-scale assessments focus on 13 areas across Queensland, NSW, Victoria and SA where coal resource development is taking place, or could take place.

The assessments identify areas where water resources and water-dependent assets are *very unlikely* to be impacted (with a less than 5% chance), or are potentially impacted. Governments, industry and the community can then focus on areas that are potentially impacted when making regulatory, water management and planning decisions.

This assessment investigates:

- the characteristics of the bioregion, including water resources, assets, and coal and CSG resources (Component 1)
- how future coal resource development could affect surface water and groundwater (Component 2).

The Clarence-Moreton Bioregional Assessment comprises 10 technical products (Box 1), which are summarised in this synthesis. They include: contextual information (Component 1) and model-data analysis (Component 2). Impact and risk analysis (Component 3 and Component 4) was not conducted as hydrological changes were minimal. In addition, the West Casino Gas Project (the only new proposal), referred to as the additional coal resource development, did not proceed. However, the methods and models developed allow future assessments to be undertaken.

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

FIND MORE INFORMATION

www.bioregionalassessments.gov.au includes all technical products as well as information about all datasets used or created, most of which can be downloaded from data.gov.au. Additional resources are cross-referenced in this synthesis, and include methodologies, maps, models and lists of water-dependent assets, landscape classes and potential hazards. References, further reading and datasets are listed at the end of this synthesis.

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CITATION

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COVER PHOTOGRAPH

Rainforest waterfall in Border Ranges National Park, NSW, 2008.
Credit: Liese Coulter, CSIRO

Box 1 Technical products for the Clarence-Moreton bioregion

Component 1: Contextual information

1.1 Context statement
1.2 Coal and coal seam gas resource assessment
1.3 Description of the water-dependent asset register
1.5 Current water accounts and water quality
1.6 Data register

Component 2: Model-data analysis

2.1-2.2 Observations analysis, statistical analysis and interpolation
2.3 Conceptual modelling
2.5 Water balance assessment
2.6.1 Surface water numerical modelling
2.6.2 Groundwater numerical modelling

The pages of this synthesis follow this colour guide when describing the assessment outputs. Product 2.7 (receptor impact modelling) and product 3-4 (impact and risk analysis) were not produced for this bioregion. Product 1.4 (receptor register) and product 2.4 (two-and three-dimensional visualisations) were not produced for any bioregional assessment as evolution of the methods rendered them obsolete.

Box 2 Investigating two futures

Results are reported for two potential futures:

- **baseline coal resource development (baseline):** a future that includes all coal mines and CSG fields that are commercially producing as of December 2012
- **coal resource development pathway (CRDP):** a future that includes all coal mines and CSG fields that are in the baseline as well as the **additional coal resource development** (those developments that were 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 **additional coal resource development**.

The CRDP for the Clarence-Moreton bioregion was based on information available as of July 2015. However, coal resource developments may change over time or be withdrawn, or timing of developments may change. Factors such as climate change or land use were held constant between the two futures. Although actual climate or land use may differ, the effect on results is expected to be negligible as the assessment focused on the difference in the results between the CRDP and baseline.

Executive summary

About the bioregion *see p. 2*

This synthesis presents the key findings from the bioregional assessment of the Clarence-Moreton bioregion.

The Clarence-Moreton bioregion covers 24,292 square kilometres (km^2), including the towns of Casino, Lismore and Grafton in northern NSW, and Gatton in south-east Queensland (Figure 1). Land is predominantly used for dryland farming and plantations, and as grazing land for livestock. The bioregion contains large river systems, national parks and forest reserves, and nationally significant wetlands.

The bioregion has one operating coal mine, Jeebropilly Mine, in the Bremer river basin near Ipswich in Queensland. Exploration and pilot production testing for coal seam gas (CSG) resources have mainly occurred near Casino in northern NSW.

Potential hydrological changes *see p. 8*

This assessment considered potential cumulative impacts of the existing Jeebropilly Mine and the proposed West Casino Gas Project in the Richmond river basin near Casino. The West Casino Gas Project had been proposed at the start of the Bioregional Assessment Programme; however, licences for the West Casino Gas Project were acquired and then cancelled by the NSW Government in December 2015. The potential for commercial production of CSG resources is very limited in the Queensland portion of the bioregion within the foreseeable future, and no other coal mining development was identified in the bioregion.

The assessment investigated potential hydrological changes in groundwater and surface water due to coal resource development for two futures (Box 2). The **baseline** future includes the Jeebropilly Mine. The **coal resource development pathway** (CRDP) future includes the baseline coal resource development and one **additional coal resource development,** the West Casino Gas Project. Analysis of a three-dimensional geological model (see p. 4) indicated that the West Casino Gas Project is hydrologically disconnected from the Jeebropilly Mine by a geological basement ridge that forms a natural barrier separating the groundwater and surface water systems in the Richmond river basin from those of the Bremer river basin. There is no hydrological influence from the baseline Jeebropilly Mine on the West Casino Gas Project, and hence no potential for cumulative impacts. Because of this, and because the assessment focused on potential impacts due to additional coal resource development (Box 2), only the West Casino Gas Project was modelled. Hydrological modelling predicted that potential changes to surface water and shallow groundwater due to the proposed West Casino Gas Project are minimal.

The surface exposures of the Lamington and Main Range volcanics are the bioregion's major areas of groundwater recharge. Recharge from the volcanics to the near-surface aquifers would dwarf any potential drawdown (Box 4) due to additional coal resource development, thus minimising potential impacts.

The assessment found that the **zone of potential hydrological change** (Box 3) covers an area of 249 square kilometres (km^2) and extends no more than 10 km west of the West Casino Gas Project (Figure 5). Outside this zone, hydrological changes (and hence impacts) are *very unlikely* (less than 5% chance). Within this zone, the maximum chance of exceeding the 0.2 metre (m) drawdown threshold due to additional coal resource development is estimated at 36% (Box 5). It is *very likely* (95% chance) that the drawdown is less than 1 m anywhere in the near-surface aquifer.

In the Richmond river basin, impacts on annual streamflow due to additional coal resource development are *very likely* to be minimal for all but the very lowest streamflows.

Multiple regionally extensive aquitards (which share boundaries) directly overlie the Walloon Coal Measures (the main coal-bearing resource in the bioregion) in the area of the West Casino Gas Project. The very low permeability of these aquitards, and their combined thickness of over several hundred metres, impedes almost all of the hydrological effects of coal seam depressurisation from reaching the surface.

Impact and risk analysis was not undertaken in this assessment because the projected hydrological changes from the West Casino Gas Project at the surface are very small.

About the bioregion

The Clarence-Moreton bioregion spans north-east NSW and south-east Queensland, covering an area of about 24,292 km^2, about 9,500 km^2 of which is in Queensland (Figure 1). In NSW it contains much of the Clarence and Richmond river basins, while in south-east Queensland it covers the mid and upper parts of the Logan-Albert river basin, Bremer river basin, Lockyer Valley, and parts of the Brisbane river basin. It contains nationally important wetlands, numerous national parks and forest reserves, and sites of international importance for bird conservation. It includes potential habitat for 432 threatened species under Queensland, NSW and Commonwealth legislation.

The outcrop area of the aquifers of the Lamington and Main Range volcanics is the major groundwater recharge area within the Clarence-Moreton bioregion, particularly in the Richmond river basin where most of the surface water runoff is generated. Recharge rates to these aquifers are at least ten times higher than recharge rates to sedimentary bedrock units such as the Walloon Coal Measures.

The bioregion's main natural and human-modified ecosystems were categorised in a landscape classification that was based on the physical features of the region, including its geology; hydrogeology, which describes the way water moves underground; land use; and ecology (see p. 12 for more information).

