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 Gloucester subregion: key findings

Product 5: Outcome synthesis for the Gloucester subregion from the Northern Sydney Basin Bioregional Assessment

2018

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

Gloucester assessment at a glance

This bioregional assessment considered the potential cumulative impacts on water and water-dependent assets due to four future additional coal resource developments in the Gloucester subregion of NSW (Figure 1). The assessment is a regional overview of potential impacts on, and risks to, water-dependent ecological, economic and sociocultural assets, identifying where potential changes in water resources and ecosystems may occur, and ruling out areas where impacts are *very unlikely*. Governments, industry and the community can then focus on the areas that are potentially impacted and apply local-scale modelling when making regulatory, water management and planning decisions.

HEADLINE FINDING

Expanding coal mining and coal seam gas development is predicted to cause minimal impacts on water resources and water-dependent assets in the Gloucester subregion.

Groundwater: An area of 100 km² has at least a 5% chance of greater than 0.2 m drawdown due to additional coal resource development. Of this, an area of 52 km² potentially already experiences drawdown due to baseline coal resource development. *See page 9*

Surface water: There is at least a 5% chance that low-flow days in 43 km of streams around the Rocky Hill, Stratford and Gloucester Gas developments could increase by more than 20 days per year due to additional coal resource development. Changes in high-flow days and annual flow are smaller. *See page 13*

Ecosystem impacts: Hydrological changes may be experienced in parts of riverine ecosystems (242 km of the total 344 km of streams) and groundwater-dependent ecosystems (3.3 km² of total 10.3 km²). Modelling predicts the resulting ecosystem impacts to be minimal. *See page 17*

Asset impacts: Almost all sociocultural and economic assets are *very unlikely* to be impacted. Detectable impacts on ecological assets are likely to be restricted to the north of the subregion, and are expected to be minor and localised near additional coal resource development. *See page 22*

BASELINE COAL RESOURCE DEVELOPMENTS (BOX 1)

2 x mines, 0 x CSG

ADDITIONAL COAL RESOURCE DEVELOPMENTS (BOX 1)

3 x mines

GAS

1 x CSG

Throughout this synthesis, the term '*very likely*' is used where modelling predicts a greater than 95% chance of something occurring, and '*very unlikely*' is used where modelling predicts a less than 5% chance.

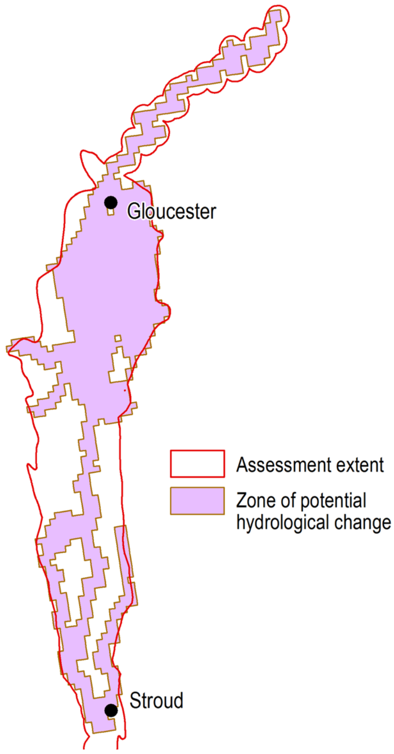

Figure 1 The zone of potential hydrological change

The pink zone (defined further in Box 4) was developed for the Gloucester subregion to identify the area, outside of which impacts are ruled out.

The assessment of potential impacts was therefore focused within this zone, which combines:

- the area with at least a 5% chance of exceeding 0.2 m drawdown due to additional coal resource development
- the area with at least a 5% chance of exceeding changes in specified surface water characteristics that arise due to additional coal resource development.

Data: Bioregional Assessment Programme (Dataset 1)

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CITATION

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COVER PHOTOGRAPH

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

Credit: Heinz Buettikofer, CSIRO

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Executive summary

About the subregion *see page 3*

This synthesis presents key findings from the bioregional assessment of the Gloucester subregion, part of the Northern Sydney Basin bioregion.

The subregion, north of the Hunter Valley in NSW, is defined by the geological Gloucester Basin and is home to about 5000 people, mainly in the towns of Gloucester and Stroud. Town water is extracted from local rivers and there are no major dams or wetlands. The majority of the subregion is cleared of native vegetation and supports agricultural uses. The groundwater system is confined within the subregion, so potential impacts on groundwater cannot propagate beyond its boundaries.

A small east–west ridge divides the Avon River catchment in the north from the Karuah river basin in the south. The subregion covers 348 km^2; however, the total area investigated in this assessment, the **assessment extent,** is 481 km^2 as it extends along the Karuah and Gloucester rivers beyond the subregion boundaries (Figure 2).

Potential hydrological changes *see page 7*

Hydrological modelling identified potential changes in groundwater and streamflow due to coal resource development for two futures, the baseline and coal resource development pathway (Box 1). The **baseline** includes two open-cut mines: Duralie Coal Mine in the south, and Stratford Mining Complex in the north. The coal resource development pathway includes the baseline mines plus four **additional coal resource developments**: mine expansions for the two baseline mines, one new open-cut coal mine at Rocky Hill, north of Stratford, and one coal seam gas (CSG) development, Gloucester Gas Project Stage 1. Note that the Gloucester Gas Project Stage 1 has been withdrawn and in December 2017 the NSW Planning Assessment Commission refused consent for the Rocky Hill Coal Project to proceed.

To rule out impacts on water-dependent ecosystems and assets, a zone of potential hydrological change (Box 4) identified areas where modelling predicted potential changes in surface water and groundwater due to additional coal resource development. The zone comprises 52% of the assessment extent, covers 250 km^2 and includes 242 km of streams.

Potential impacts *see pages 17 and 22*

Cumulative hydrological impacts due to additional coal resource development are predicted to be minor. No impacts on ecological assets are predicted in the south, given the limited additional coal resource development. In the north, potential impacts on ecological assets are expected to be minor and localised due to the relatively small magnitude of predicted hydrological changes.

All 38.4 km^2 of the subregion's estuarine ecosystems are *very unlikely* to be impacted, along with 7.1 km^2 of the total 10.3 km^2 of groundwater-dependent ecosystems, and 67 km of the total 344 km of riverine ecosystems.

In the Avon River and Upper Gloucester River, there is a 95% chance that reductions in water availability are less than 1.6 GL per year due to additional coal resource development, which is a 1% to 2% change relative to the baseline.

Modelling suggests that reliability of water supply is *very unlikely* to be impacted, with no change in cease-to-pump days in the Upper Gloucester River and Karuah River (upper management zone). It is *very likely* that there will be fewer than 3 additional low-flow days per year in the Avon River, with the impact on cease-to-pump days expected to be smaller.

The greatest confidence in hydrological modelling results is in areas that are *very unlikely* to be impacted. Where potential impacts are identified, further local-scale modelling may be required to determine the presence and magnitude of ecosystem impacts.

Box 1 Investigating two potential futures

Results are reported for two potential futures:

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

The difference in results between the CRDP and baseline is the change that is primarily reported in a bioregional assessment. This change is due to the **additional coal resource development**.

The CRDP for the Gloucester subregion was based on information available as of October 2015. However, coal resource developments may change over time or be withdrawn, or timing of developments may change. Factors such as climate change and 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 minimal as the assessment focused on the difference in the results between the CRDP and baseline, minimising the impacts of changes that occur in both futures.

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 rule out areas where impacts on water resources and water-dependent assets are *very unlikely* (with a less than 5% chance). The zone of potential hydrological change (Box 4) identifies where potential impacts cannot be ruled out. Governments, industry and the community can then focus on those areas that are potentially impacted and apply local-scale modelling when making regulatory, water management and planning decisions.

The assessments investigate:

- the characteristics of the subregion, including water resources, assets, and coal and CSG resources (Component 1)
- how future coal resource development could affect surface water and groundwater (Component 2)
- how hydrological changes could impact on water-dependent ecosystems and assets (Component 3 and Component 4).

The assessments consider potential changes in water quantity and some impacts related to salinity but they do not assess a full suite of impacts on water quality.

The assessment of the **Gloucester subregion**, part of the Northern Sydney Basin Bioregional Assessment, is reported in 12 technical products (Box 2), which are summarised in this synthesis.

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 listed in this synthesis, and include methodologies, maps, models and lists of water-dependent assets, ecosystems and potential hazards. Users can visualise where potential impacts might occur using a map-based interface on the BA Explorer, at www.bioregionalassessments.gov.au/explorer/GLO. References, further reading and datasets are listed at the end of this synthesis.

Box 2 The technical products for the Gloucester subregion

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
2.7 Receptor impact modelling

Component 3 and Component 4: Impact and risk analysis
3-4 Impact and risk analysis

The pages of this synthesis follow this colour guide when describing the assessment outputs. 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.

CONTENTS OF THIS SYNTHESIS

About the subregion

The Gloucester subregion (Figure 2) spans an area of 348 km^2 and is defined by the underlying Gloucester Basin, a small sedimentary geological basin. It is north of Newcastle in NSW, and extends 55 km north–south at its longest, and 15 km east–west at its widest.

A small east–west ridge across the middle of the subregion forms a catchment divide between the Manning and Karuah river basins. Northern-flowing rivers contribute to the Manning River and discharge to the Tasman Sea beyond Taree, while the southern-flowing rivers contribute to the Karuah River and discharge into Port Stephens.

The subregion contains two main aquifers, an alluvial aquifer and weathered bedrock aquifer within 150 m of the ground surface. The subregion is a closed hydrogeological system, which means groundwater is confined within its boundary. Groundwater quality data indicate in-situ mineralisation, with salinity levels increasing with depth from nearly fresh to brackish. There are also elevated naturally occurring concentrations of strontium, iron, bromine and methane in both aquifers. Currently, commercial, industrial, irrigation, mining, stock, domestic and farming activities use up to about 0.52 GL per year of groundwater.

The main natural and human-modified ecosystems in the assessment extent were categorised through a landscape classification (Box 6), based on the subregion's geology, geomorphology (physical features), hydrogeology (the way water moves through porous rocks), land use and ecology. See 'What are the potential impacts of additional coal resource development on ecosystems?' (page 17) for more information.

The community nominated assets that they consider important due to their ecological, economic or sociocultural values (Bioregional Assessment Programme, 2017; McVicar et al., 2015). These include ecosystems such as stream vegetation that provides habitat for frogs, groundwater used for agriculture, and sites of cultural significance. See 'What are the potential impacts of additional coal resource development on water-dependent assets?' (page 22) for more information.

Coal resource development

Key finding 1: The coal resource development pathway (Box 1) defines the most likely future for the subregion as at October 2015. It includes two baseline mines (Duralie and Stratford) and four additional coal resource developments: a new open-cut coal mine at Rocky Hill, expansions of the two baseline mines, and the Gloucester Gas Project Stage 1 coal seam gas development.

Note that the Gloucester Gas Project Stage 1 has been withdrawn and in December 2017 the NSW Planning Assessment Commission refused consent for the Rocky Hill Coal Project to proceed.

Coal is extracted from two existing open-cut coal mines in the subregion, Duralie Coal Mine and Stratford Mining Complex, owned by Yancoal Australia Ltd. They are known in the assessment as baseline mines (Figure 2 and Figure 3).

Coal seams in the geological Gloucester Basin (Figure 4) are present within the:

- Alum Mountain Volcanics
- Dewrang Group, including two coal seams that are the coal resource of the Duralie Coal Mine
- Craven and Avon subgroups of the Gloucester Coal Measures, from which the Stratford open-cut mine extracts coal.

The coals are thicker and of better quality on the eastern margins of the Gloucester Basin. No conventional hydrocarbons are produced from the basin; however, it has been an area of significant interest for coal seam gas (CSG) exploration.

This assessment focused on the potential cumulative impact of four additional coal resource developments. These include mine expansions for the two baseline mines; a new open-cut mine at Rocky Hill, proposed by Gloucester Resources Limited; and the Gloucester Gas Project Stage 1 CSG development by AGL Energy Limited.

In December 2017 the NSW Planning Assessment Commission refused consent for the Rocky Hill Coal Project to proceed. In addition, AGL announced in February 2016 it would not proceed with Gloucester Gas Project Stage 1, and would relinquish its petroleum exploration licence for the Gloucester region to the NSW Government (AGL, 2016). Both the Rocky Hill Coal Project and the Gloucester Gas Project Stage 1 were included in the hydrological modelling for the coal resource development pathway (CRDP), which was finalised in October 2015. Therefore, this assessment was based on these developments proceeding.

The timeline of construction and production for each coal resource development is shown in Figure 5.

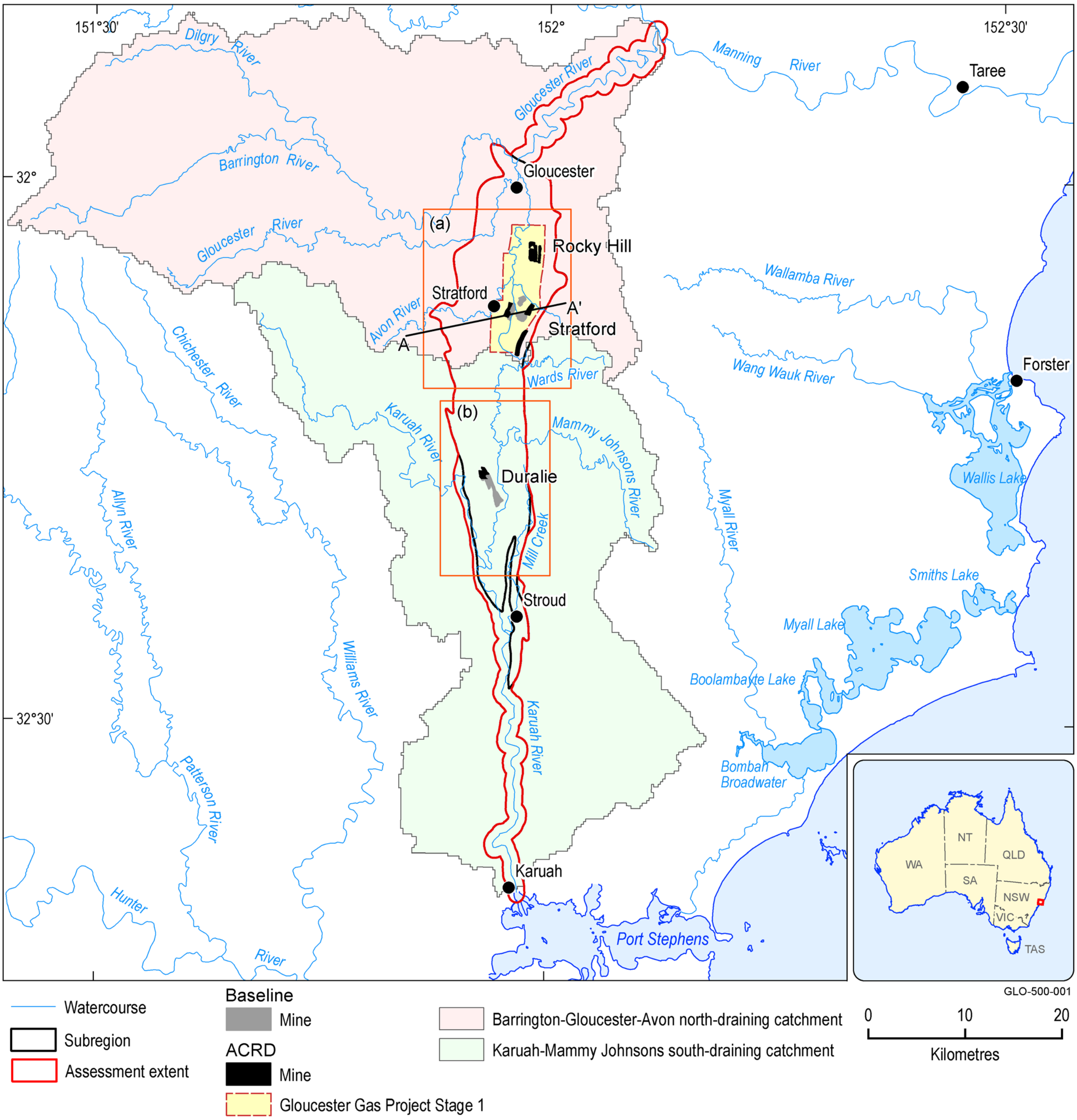

Figure 2 Coal resource development in the Gloucester subregion

The coal resource development pathway includes baseline coal resource developments (commercially producing as of December 2012) and additional coal resource developments (ACRD, the coal resource developments most likely to proceed in future, as assessed in October 2015). Close-ups of (a) and (b) are shown in Figure 3. See Figure 4 for cross-section of line A–A'.
Data: Bioregional Assessment Programme (Dataset 2, Dataset 3, Dataset 5); AGL (Dataset 4)