Coal resource development

Key finding 1: The main coal-bearing resource within the bioregion, the Walloon Coal Measures, supports one operational coal mine, Jeebropilly Mine in Queensland, which is in the baseline (Box 2 and Figure 1). The additional coal resource development mapped for this assessment is the West Casino Gas Project in northern NSW, which is no longer proceeding. The potential for commercial production of CSG resources is very limited in the Queensland portion of the bioregion within the foreseeable future, and no other coal mining development was identified in the bioregion.

The West Casino Gas Project was identified as the only additional coal resource development for the assessment. It was an exploration and pilot production CSG development in the Richmond river basin, with plans to later progress to a commercially producing gas field. The proposed project was located in this area due to the presence of coal seams with high gas saturations and permeabilities within the Walloon Coal Measures. These coal seams are located along the western side of the Casino Trough at depths as shallow as 250 m. This assessment assumed that the West Casino Gas Project would begin commercial CSG production in 2018, extracting gas for 20 years from around 90 production wells, each with two lateral extensions into the productive coal seam.

The NSW Government began negotiations with the West Casino Gas Project proponent, Metgasco, in mid-2015 as part of the state-wide buy-back program for petroleum exploration licences. In late 2015, Metgasco shareholders approved the negotiated agreement, which involved NSW acquiring (and subsequently cancelling) Metgasco's three petroleum exploration licences near Casino, withdrawing their petroleum production licence application, and resolving all outstanding legal disputes. Consequently, Metgasco did not proceed with the West Casino Gas Project. This decision was made, however, after the CRDP was agreed for this bioregional assessment, and therefore the West Casino Gas Project was included as the only additional coal resource development.

FIND MORE INFORMATION

Context statement, product 1.1 (Rassam et al., 2014)

Coal and coal seam gas resource assessment, product 1.2 (Raiber et al., 2014)

Description of the water-dependent asset register, product 1.3 (Murray et al., 2015a)

Conceptual modelling, product 2.3 (Raiber et al., 2016b)

Compiling water-dependent assets, submethodology M02 (Mount et al., 2015)

Developing a coal resource development pathway, submethodology M04 (Lewis, 2014)

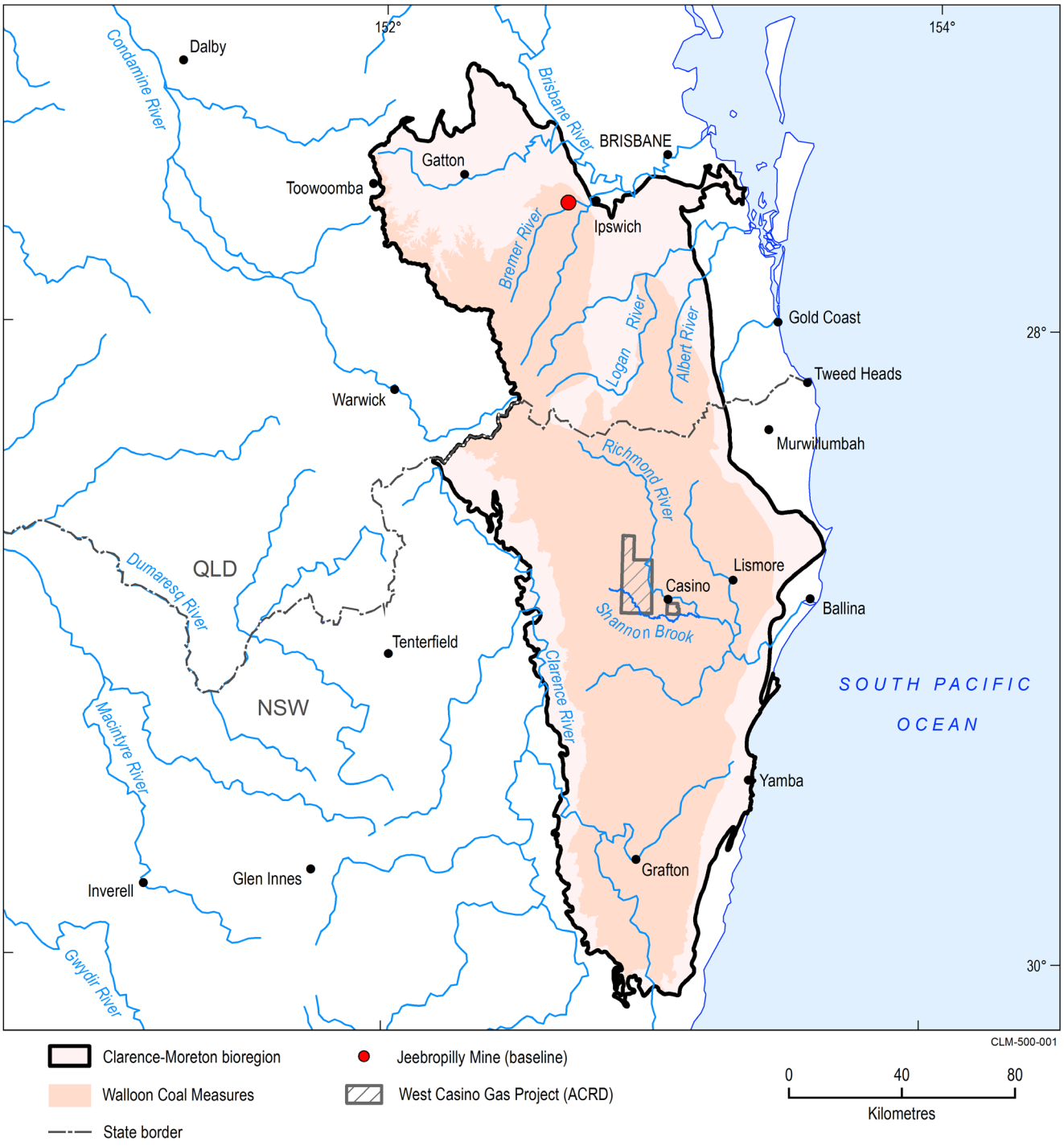

Figure 1 Clarence-Moreton bioregion

The Jeebropilly Mine in the Bremer river basin was commercially producing in December 2012 and thus is in the baseline, while the West Casino Gas Project in the Richmond river basin was expected to begin commercial production after December 2012 and thus is the only additional coal resource development for the assessment. The coal resource development pathway includes both the baseline development and the additional coal resource development (ACRD). Shown here is the known extent of the Walloon Coal Measures within the bioregion, both exposed at surface and also buried at depth below younger rocks. Its outcrop area (at the surface) is much smaller.

Data: NSW Department of Trade and Investment (Dataset 1); Bioregional Assessment Programme (Dataset 2)

How does the bioregion's geology and hydrogeology influence water movement?

Key finding 2: The West Casino Gas Project is hydrologically disconnected from the Jeebropilly Mine by a geological basement ridge that forms a natural barrier separating the groundwater and surface water systems in the Richmond river basin in NSW from those of the Bremer river basin in Queensland.

Key finding 3: Groundwater flow from the Lamington and Main Range volcanics to near-surface (alluvial) aquifers and associated streams is much greater than any potential drawdown due to additional coal resource development, minimising potential impacts.

To enable accurate hydrological modelling of areas of potential change, a bioregion-wide three-dimensional geological model was developed for the assessment (Figure 2). The model provided an understanding of the bioregion's geology and hydrogeology to identify pathways between different parts of the hydrological cycle.

Analysis of the model demonstrated that a geological basement ridge forms a natural barrier separating the Richmond river basin in NSW and the Bremer river basin in Queensland. This means the West Casino Gas Project is hydrologically disconnected from the baseline Jeebropilly Mine. Because of this, and because the assessment focused on potential impacts due to additional coal resource development (Box 2), only the West Casino Gas Project was modelled.