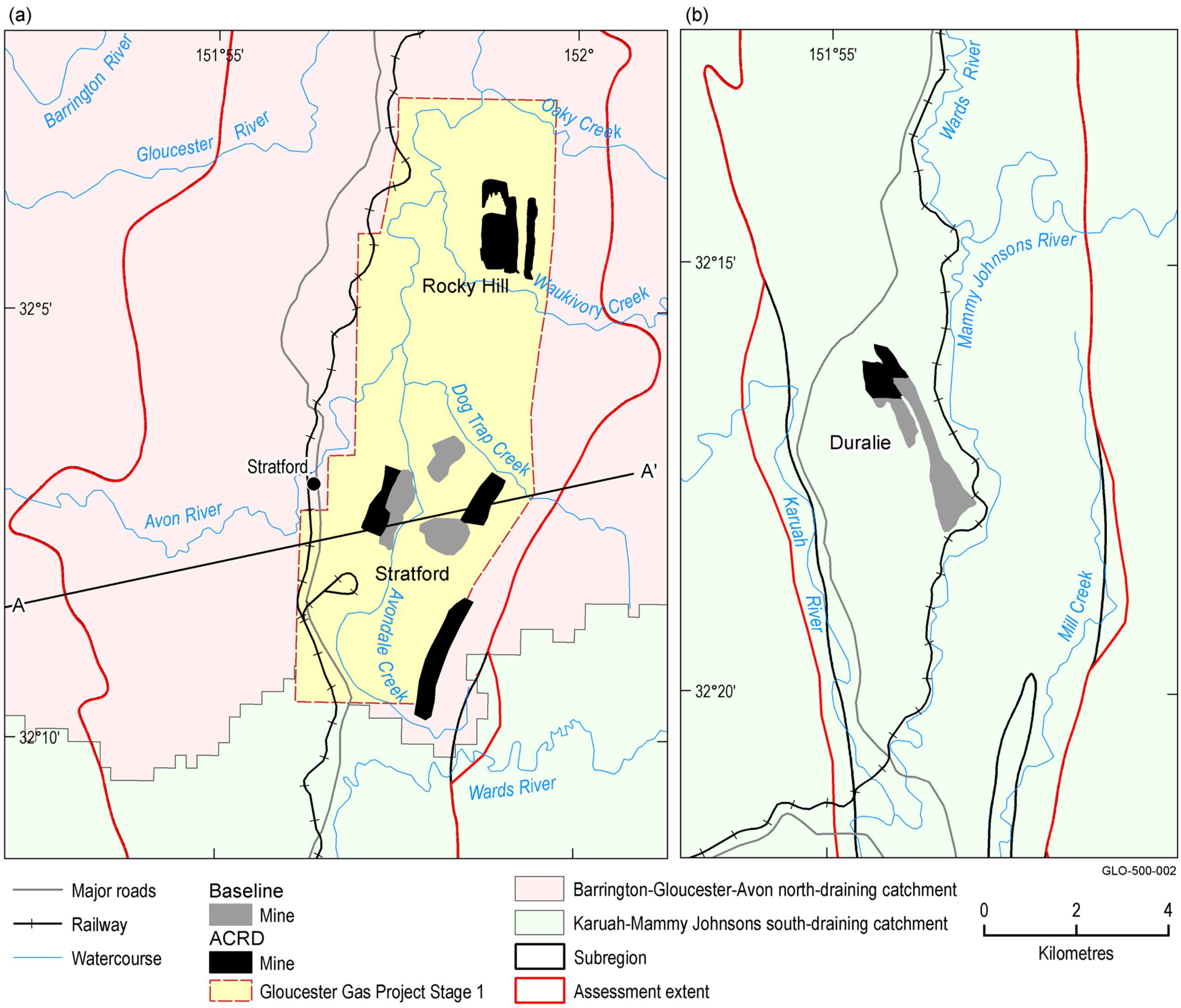

Figure 3 Close-up of coal resource development in the Gloucester subregion

The coal resource development pathway includes baseline coal resource developments (commercially producing as of December 2012) and additional coal resource developments (ACRD, the coal resource developments most likely to proceed in future, as assessed in October 2015). Figure 2 shows the location of insets (a) and (b) within the broader subregion. See Figure 4 for cross-section of line A–A'.
Data: Bioregional Assessment Programme (Dataset 2, Dataset 3, Dataset 5); AGL (Dataset 4)

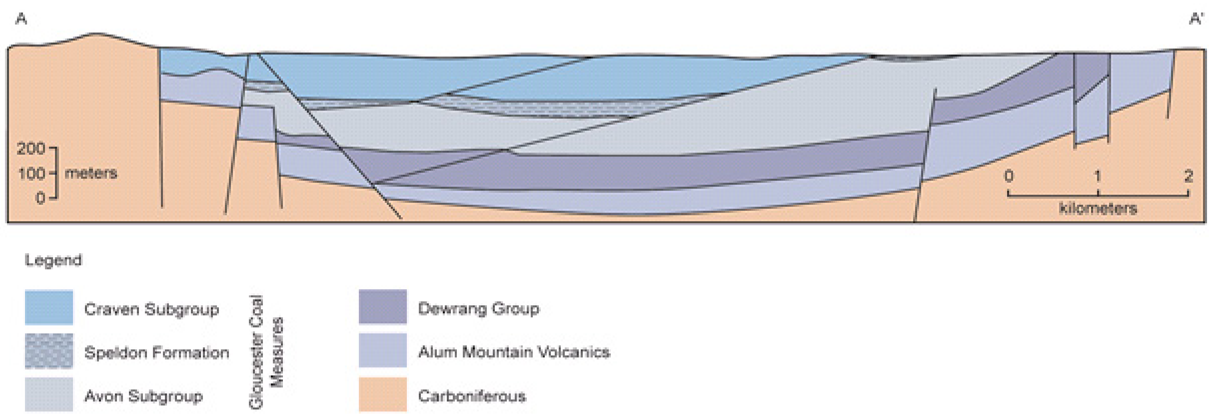

Figure 4 Simplified regional cross-section for the geological Gloucester Basin

Figure 3 shows the location of the line A–A' within the Gloucester subregion.
Source: Roberts et al. (1991). Note that this figure is not covered by Creative Commons. It has been reproduced with the permission of NSW Trade and Investment.

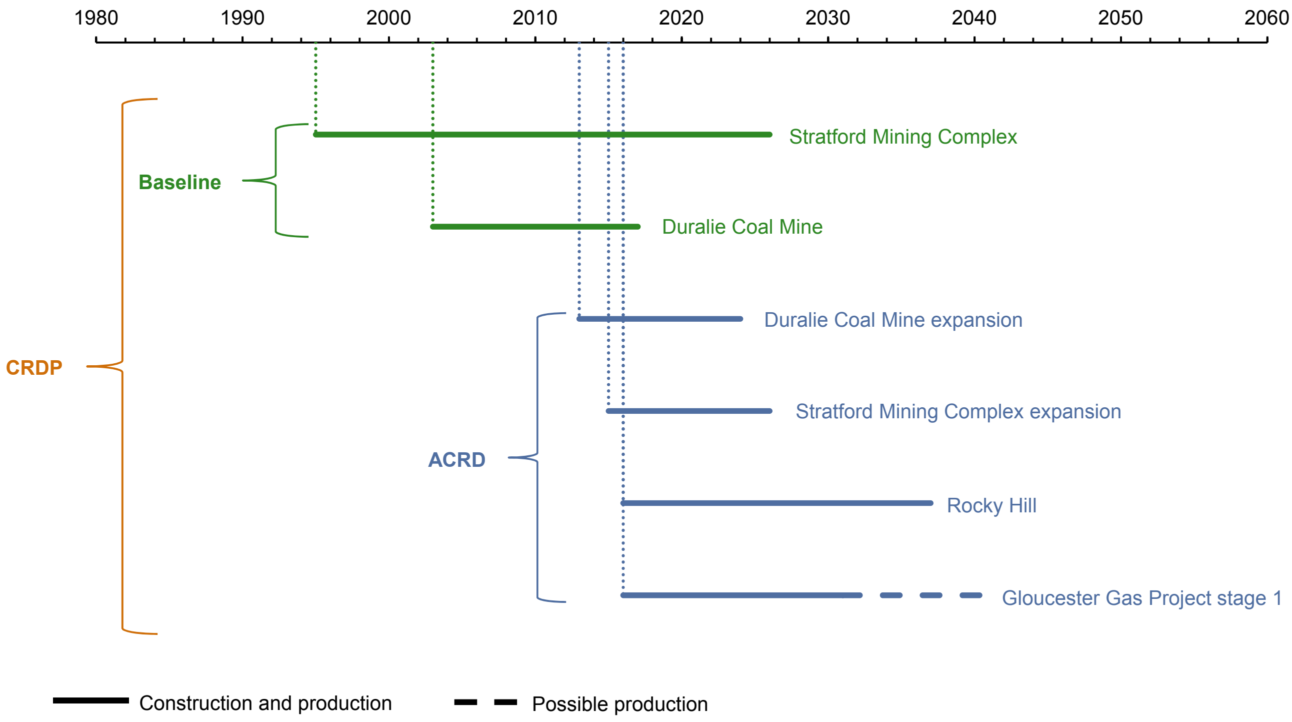

Figure 5 Timelines for coal resource developments in the coal resource development pathway in the Gloucester subregion

These timelines were used in the hydrological modelling based on information available in 2015.
ACRD = additional coal resource development, CRDP = coal resource development pathway (Box 1)

FIND MORE INFORMATION

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

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

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

Conceptual modelling, product 2.3 (Dawes et al., 2018)

Surface water numerical modelling, product 2.6.1 (Zhang et al., 2018)

Groundwater numerical modelling, product 2.6.2 (Peeters et al., 2018)

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

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

How could coal resource development result in hydrological changes?

The assessment identified potential hazards (Dataset 6) associated with coal resource development that could result in hydrological changes, such as aquifer depressurisation due to groundwater extraction. Hazards in scope were further assessed by first estimating relevant hydrological changes through surface water and groundwater modelling and then identifying potential impacts on, and risks to, water-dependent ecosystems and assets (described in the following sections).

After the potential hazards were identified, the chain of events that commonly arise from coal resource development activities were analysed and categorised into four causal pathway groups (Figure 6):

A. **'Subsurface depressurisation and dewatering'** istriggered by extraction of groundwater to enable CSG extraction and dewatering of open-cut mine pits. This potentially directly affects the groundwater system, and indirectly affects surface water – groundwater interactions. Potential effects are likely to be in the short term (less than 5 years) for groundwater pressure changes, to long term (10 to 100 years) for changes in groundwater movement or quality.

B. **'Subsurface physical flow paths'** are initiated by activities that cause physical changes to the rock mass or geological layers, resulting in new physical paths that water may potentially gain access to and flow along. Potential effects are in the medium (5 to 10 years) to long term and are likely to be restricted to aquifer or aquifer outcrop areas, but can also affect connected watercourses within and downstream of mines.

C. **'Surface water drainage'** starts with activities that physically disrupt the surface and near-surface materials (vegetation, topsoil, weathered rock). Medium- to long-term cumulative effects are possible for watercourses within and downstream of development. Activities may include construction of diversion walls and drains, interception of runoff, realignment of streams, and groundwater extraction for CSG production or underground coal mining leading to subsidence of land surface.

D. **'Operational water management'** is triggered by modification of surface water systems to allow storage, disposal, processing and use of extracted water. Potential effects are likely to be in the medium to long term and include impacts on watercourses within and downstream of operations.

Many activities related to coal resource development may cause local or on-site changes to surface water or groundwater. These are not considered explicitly in bioregional assessments because they are assumed to be adequately managed by site-based risk management and mitigation procedures, and are unlikely to result in cumulative impacts.

Based on the licence conditions as summarised in the relevant environmental impact assessments, it was assumed that no water used in coal resource development is released back into the stream network.

FIND MORE INFORMATION

Conceptual modelling, product 2.3 (Dawes et al., 2018)

Surface water numerical modelling, product 2.6.1 (Zhang et al., 2018)

Groundwater numerical modelling, product 2.6.2 (Peeters et al., 2018)

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)

Impact Modes and Effects Analysis for the Gloucester subregion (Dataset 6)

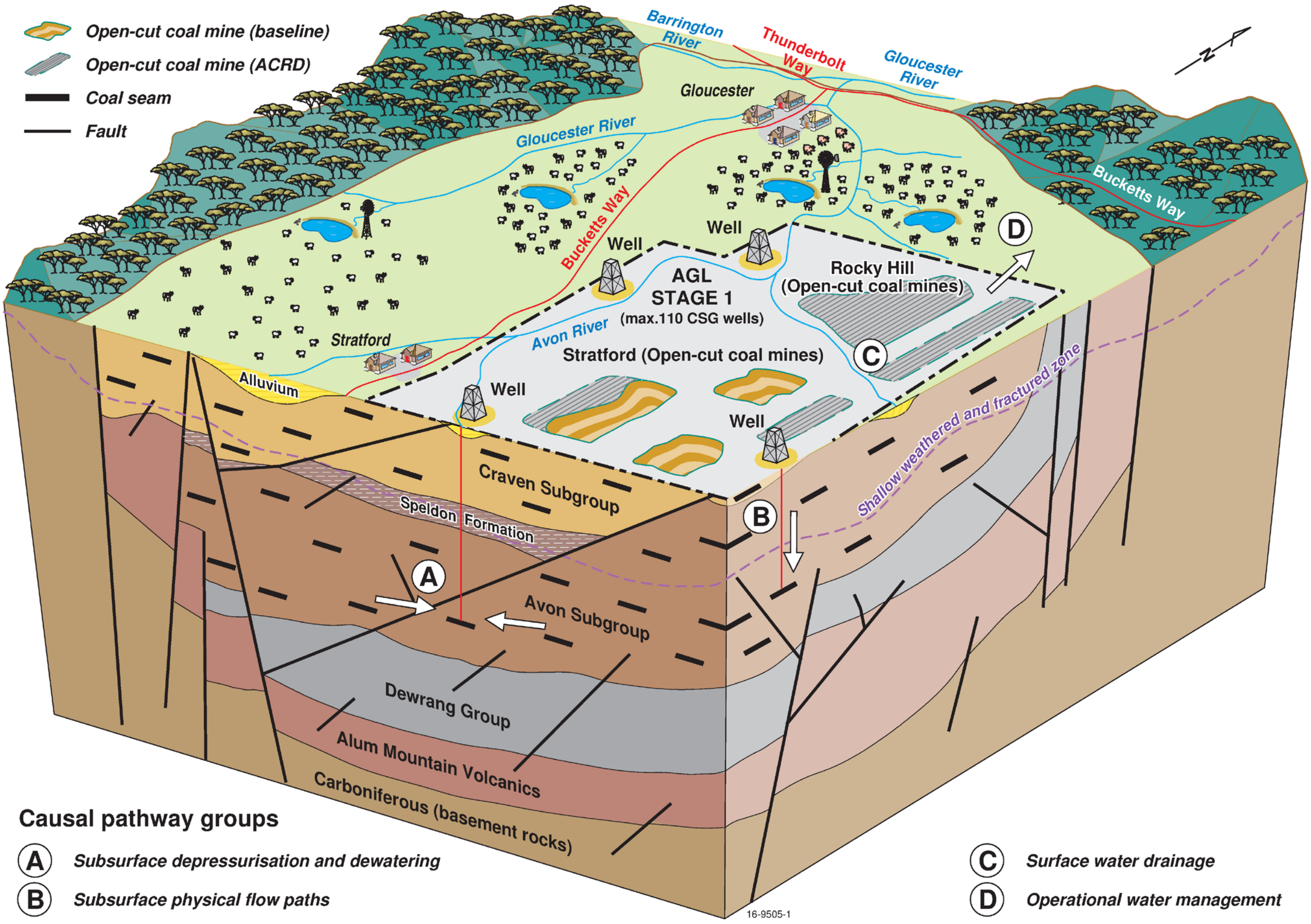

Figure 6 Conceptual diagram of the causal pathway groups associated with coal seam gas operations and open-cut coal mines for the northern Gloucester subregion

This schematic diagram is not drawn to scale. CSG = coal seam gas

What are the potential hydrological changes?