The analysis based on the geological model also improved understanding of the geological structure and layers, helping to map the three-dimensional extent of the Walloon Coal Measures, the main target of CSG exploration in this bioregion, and other key aquifers such as the alluvium and Lamington Volcanics, as well as aquitards including the MacLean Sandstone, Bungawalbin Member and parts of the Grafton Formation (Figure 3). In addition, it highlighted the role of the outcropping Lamington Volcanics in NSW and Main Range Volcanics in Queensland as the main groundwater recharge areas in the bioregion. These aquifers are mostly less than 200 m thick but are locally up to 900 m thick near major extinct volcanoes. Due to its regional extent, considerable thickness and high recharge rates, the Lamington Volcanics form a major regional aquifer system with a very large storage volume, which sustains permanent or near-permanent flows in most major streams within the Richmond river basin.

The groundwater recharge assessment showed that within the Richmond river basin, groundwater recharge rates to the Lamington and Main Range volcanics are at least ten times higher than recharge rates to sedimentary bedrock units such as the Walloon Coal Measures. A large proportion of groundwater recharge to the Lamington Volcanics discharges locally with short transit times into the alluvium or streams, with only a small proportion percolating to deeper aquifers. This means that water in alluvia or streams associated with the Lamington Volcanics is generally fresh, whereas groundwater in the sedimentary bedrock is typically brackish or saline.

Conceptual uncertainties about the connectivity between deep and shallow aquifers in general, and the role of faults as potential pathways linking the Walloon Coal Measures to shallow aquifers and surface water features in the Richmond river basin, are further explained in 'How to use this assessment' on p. 13.

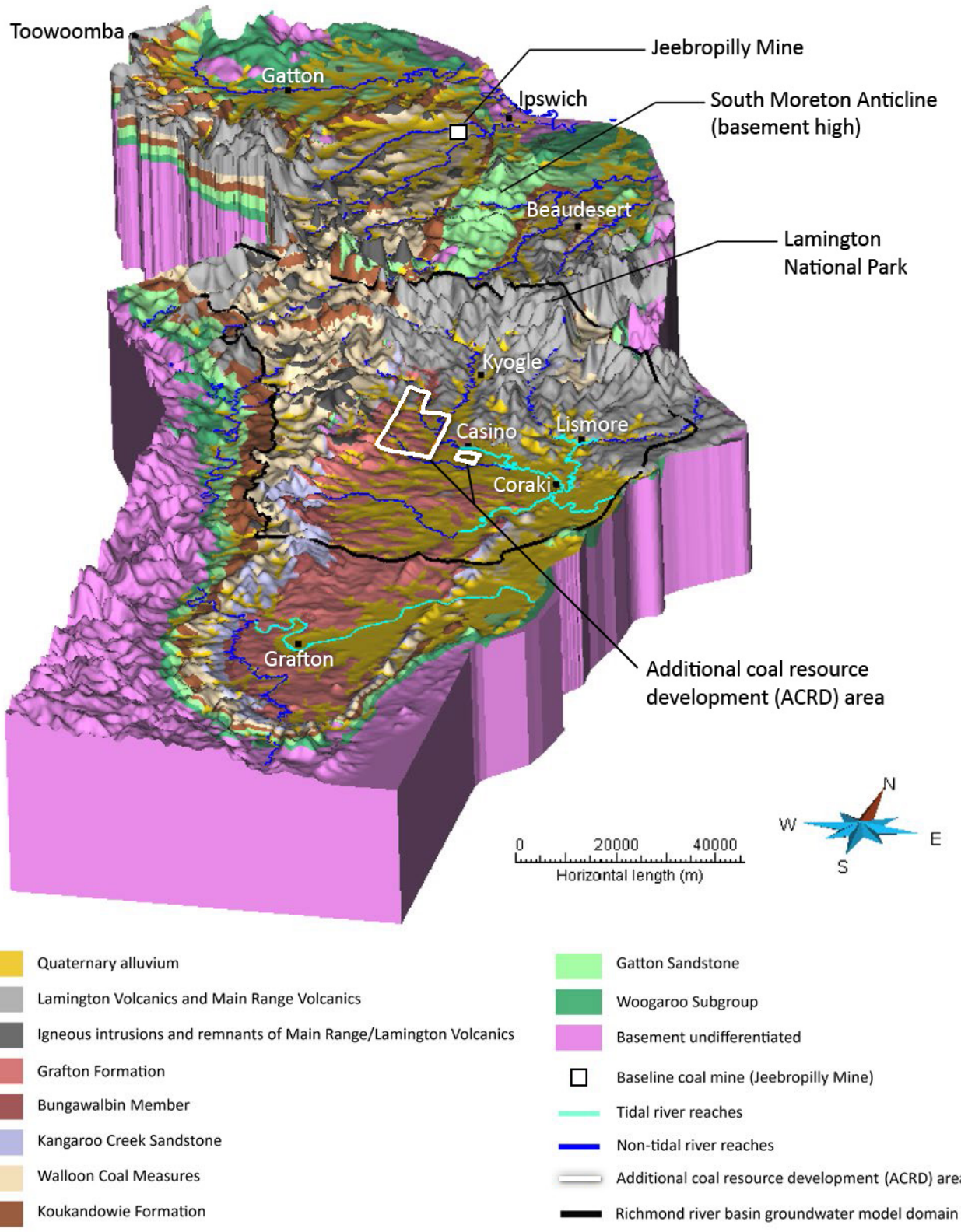

Figure 2 Three-dimensional geological model of the Clarence-Moreton bioregion viewed from the south-east, showing the distribution of the different types of aquifers (alluvial, volcanic and sedimentary bedrock)

The vertical extent is from –2500 to +1400 m Australian Height Datum (AHD). The north–south extent is 320 km; the maximum east–west extent is 140 km; and the vertical exaggeration is 10. Vertical exaggeration is the scale used in raised-relief maps to emphasise vertical features that might be too small to identify relative to the horizontal scale.

Data: Bioregional Assessment Programme (Dataset 2, Dataset 3, Dataset 4); NSW Department of Trade and Investment (Dataset 1)