Key finding 2: The zone of potential hydrological change (Figure 1 and Box 4) covers an area of 250 km^2 including 242 km of streams. This represents 52% of the area and 70% of the stream length in the entire Gloucester assessment extent.

The area defined by the 250 km^2 zone of potential hydrological change, including the mine pit exclusion zone (Box 3), is potentially impacted by additional coal resource developments.

Groundwater

Potential drawdown due to additional coal resource development occurs in two areas, associated with the Rocky Hill Coal Project, Stratford extension and Gloucester Gas Project Stage 1 in the north (Figure 3a), and the proposed Duralie extension in the south (Figure 3b).

The assessment investigated the maximum difference in drawdown (Box 3) between two potential futures (Box 1) to assess potential impacts on groundwater (Figure 7 and Figure 8). Results are reported for the regional watertable, which comprises the alluvial aquifer, as well as weathered and fractured rock aquifers. The largest additional drawdown generally occurs during or shortly after the active mining period. The time to maximum drawdown increases with distance from the mines (Peeters et al., 2018).

Key finding 3: The area with at least a 5% chance of greater than 0.2 m drawdown due to additional coal resource development is 100.1 km^2. Under the baseline it is almost 140 km^2 across the entire assessment extent. The area of overlap between these two is 52 km^2, which is where there is potential for cumulative groundwater impacts between baseline and additional coal resource developments.

It is *very likely* that 19.7 km^2 will experience at least 0.2 m of drawdown due to additional coal resource development, which includes 17.2 km^2 in the Gloucester river basin and 2.5 km^2 near Duralie Coal Mine in the Karuah river basin. It is *very unlikely* that more than 100.1 km^2 will experience drawdown of more than 0.2 m due to additional coal resource development (Table 6 and Figure 16 in Section 3.3 of Post et al. (2018)).

Across both river basins, it is *very unlikely* that more than 15.8 km^2 will exceed 2 m of drawdown, or that more than 4.3 km^2 will exceed 5 m of drawdown due to additional coal resource development. Under the baseline, it is *very unlikely* that more than 17.2 km^2 will exceed 2 m of drawdown or that more than 6.0 km^2 will experience more than 5 m of drawdown (Table 6, Table 7, Figure 16 and Figure 17 in Section 3.3 of Post et al. (2018)).

In the Gloucester river basin, 50.2 km^2 are predicted to have a 5% chance of at least 0.2 m drawdown under the baseline, while additional coal resource development is predicted to affect 88.1 km^2 with the same probability. In the Karuah river basin, 31.6 km^2 are predicted to have a 5% chance of at least 0.2 m drawdown under the baseline, while additional coal resource development is predicted to affect 12.0 km^2 with the same probability.

Note that these numbers include the area covered by the mine pit exclusion zone, whereas these areas were excluded when impacts on ecosystems were assessed (see Box 3 and Box 7).

Box 3 Calculating groundwater drawdown

Drawdown is a lowering of the groundwater level, caused, for example, by pumping. The groundwater model predicted drawdown under the coal resource development pathway and drawdown under the baseline (baseline drawdown). The difference in drawdown between the coal resource development pathway and baseline futures (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 changes in depth to the watertable.

The maximum drawdown over the course of the groundwater model simulation (from 2013 to 2102) is reported for each 0.25 km^2 grid cell, and is expected to occur at different times across the area assessed. It is not expected that the year of maximum baseline drawdown coincides with the year of maximum additional drawdown. Therefore, simply adding the two figures will result in a drawdown amount that is not expected to eventuate.

Close to open-cut mines, confidence in the results of the groundwater model is very low because of the very steep hydraulic gradients at the mine pit interface. As a result, a 'mine pit exclusion zone' was defined. Groundwater drawdown inside this zone is not used in the assessment of ecological impacts.

CSG depressurisation, mine dewatering and the impacts of naturally occurring faults were represented in the modelling but their individual effects on groundwater drawdown were not differentiated.

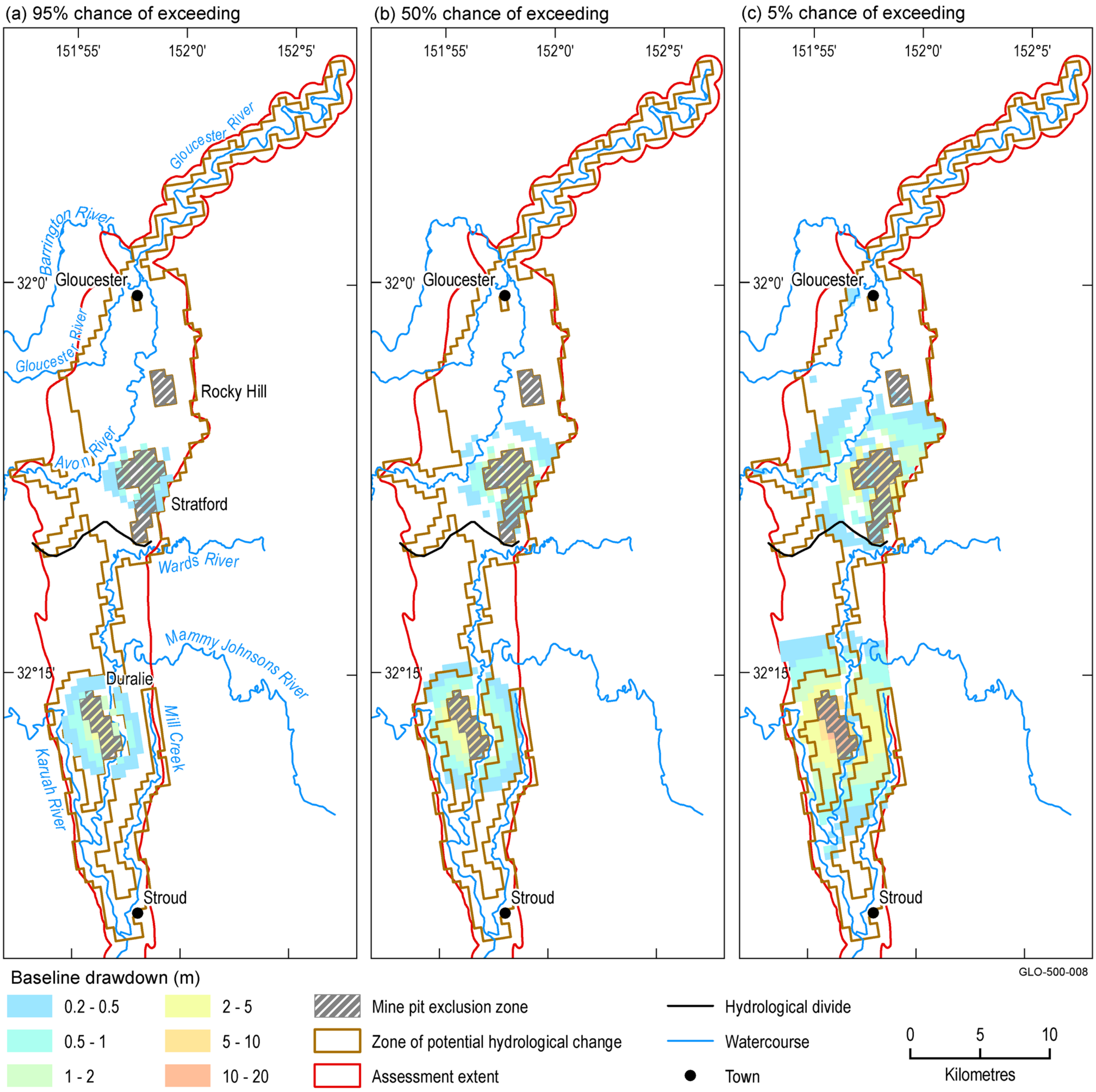

Figure 7 Baseline drawdown (m) in the regional watertable (95%, 50% and 5% chance of exceeding given values of drawdown)

Baseline drawdown is the maximum difference in drawdown under the baseline relative to no coal resource development (Box 3). Results are shown as percent chance of exceeding drawdown thresholds (Box 5). These appear in Post et al. (2018) as percentiles. Areas reported for drawdown exclude the mine pit exclusion zones.
Data: Bioregional Assessment Programme (Dataset 1)

Box 4 The zone of potential hydrological change

A zone of potential hydrological change (Figure 1) was defined to rule out potential impacts. It was derived by combining the groundwater zone of potential hydrological change with the surface water zone of potential hydrological change (see Section 3.3.1 in Post et al. (2018)). These zones were defined using hydrological response variables, which are the hydrological characteristics of the system that potentially change due to coal resource development – for example, groundwater drawdown or the number of low-flow days.

The groundwater zone is the area with at least a 5% chance of greater than 0.2 m drawdown (Box 3) due to additional coal resource development. This threshold is consistent with the most conservative minimal impact thresholds in NSW state regulations. The groundwater zone was defined by changes in the regional watertable from which most ecological assets source water.

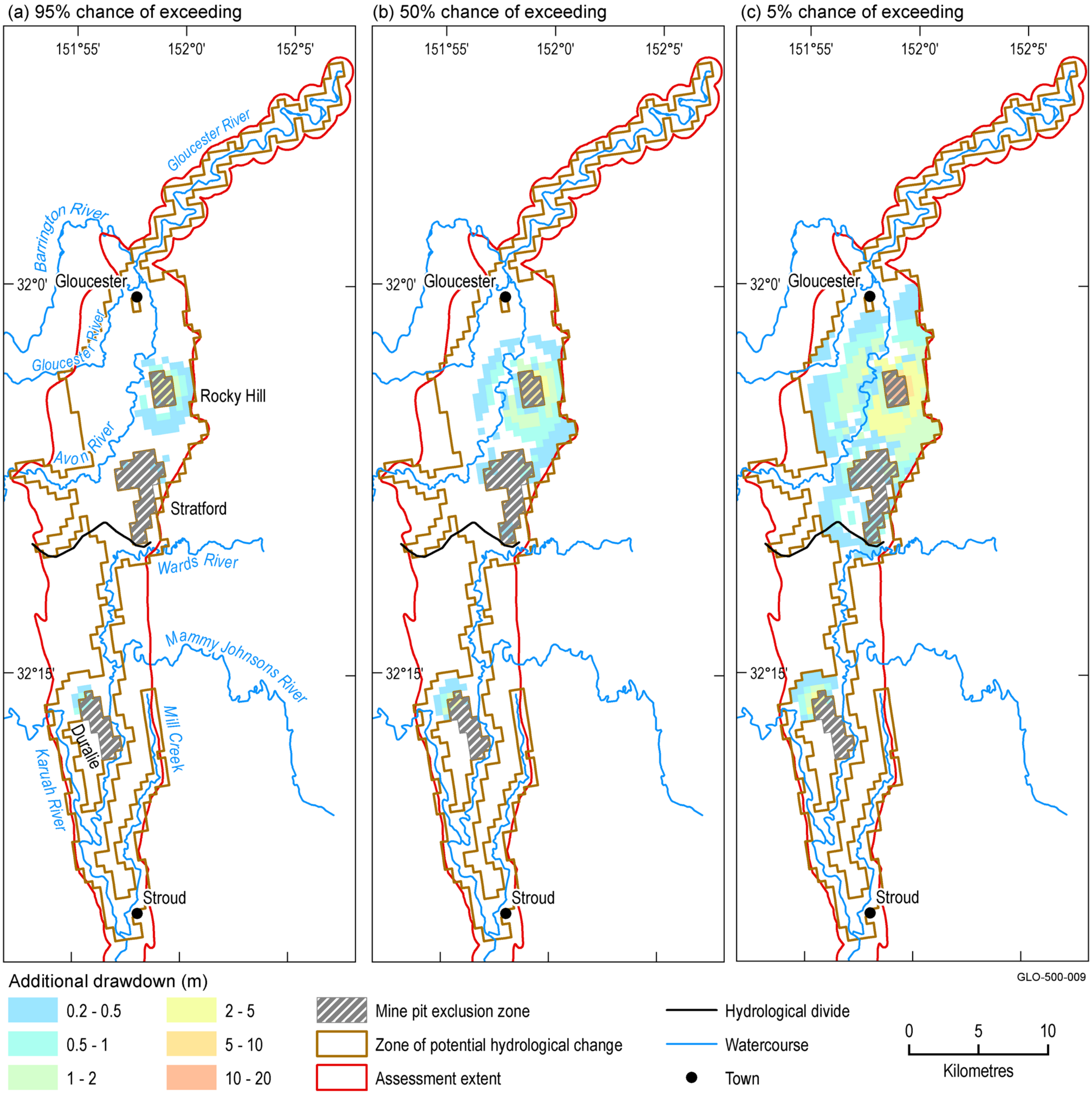

Figure 8 Additional drawdown (m) in the regional watertable (95%, 50% and 5% chance of exceeding given values of drawdown)

Additional drawdown is the maximum difference in drawdown between the coal resource development pathway and baseline, due to additional coal resource development (Box 3). Results are shown as percent chance of exceeding drawdown thresholds (Box 5). These appear in Post et al. (2018) as percentiles. Areas reported for drawdown exclude the mine pit exclusion zones.
Data: Bioregional Assessment Programme (Dataset 1)

The surface water zone contains those river reaches where there is at least 5% chance that a change in any one of eight surface water hydrological response variables used in the Gloucester subregion exceeds specified thresholds (see Table 5 in Post et al. (2018)).

Water-dependent ecosystems 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. This assessment used regional-scale receptor impact models (Box 8) to translate predicted changes in hydrology within the zone into a distribution of ecological outcomes that may arise from those changes. However, to take account of local conditions, smaller-scale assessments may need to be undertaken.

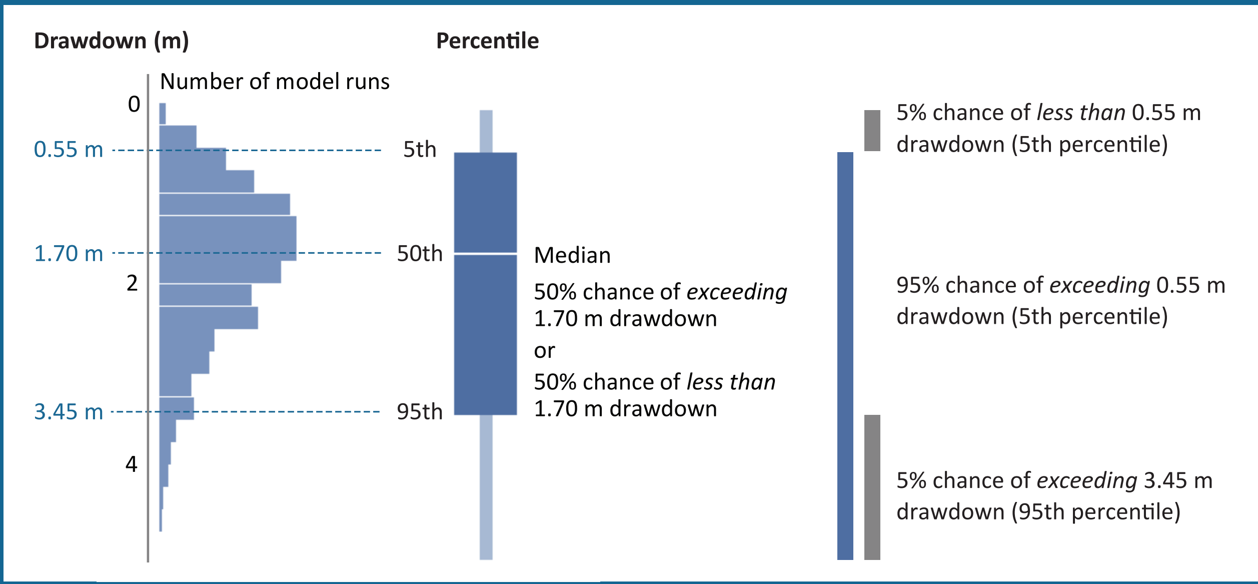

Figure 9 Illustrative example of probabilistic drawdown results using percentiles and percent chance

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 or changes in streamflow 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 9). This approach allows an assessment of the likelihood of exceeding a given magnitude of change, and underpins the assessment of risk.