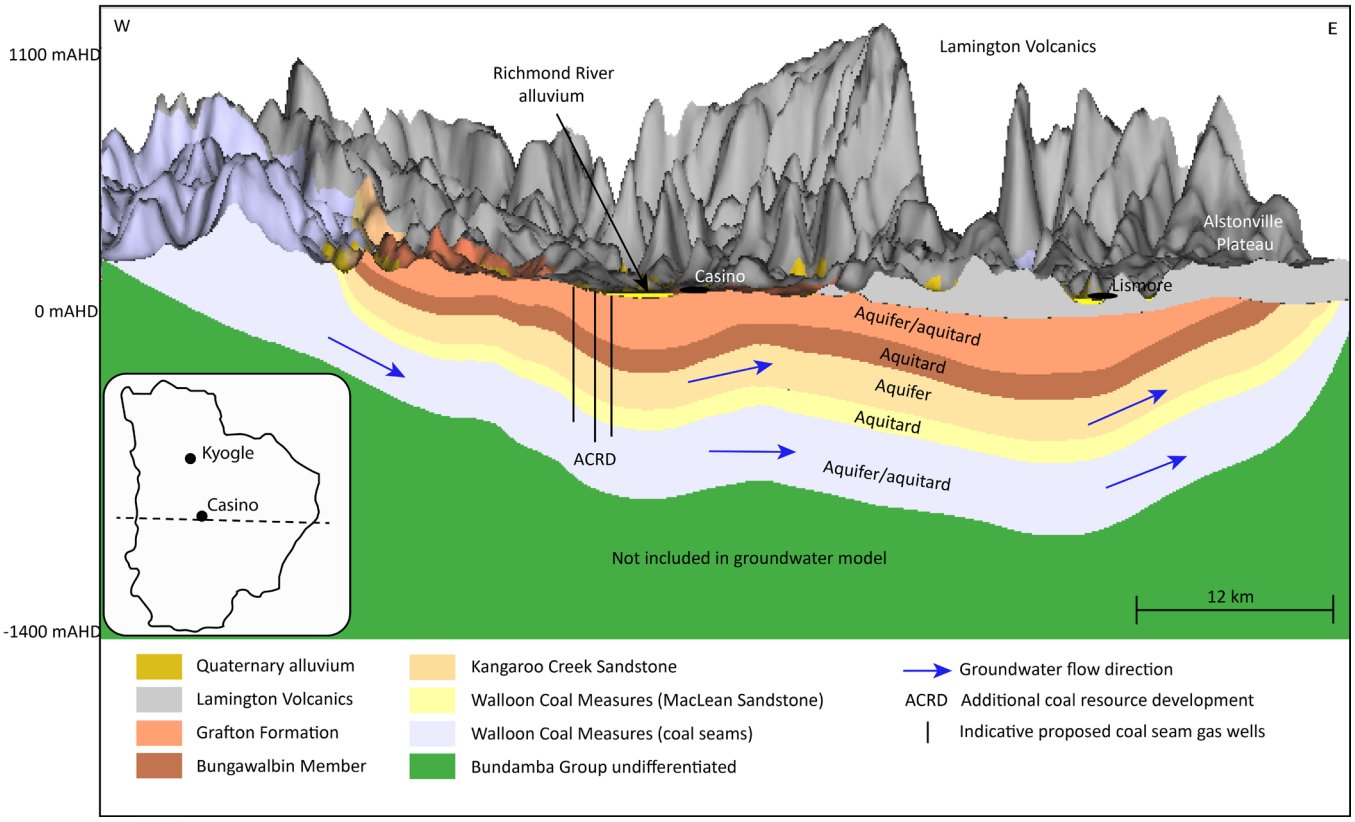

Figure 3 Simplified conceptual diagram of the cross-section through the central Richmond river basin, highlighting aquifer geometry and relative thicknesses of aquifers and aquitards

This cross-section is a stylised representation from the geological model, and has been vertically exaggerated (by a factor of 12, both above and below ground) in order to make it easier to distinguish the relationship between different geological units. The additional coal resource development (ACRD) only includes the West Casino Gas Project.
mAHD = metres above Australian Height Datum
Data: Bioregional Assessment Programme (Dataset 5)

FIND MORE INFORMATION

Observations analysis, statistical analysis and interpolation, product 2.1-2.2 (Raiber et al., 2016a)

Data used to develop the three-dimensional geological model (Dataset 4)

How could coal resource development result in hydrological changes?

Coal mine and CSG operations can induce changes in groundwater and surface water; such changes depend on varying factors such as hydraulic properties of the rocks and sediments near operations, and geological fracturing and faulting. This in turn can potentially reduce the quantity of water that would otherwise discharge to a stream, or may cause a drop in water level in a groundwater bore, which makes water extraction more difficult, or cause the bore to dry out (periodically or permanently).

The assessment identified the hazards associated with CSG operations that could potentially result in hydrological changes; this process provided a crucial underpinning to hydrological modelling. The chain of events that commonly arise from these hazards were subsequently analysed and categorised into four major causal pathway groups (Figure 4):

A. **'Subsurface depressurisation and dewatering'** includes extraction of groundwater to enable CSG production. It has the potential to directly affect the regional groundwater system, and indirectly affect surface water – groundwater interactions. Potential effects are in the medium term (5 to 10 years) to long term (10 to 100 years).

B. Changes to **'Subsurface physical flow paths'** might occur due to hydraulic fracturing of coal seams (fracking) or when wells drilled for groundwater or gas extraction leak. Potential effects are in the medium to long term and are probably restricted to aquifer or aquifer outcrop areas, but can also affect connected watercourses within and downstream of coal resource development.

C. Changes to **'Surface water drainage'** might occur when CSG operations alter surface water systems or cause the land surface to sink (subsidence). These changes have potential medium-term to long-term cumulative effects on watercourses within and downstream of coal resource development.

D. **'Operational water management'** involves storing, disposing, processing and using extracted water. Potential effects are in the medium to long term and include watercourses that are within and downstream of coal resource development.

Hazards and causal pathways associated with coal mining were not considered further because no coal mines were modelled. Hazards ruled out of the assessment include accidents and those managed by regulation or site-based risk management.

FIND MORE INFORMATION

Conceptual modelling, product 2.3 (Raiber et al., 2016b)

Developing the conceptual model for causal pathways, submethodology M05 (Henderson et al., 2016)

Systematic analysis of water-related hazards associated with coal resource development, submethodology M11 (Ford et al., 2016)

List of potential hazards (Dataset 6)

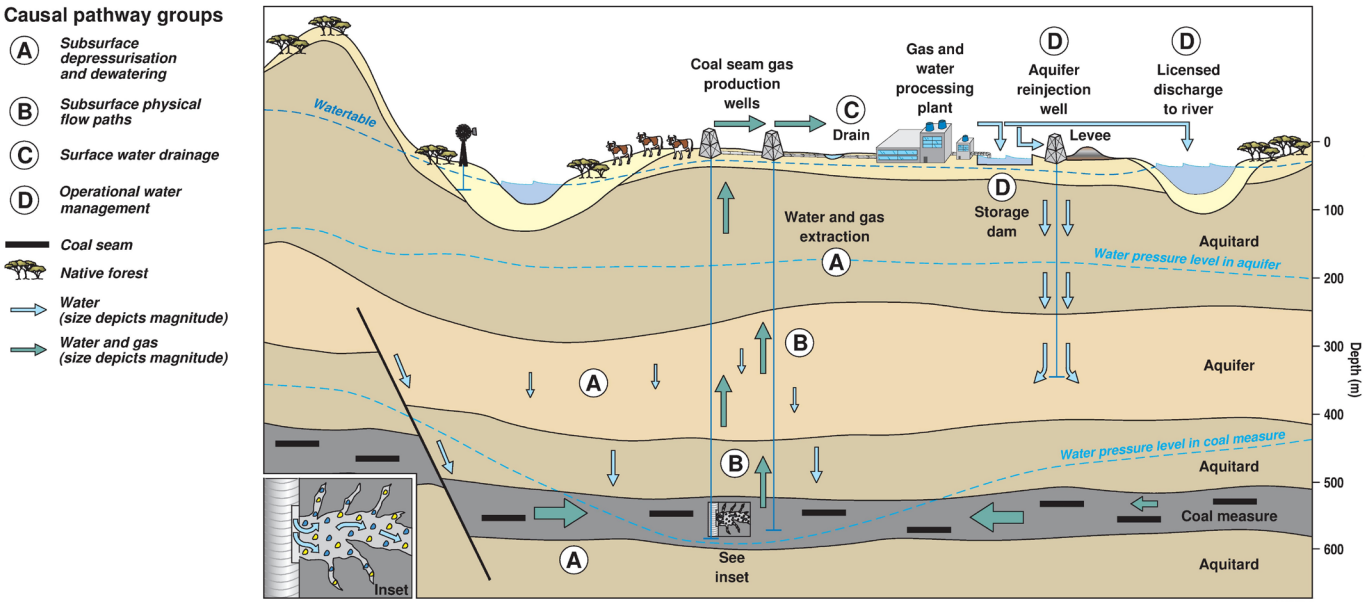

Figure 4 Conceptual diagram of the causal pathway groups associated with coal seam gas operations

This schematic diagram is not drawn to scale and is generic. In a hydrologically confined aquifer or coal measure, the water pressure level may rise above the top of the geological layer. Groundwater drawdown caused by coal seam gas extraction does not necessarily translate to changes in depth to the watertable (Box 4). The inset schematic shows hydraulic fracturing of a coal seam, where a mixture predominantly composed of water (blue) and sand (yellow), with minor amounts of chemical additives, is injected at high pressure into the well to produce small cracks in the coal (lighter grey zone). This process enhances the permeability of the coal seam, enabling larger volumes of gas and water to be subsequently pumped from the well.