Hydrological models require information about physical properties, such as the thickness of geological layers and how porous aquifers are. Because it is unknown how these properties vary across the entire assessment extent (both at surface and at depth), 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, which enables decision makers to anticipate potential impacts more precisely. A wider range indicates less agreement between the model runs and hence more uncertainty in the outcome.

The distributions created from these model runs are expressed as probabilities that hydrological response variables (such as drawdown) exceed relevant thresholds, as there is no single 'best' estimate of change.

In this assessment, results are shown as a 95%, 50% or 5% 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 models are based on the best available information, if the range of parameters used is not realistic, or if the modelled system does not reflect reality sufficiently, these modelled probabilities might vary from the actual changes that occur in reality. These regional-level models provide evidence to rule out potential cumulative impacts due to additional coal resource development in the future.

The assessment extent was divided into smaller square assessment units and the probability distribution (Figure 9) was calculated for each. In this synthesis, results are reported with respect to the following key areas (Figure 10):

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 ecosystems

C. assessment units 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. assessment units 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).

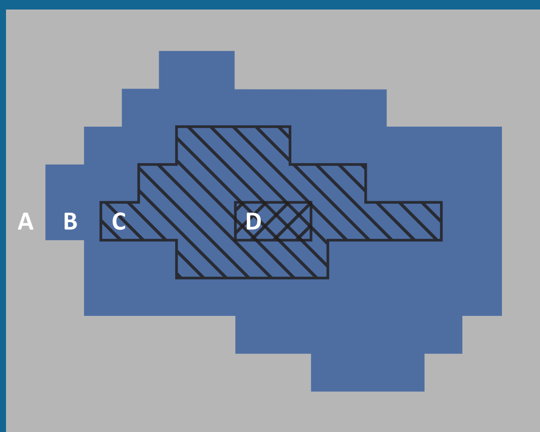

Figure 10 Key areas for reporting probabilistic results

Surface water

The zone of potential hydrological change in the Gloucester subregion has 242 km of stream network. Hydrological modelling shows surface water changes will be relatively small. Most streamflow changes are predicted to occur in the north of the subregion in Avondale Creek, Dog Trap Creek, Waukivory Creek, Oaky Creek and the Avon River (Figure 3), near where two of the three coal mines and most of the CSG wells are located.

Maximum changes in low-flow days, high-flow days and annual flows due to additional coal resource development are the hydrological response variables (Box 4) chosen to represent the modelled changes in overall streamflow. Changes in these variables indicate the dominant hydrological drivers: low flows are sensitive to both the interception of surface runoff and the cumulative impact on baseflow over time caused by groundwater drawdown, while high flows are more sensitive to interception of surface runoff (Zhang et al., 2018). Changes in other hydrological response variables can be viewed on the BA Explorer at www.bioregionalassessments.gov.au/explorer/GLO/hydrologicalchanges.

Key finding 4: It is *very unlikely* that low-flow days will increase by more than 20 days per year in the Avon River near Rocky Hill, Stratford and Gloucester Gas Project Stage 1, due to additional coal resource development. These changes are similar to, or greater than, the interannual variability under the baseline, which is more likely to move the system outside the range of conditions previously encountered.

Changes in high-flow days and annual flow are predicted to occur in a much smaller length (8.5 and 1.7 km of streams, respectively) and are both less than the interannual variability under the baseline at most locations.

Low-flow days

Regional modelling quantified the median change in the number of low-flow days due to additional coal resource development for 251 km of the 344 km of streams covered by the assessment.

Results indicated that it is *very unlikely* that more than 92 km of streams will experience increases in low-flow days of more than 3 per year. There is a 5% chance that 47 km of modelled streams in the zone will experience 20 or more additional low-flow days per year, and a 5% chance that 5.7 km of these will experience 80 or more additional low-flow days per year.

The median result indicates increases in low-flow days of between 3 and 20 days per year in the Avon River between its junctions with Avondale Creek and the Gloucester River, with no increases of more than 20 days per year expected in any streams (Figure 11). There are no modelled streams where increases in the number of low-flow days due to additional coal resource development are *very likely*. See Figure 11 for details.

It was not possible to quantify the median change in low-flow days for 93 km of streams, including Avondale, Dog Trap and Waukivory creeks and part of Mammy Johnsons River, which flow close to the mine sites (see Figure 11). This was either because of their proximity to the mines or due to difficulties in extrapolating results from model nodes to links. For further explanation, see Section 3.2.3 of Post et al. (2018). Potential changes in these streams cannot be ruled out.

Modelled increases in the number of low-flow days are less than the interannual variability seen under the baseline in most locations and for most probabilities of change (Figure 12). However, at some locations near the Rocky Hill and Stratford mines, there is a 5% chance that some of these increases are similar to or even greater than the interannual variability seen under the baseline (Figure 12), which is more likely to move the system outside the range of conditions previously encountered. For more information, see Section 3.3.3.1 of Post et al. (2018).

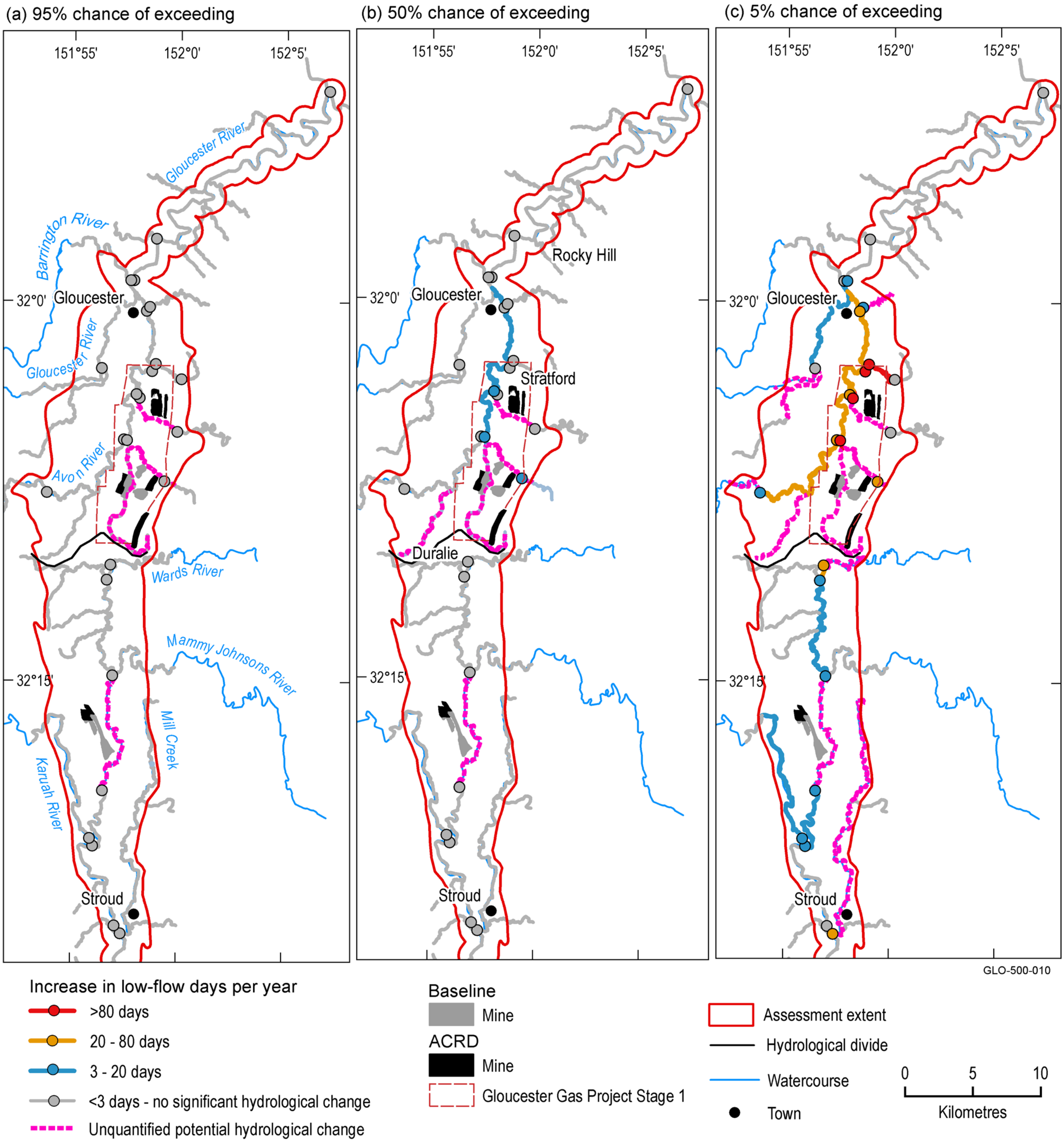

Figure 11 Maximum increase in the number of low-flow days due to additional coal resource development (95%, 50% and 5% chance of exceeding given values of change)