What are the potential hydrological changes?

In the Clarence-Moreton bioregion, surface water and groundwater modelling was undertaken to investigate potential hydrological changes in the Richmond river basin due to additional coal resource development.
To represent changes in the near-surface aquifer from which most ecological assets source water, a **zone of potential hydrological change** (Box 3) was developed based on the groundwater modelling. This identifies the area where additional coal resource development may affect water-dependent landscapes and assets due to hydrological changes in the near-surface aquifer. Outside the zone, CSG development is *very unlikely* (less than 5% chance) to have any appreciable impact on hydrology, and therefore on water-dependent landscapes or assets.

Groundwater

Key finding 4: The zone of potential hydrological change (Box 3) covers an area of about 249 km^2 (Figure 5) and extends no more than 10 km west of the West Casino Gas Project. Groundwater modelling found that within this zone, the maximum chance of exceeding the 0.2 m drawdown threshold (Box 3) due to additional coal resource development is estimated at 36%. It is *very likely* that the drawdown in the near-surface aquifer is less than 1 m across the entire assessment extent.

The simulated median annual groundwater extraction due to the West Casino Gas Project corresponds to 0.02% of the median annual recharge in the modelled part of the Richmond river basin for the time period 2013 to 2042. This very small percentage is attributed to the relatively small number of CSG wells, the hydraulic properties of the coal seams, and the high rate and volume of recharge to the Lamington Volcanics (most of which then discharges rapidly to streams and alluvial aquifers). Likewise, the predicted changes to surface water flows are insignificant because the streamflow rates in the Richmond river basin are overall very high (also driven to a large extent by the Lamington Volcanics) relative to the CSG groundwater extraction volumes.

Potential changes in drawdown were assessed for all hydrogeological layers shown in Figure 3, except for the Bundamba Group that underlies the Walloon Coal Measures.

Box 3 The zone of potential hydrological change

The predicted drawdown (Box 4) is used to define a zone to 'rule-in' or 'rule-out' potential hydrological change. The zone is the area with at least a 5% chance of greater than 0.2 m drawdown due to additional coal resource development (Figure 5). This threshold is consistent with the most conservative minimal impact thresholds in Queensland or NSW state regulations. Because impact and risk analysis was not undertaken for this bioregion, only groundwater hydrological changes were used to define the zone. The zone is defined by changes in the near-surface aquifer from which most ecological assets source water. Water-dependent landscapes and ecological assets outside of this zone are *very unlikely* to experience any hydrological change due to additional coal resource development. Within the zone, potential impacts may need to be considered further in an impact and risk analysis and smaller-scale analyses that take into account local conditions.

The zone of potential hydrological change can also be defined in deeper geological layers. Impact and risk analysis was not carried out for the Clarence-Moreton bioregion and hence impacts at these deeper layers were not assessed. Figure 42 of Cui et al. (2016b) shows the probability of exceeding 0.2 m drawdown at model nodes in deeper layers.

Box 4 Calculating groundwater drawdown

Drawdown is a lowering of the groundwater level, caused, for example, by pumping. The groundwater model predicts drawdown under the CRDP and drawdown under the baseline (**baseline drawdown**). The difference in drawdown between CRDP and baseline (referred to as **additional drawdown**) is due to additional coal resource development. In a confined aquifer, drawdown relates to a change in water pressure and does not necessarily translate to direct changes in depth to watertable.

The groundwater model simulation is reported for each grid cell individually. The maximum drawdown of each grid cell occurs at different times across the area assessed and the year of maximum baseline drawdown does not necessarily coincide with the year of maximum additional drawdown. Therefore, adding the baseline drawdown and additional drawdown results in a drawdown that is not expected to eventuate.

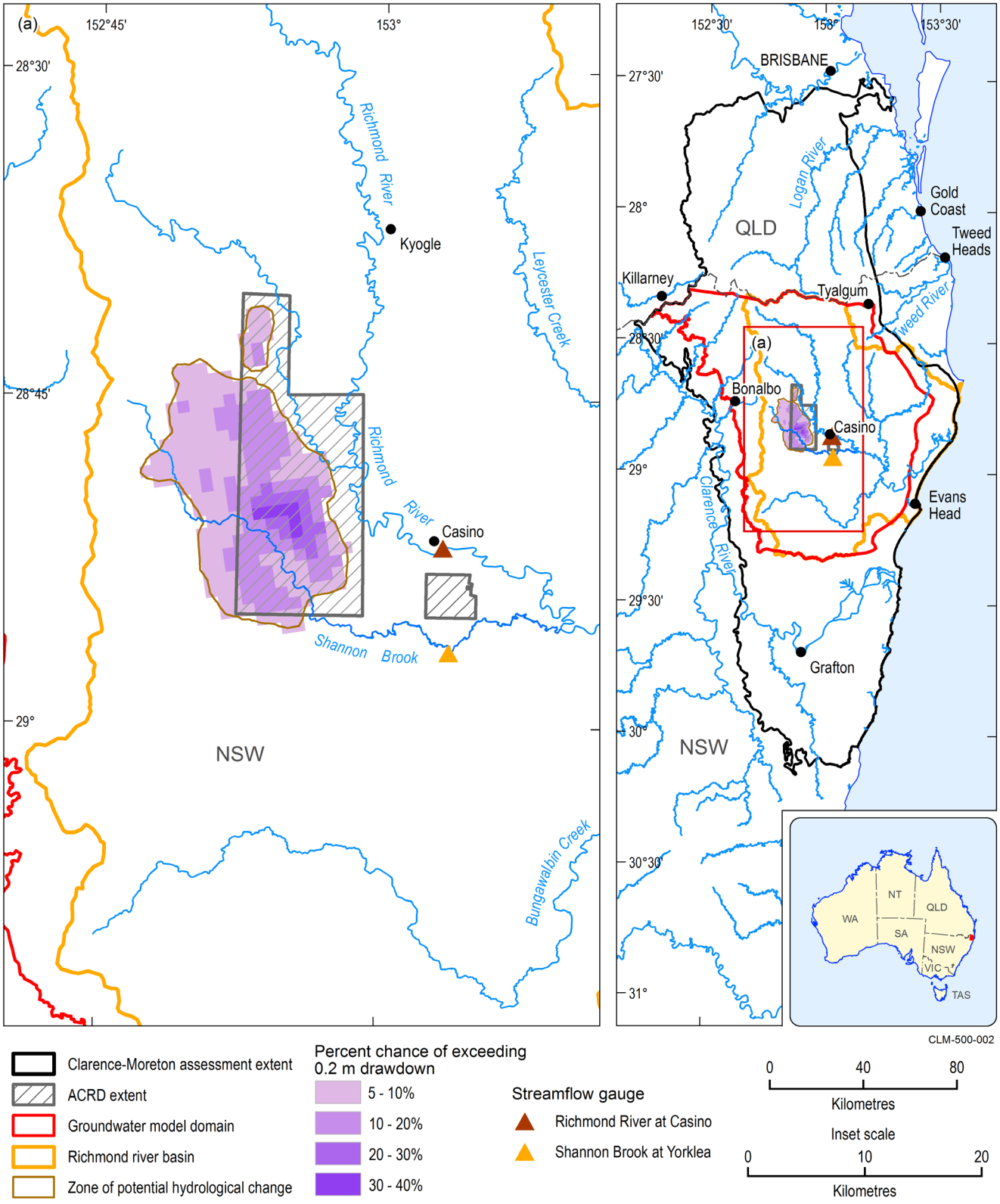

Figure 5 The percent chance of exceeding 0.2 m drawdown in the near-surface aquifer due to additional coal resource development

This figure shows the drawdown due to additional coal resource development (ACRD, in this case West Casino Gas Project), which is obtained by subtracting drawdown under the baseline from drawdown under the coal resource development pathway. The Clarence-Moreton assessment extent is the area within which potential impacts to groundwater and surface water systems are investigated in this assessment. Only groundwater hydrological changes were used to define the zone of potential hydrological change. Data: Bioregional Assessment Programme (Dataset 7)

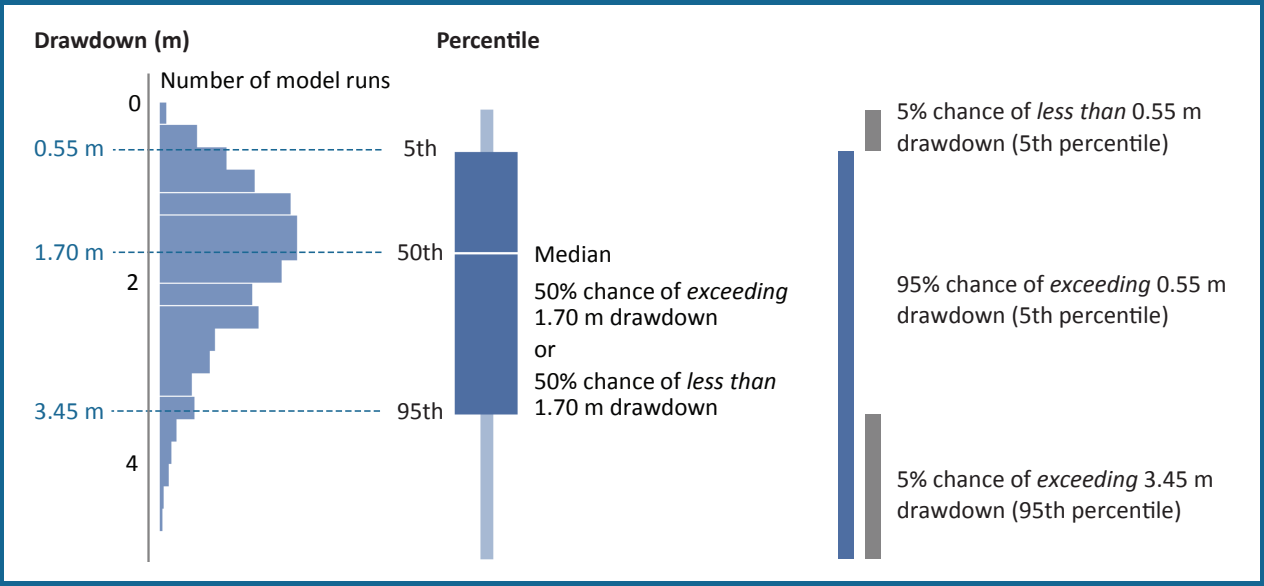

Figure 6 Illustrative example of probabilistic drawdown results using percentiles and percent chance

The chart on the left shows the distribution of results for drawdown in one assessment unit, obtained from an ensemble of thousands of model runs that use many sets of parameters. These generic results are for illustrative purposes only.

Box 5 Understanding probabilities

The models used in the assessment produced a large number of predictions of groundwater drawdown and streamflow characteristics rather than a single number. This results in a range or distribution of predictions, which are typically reported as probabilities – the percent chance of something occurring (Figure 6). This approach allows an assessment of the likelihood of exceeding a given magnitude of change, and underpins the assessment of the risk.

Hydrological models require information about physical properties such as the thickness of geological layers and how porous aquifers are. It is unknown how these properties vary across the entire assessment extent (both at surface and at depth), and therefore the hydrological models were run thousands of times using different sets of values from credible ranges of those physical properties each time. The model runs were optimised to reproduce historical observations, such as groundwater level and changes in water movement and volume.

A narrow range of predictions indicates more agreement between the model runs about the result, which enables decision makers to anticipate potential impacts more precisely, and a wider range indicates less agreement and hence more uncertainty in the outcome.

The distributions created from these model runs are expressed as probabilities that hydrological variables (such as drawdown) exceed relevant thresholds, as there is no single 'best' estimate of change. In this assessment, the estimates of drawdown are shown as a 5%, 50% or 95% chance of exceeding thresholds. Throughout this synthesis, the term '*very likely*' is used to describe where there is a greater than 95% chance that the model results exceed thresholds, and '*very unlikely*' is used where there is a less than 5% chance. While the model was based on the best available information, if the range of parameters used was not realistic, or if the modelled system does not reflect reality sufficiently, these modelled probabilities might vary from the actual probability of exceeding thresholds.

The assessment extent was divided into smaller square assessment units and the probability distribution (Figure 6) was calculated for each. In this synthesis, results are reported with respect to the following key areas (Figure 7):

A. outside the zone of potential hydrological change, where hydrological changes (and hence impacts) are *very unlikely* (defined by maps showing the 5% chance)

B. inside the zone of potential hydrological change, comprising the assessment units with at least a 5% chance of exceeding the threshold (defined by maps showing the 5% chance). Further work is required to determine whether the hydrological changes in the zone translate into impacts for water-dependent assets and landscapes

C. with at least a 50% chance of exceeding the threshold (i.e. the assessment units where the median is greater than the threshold; defined by maps showing the 50% chance)

D. with at least a 95% chance of exceeding the threshold (i.e. the assessment units where hydrological changes are *very likely*; defined by maps showing the 95% chance).

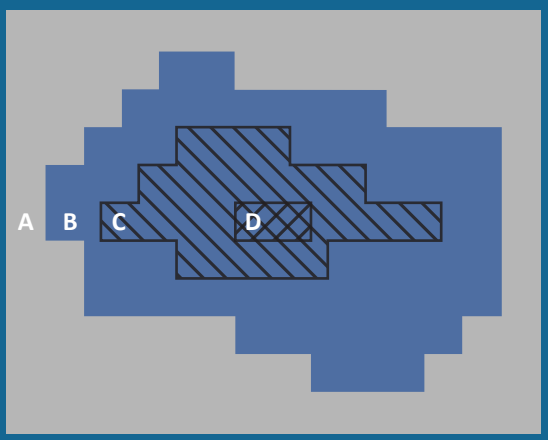

Figure 7 Key areas for reporting probabilistic results

Surface water

Key finding 5: In the Richmond river basin, the predicted maximum decrease in annual streamflow due to additional coal resource development is several orders of magnitude smaller than the observed mean streamflow. Impacts are *very likely* to be minimal for all but the very lowest streamflows.

Analysis of the surface modelling results indicates that it is *very likely* (95% chance) that the reduction in annual streamflow would not exceed 100 ML/year in the Richmond River due to additional coal resource development. This maximum change is modelled to occur at Casino and represents less than 0.1% of the annual streamflow at that point.

For all simulated nodes, the median change in streamflow is less than 10 ML/year, which amounts to less than 0.02% of mean annual streamflow. This potential change would have almost no effect on total streamflow but would cause minor changes during low-flow periods in small tributaries such as Shannon Brook at Yorklea (Figure 5). For all but three simulated nodes, 90% of model runs have a change in streamflow less than 35 ML/year (see Figure 10 in Gilfedder et al. (2016)).

Accurate measurement and modelling of low flows is very challenging, and leads to high uncertainties in predictions. The largest effect on low flows (i.e. the lowest 1% of streamflow) is predicted in Shannon Brook, where the median result is a reduction in streamflow of 20%.

Due to the likelihood of very small hydrological changes to surface water and the near-surface aquifer, further impact and risk analysis was not carried out.

FIND MORE INFORMATION

Water balance assessment, product 2.5 (Cui et al., 2016a)

Surface water numerical modelling, product 2.6.1 (Gilfedder et al., 2016)

Groundwater numerical modelling, product 2.6.2 (Cui et al., 2016b)

Surface water modelling, submethodology M06 (Viney, 2016)

Groundwater modelling, submethodology M07 (Crosbie et al., 2016)

Surface water model (Dataset 8)

Surface water modelling, input and output data (Dataset 9)

Groundwater model (Dataset 10)

Groundwater modelling, input and output data (Dataset 7)

What are the potential impacts of the hydrological changes?

The assessment found that the maximum potential hydrological changes due to additional coal resource development in the bioregion occur during low flows in the Richmond River at Casino and Shannon Brook at Yorklea, south of Casino.

The model predicted only very small hydrological changes and therefore the potential impacts were not further assessed.

The landscape classes and water-dependent assets were summarised for the bioregion. This information is highlighted below and is available for future assessments or monitoring programs.

Landscape classes

Hydrological changes can impact ecosystems, such as wetlands, irrigated agriculture or dryland remnant vegetation, at a landscape scale.

Ecosystems in the Clarence-Moreton bioregion were classified into 35 landscape classes. Landscape classes were aggregated into landscape groups based on whether they respond similarly to changes in groundwater and/or surface water.

More than half of the bioregion is used for dryland agriculture (57.5% of the assessment extent, which is the area in which potential impacts to groundwater and surface water systems are investigated). Natural vegetation covers 37.8% of the area, including woodlands, open forest and rainforest.

The landscape classification is based on the geology; the physical features of the region, known as geomorphology; hydrogeology, which describes the way water moves underground; land use; and ecology. Existing classification systems and datasets were used where relevant and modified as necessary.

Water-dependent assets

At the start of the assessment, representatives from governments, natural resource management groups and community groups identified more than 2000 ecological, economic and sociocultural assets of value to the community. The list of these assets that could potentially be affected by changes in water due to coal resource development, known as water-dependent assets, included (as of August 2015):

- **1520 ecological assets**, including the potential habitat of 186 threatened or endangered species, 4 globally important habitats for birds, 170 wetlands, 7 threatened ecosystems, and 157 ecosystems that rely on groundwater
- **752 economic assets**, including water access rights
- **160 sociocultural assets**, including 110 recreational sites, 15 heritage sites and 35 Indigenous sites.

FIND MORE INFORMATION

Description of the water-dependent asset register, product 1.3 (Murray et al., 2015a)

Water-dependent asset register, product 1.3 (Murray et al., 2015b)

Conceptual modelling, product 2.3 (Raiber et al., 2016b)

Landscape classification (Dataset 12)

Data on water-dependent assets (Dataset 11)

How to use this assessment

Bioregional assessment findings can help governments, industry and the community provide better-informed regulatory, water management and planning decisions.

Assessment results flag where future efforts of regulators and proponents can be directed, and where further attention is not necessary. This is emphasised through the **'rule-in–rule-out'** process, which focuses on areas where hydrological changes are predicted. This process identified areas, and consequently water resources and water-dependent assets, that are *very unlikely* to experience hydrological change or impact due to additional coal resource development.

This assessment predicts the likelihood of exceeding levels of potential hydrological change at a **regional level**. It also provides important context to identify potential issues that may need to be addressed in local-scale environmental impact assessments of new coal resource developments. It should help project proponents to meet legislative requirements to identify the environmental values that may be affected by changing groundwater, and to adopt strategies to avoid, mitigate or manage the predicted impacts. These assessments do not investigate the social, economic or human health impacts of coal resource development, nor do they consider risks of fugitive gases and impacts unrelated to water. Water quality is investigated only for salinity, where models and data are available.

Bioregional assessments are not a substitute for careful assessment of proposed coal mine or CSG extraction projects under Australian or state environmental law. Such assessments may use finer-scale groundwater and surface water models and consider impacts on matters other than water resources. However, the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (a federal government statutory authority established in 2012 under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999*) can use these assessment results to formulate their advice.

The full suite of information is provided at www.bioregionalassessments.gov.au, including all technical products as well as information about all datasets used or created, most of which can be downloaded from data.gov.au. These underpinning datasets, including shapefiles of geographic data and modelling results, can assist decision makers at all levels to review the work undertaken to date, and to extend or update the assessment if new models or data become available, or if plans change for future coal resource development in the bioregion (see p. 14).

The Programme's rigorous commitment to data access is consistent with the Australian Government's principles of providing publicly accessible, transparent and responsibly managed public sector information.

Building on this assessment

Bioregional assessments can be updated, for example, incorporating new coal resource developments in the groundwater model. Existing lists such as the water-dependent asset register will remain relevant for future assessments. If new coal resource developments emerge in the future, the data, information, analytical results and models from this assessment provide a comprehensive basis for bioregion-scale re-assessment of potential impacts under an updated coal resource development pathway. It may also be applicable for other types of resource development. Guidance about how to apply the Programme's methodology is documented in detailed scientific submethodologies, listed in the references on p. 15.

Extending this bioregional assessment should focus on an improved understanding of the role of faults as conduits of groundwater flow. Drilling of groundwater observation bores in deep geological formations could also help to further reduce the uncertainty on the connection between shallow and deep geological formations. Confidence may be improved in future assessments by undertaking the following activities.

Groundwater monitoring bores

There is a lack of deep groundwater monitoring bores (greater than 100 m depth below ground surface) where groundwater levels and quality are observed in the sedimentary bedrock within the Richmond river basin. As a result, there are limited baseline data to assess hydrological processes such as aquifer connectivity or the role of faults as potential barriers or conduits to groundwater flow.

Geological data

Seismic and stratigraphic data are scarce in some areas, such as underneath the Lamington Volcanics in the Richmond river basin. Additional data would reduce the uncertainty in the geological model and identify the presence and continuity of large-scale faults, which were not accounted for in the assessment. The uncertainty from other sources (e.g. the understanding, conceptualisation and hydraulic parameterisation of the deeper geological layers) reduces confidence in local-scale changes. Additional field observations that may mitigate this problem include water level and environmental tracer measurements from future multi-level observation wells, and core analytical measurements, such as porosity and permeability of aquitards.

Climate change

In comparing results under two different futures in this assessment, factors such as climate change or land use were held constant. Future assessment iterations could look to include these and other stressors to more fully predict cumulative impacts on a landscape scale.

FIND MORE INFORMATION

See sections titled 'Gaps' in the following technical products:

Description of water-dependent asset register, product 1.3 (Murray et al., 2015a)

Current water accounts and water quality, product 1.5 (McJannet et al., 2015)

Conceptual modelling, product 2.3 (Raiber et al., 2016b)

Surface water numerical modelling, product 2.6.1 (Gilfedder et al., 2016)

Groundwater numerical modelling, product 2.6.2 (Cui et al., 2016b)

References and further reading

The information presented in this synthesis for the Clarence-Moreton Bioregional Assessment is based on the analysis and interpretation of existing data and knowledge, enhanced by new scientific studies of the geology, groundwater, surface water and ecology. All technical products developed for the Clarence-Moreton bioregion are listed here. Also listed are the submethodologies that describe the key approaches used to undertake the assessments.

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 13 September 2016, http://data.bioregionalassessments.gov.au/submethodology/bioregional-assessment-methodology.

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McJannet D, Raiber M, Gilfedder M, Cui T, Marvanek S and Rassam D (2015) Current water accounts and water quality for the Clarence-Moreton bioregion. Product 1.5 from the Clarence-Moreton Bioregional Assessment. Department of the Environment, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia. Viewed 12 September 2016, http://data.bioregionalassessments.gov.au/product/CLM/CLM/1.5.

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Datasets

Key datasets are listed here. The website www.bioregionalassessments.gov.au provides metadata for all datasets, most of which can be downloaded from data.gov.au.

Dataset 1 NSW Department of Trade and Investment (2015) CLM - CRDP Petroleum Production License Application (PPLA9). Bioregional Assessment Source Dataset. Viewed 08 March 2016, http://data.bioregionalassessments.gov.au/dataset/3ee39484-d851-4eea-99f2-28ae10b10f23.

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Dataset 3 Bioregional Assessment Programme (2015) CLM Groundwater Model Boundary. Bioregional Assessment Derived Dataset. Viewed 25 February 2016, http://data.bioregionalassessments.gov.au/dataset/dd691d5c-48a2-42fd-9902-4770c871b50f.

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Dataset 9 Bioregional Assessment Programme (2015) Clarence-Moreton AWRA-L model results. Bioregional Assessment Derived Dataset. Viewed 13 September 2016, http://data.bioregionalassessments.gov.au/dataset/70b00454-f9b5-4f12-9f97-9d08cc8cd8b0.

Dataset 10 Bioregional Assessment Programme (2015) CLM groundwater model V1. Bioregional Assessment Derived Dataset. Viewed 13 September 2016, http://data.bioregionalassessments.gov.au/dataset/2acf0342-956e-430f-9142-cf64d2b9d118.

Dataset 11 Bioregional Assessment Programme (2014) Asset database for the Clarence-Moreton bioregion on 24 February 2016 Public. Bioregional Assessment Derived Dataset. Viewed 13 September 2016, http://data.bioregionalassessments.gov.au/dataset/ba1d4c6f-e657-4e42-bd3c-413c21c7b735.

Dataset 12 Bioregional Assessment Programme (2015) Landscape classification of the Clarence-Moreton preliminary assessment extent. Bioregional Assessment Derived Dataset. Viewed 23 October 2015, http://data.bioregionalassessments.gov.au/dataset/a1d97959-d0f9-4deb-ab9b-af88120efd07.

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.

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

aquitard: a saturated geological unit that is less permeable than an aquifer, and incapable of transmitting useful quantities of water. Aquitards often form a confining layer over an artesian aquifer.

assessment extent: the geographic area associated with a subregion or bioregion in which the potential water-related impact of coal resource development on assets is assessed. The assessment extent is created by revising the preliminary assessment extent on the basis of information from Component 1: Contextual information and Component 2: Model-data analysis.

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.

causal pathway: for the purposes of bioregional assessments, the logical chain of events – either planned or unplanned – that link coal resource development and potential impacts on water resources and water-dependent assets

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

conceptual model: abstraction or simplification of reality

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

cumulative impact: for the purposes of bioregional assessments, the total change in water resources and water-dependent assets resulting from coal seam gas and coal mining developments when all past, present and reasonably foreseeable actions that are likely to impact on water resources are considered

depressurisation: in the context of coal seam gas operations, depressurisation is the process whereby the hydrostatic (water) pressure within a coal seam is reduced (through pumping) such that natural gas desorbs from within the coal matrix, enabling the gas (and associated water) to flow to surface

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

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

drawdown: a lowering of the groundwater level (caused, for example, by pumping). In the bioregional assessment (BA) context this is reported as the difference in groundwater level between two potential futures considered in BAs: baseline coal resource development (baseline) and the coal resource development pathway (CRDP). The difference in drawdown between CRDP and baseline is due to the additional coal resource development. 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.

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

hazard: an event, or chain of events, that might result in an effect (change in the quality or quantity of surface water or groundwater)

hydrogeology: the study of groundwater, including flow in aquifers, groundwater resource evaluation, and the chemistry of interactions between water and rock

impact: a change resulting from prior events, at any stage in a chain of events or a causal pathway. An impact might be equivalent to an effect (change in the quality or quantity of surface water or groundwater), or it might be a change resulting from those effects (for example, ecological changes that result from hydrological changes).

landscape class: for bioregional assessment (BA) purposes, an ecosystem with characteristics that are expected to respond similarly to changes in groundwater and/or surface water due to coal resource development. They are present on the landscape across the entire BA subregion or bioregion and their spatial coverage is exhaustive and non-overlapping. Conceptually, landscape classes can be considered as types of ecosystem assets.

recharge: see groundwater recharge

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

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.

very likely: greater than 95% chance

very unlikely: less than 5% chance

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

zone of potential hydrological change: outside this extent, hydrological changes (and hence potential impacts) are *very unlikely* (less than 5% chance). Each bioregional assessment defines the zone of potential hydrological change conservatively, using probabilities of exceeding relevant hydrological response variables. The zone of potential hydrological change is the union of the groundwater zone of potential hydrological change (the area with a greater than 5% chance of exceeding 0.2 m of drawdown in the relevant aquifers) and the surface water zone of potential hydrological change (the area with a greater than 5% chance of exceeding changes in relevant surface water hydrological response variables).

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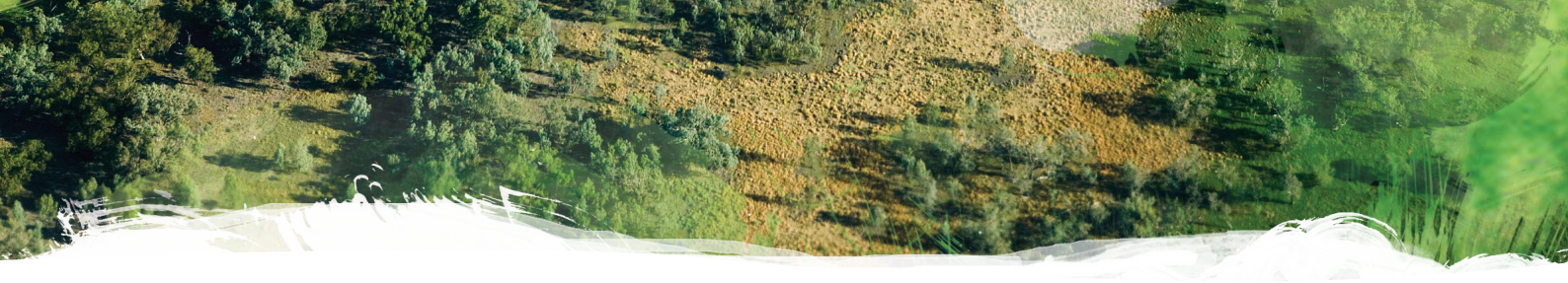

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The Department of the Environment and Energy https://www.environment.gov.au/water/coal-and-coal-seam-gas/office-of-water-science, Bureau of Meteorology http://www.bom.gov.au/water/, CSIRO http://www.csiro.au, and Geoscience Australia http://www.ga.gov.au are collaborating to undertake bioregional assessments.

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