The coal resource development pathway includes baseline and additional coal resource developments (ACRD). The difference in low-flow days between the coal resource development pathway and baseline is due to additional coal resource development (ACRD). Results are shown as percent chance of exceeding given values of change (Box 5). These appear in Post et al. (2018) as percentiles.
Data: Bioregional Assessment Programme (Dataset 1)

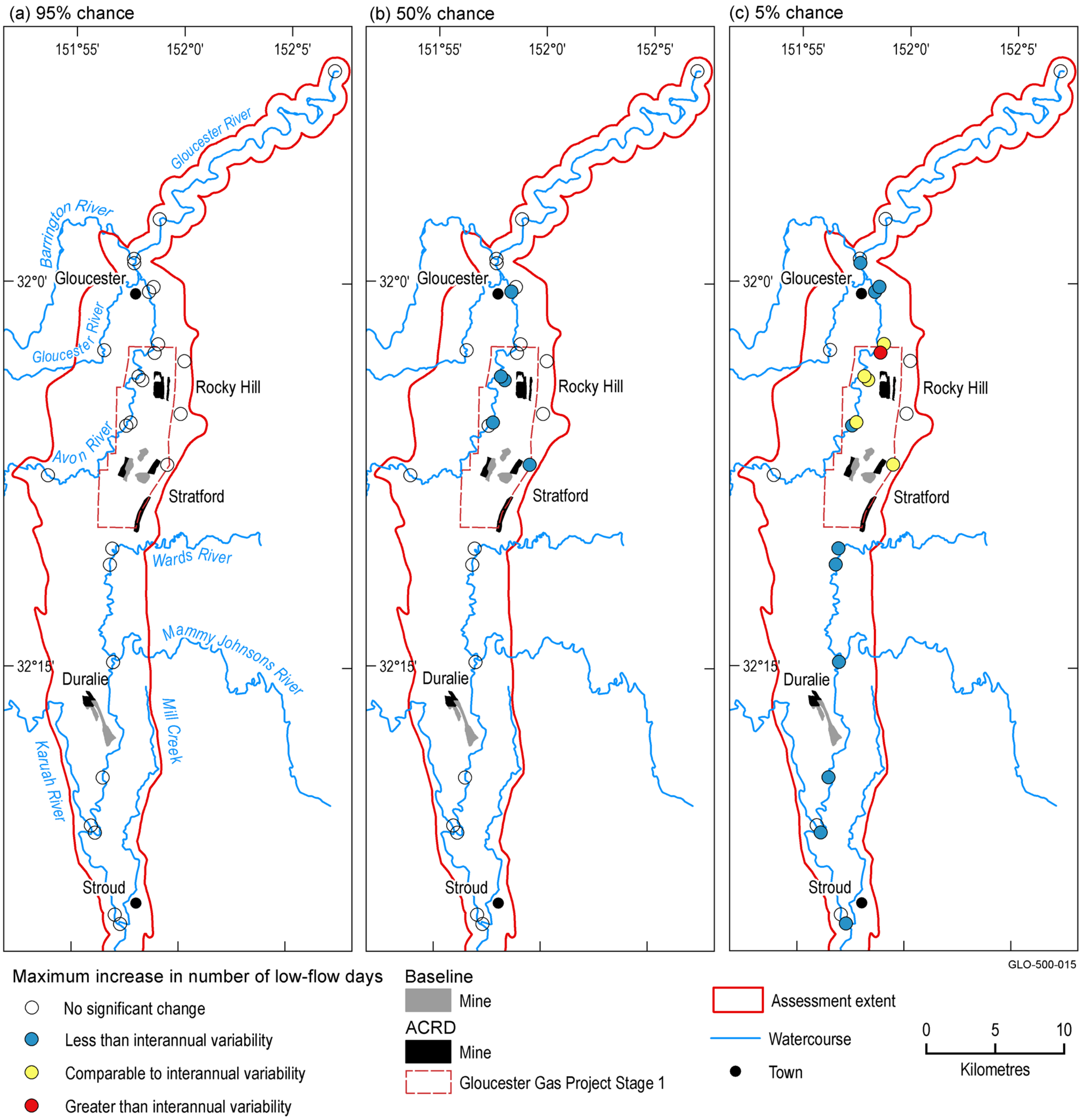

Figure 12 Ratio of maximum increase in number of low-flow days due to additional coal resource development to the interannual variability in the number of low-flow days (95%, 50% and 5% chance)

The coal resource development pathway includes baseline and additional coal resource developments (ACRD). The difference in low-flow days between the coal resource development pathway and baseline is due to additional coal resource development. Results are shown as percent chance (Box 5). These appear in Post et al. (2018) as percentiles.
Data: Bioregional Assessment Programme (Dataset 1)

High-flow days

Additional coal resource development is more likely to affect low flows than high flows, reflected by the shorter length of streams likely to experience changes in high-flow days (Figure 23 and Table 10 in Section 3.3 of Post et al. (2018)).

It is *very unlikely* that more than 46 km of streams in the 344 km in the assessment extent will experience decreases of more than 3 high-flow days per year. There is a 5% chance that 8.5 km of these streams might experience a reduction of 10 or more high-flow days per year. There is a 5% chance that 1.7 km of the Avon River might experience a reduction of 20 or more high-flow days per year. Under the median result, modelling indicates that 8.5 km of the Avon River will experience a reduction of 3 to 10 high-flow days per year, with no streams experiencing more than this reduction. In some sections of Dog Trap Creek, it is *very likely* that there will be a reduction of between 3 and 10 high-flow days per year.

Thirty-one km of streams may see median decreases of more than 3 high-flow days per year, but these streams were unable to be quantified, either because of their proximity to mine sites, or due to difficulties in extrapolating results from model nodes to links.

These decreases in the number of high-flow days are less than the interannual variability seen under the baseline in most locations and for most probabilities of change (Figure 25 in Section 3.3 of Post et al. (2018)).

Annual flow

Modelling predicted that it is *very unlikely* that more than 55 km of streams within the assessment extent will experience decreases of more than 1% in annual flow.

Immediately downstream of mine sites, 26 km of streams are *very likely* to experience reductions in annual flow of more than 1%, and 1.7 km of Dog Trap Creek is *very likely* to experience reductions of more than 5%. See Figure 26 and Table 11 in Section 3.3 of Post et al. (2018) for more information.

Another 46 km of streams may see median decreases in annual flow of greater than 1%, but these streams were unable to be quantified, either because of their proximity to mine sites, or due to difficulties in extrapolating results from model nodes to links.

These decreases in annual flow are less than the interannual variability seen under the baseline in most locations and for all probabilities of change (Figure 28 in Section 3.3 of Post et al. (2018)).

Water quality

Potential changes in hydrology could lead to changes in water quality, but these were not modelled. A number of regulatory requirements are in place in NSW to minimise potential water quality impacts from coal resource developments. See Section 3.3.4 of Post et al. (2018) for more detail. All four additional coal resource developments are operating under a 'no discharge' rule which means all water is to be retained and reused on site. Because of this, potential impacts on water quality from additional coal resource development are considered unlikely in the Gloucester subregion. Streamflow and groundwater level data suggest that any reduction in baseflow due to drawdown from additional coal resource developments is likely to lead to a decrease in stream salinity, whereas reductions in catchment runoff could lead to increases. Section 1.5.2 of Rachakonda et al. (2015) provides details of stream and groundwater salinities in the Gloucester subregion. To quantify the likely effect requires more local data and modelling.

FIND MORE INFORMATION

Explore the hydrological changes in more detail on the BA Explorer, at www.bioregionalassessments.gov.au/explorer/GLO/hydrologicalchanges.

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

Observations analysis, statistical analysis and interpolation, product 2.1-2.2 (Frery et al., 2018)

Water balance assessment, product 2.5 (Herron et al., 2018)

Surface water numerical modelling, product 2.6.1 (Zhang et al., 2018)

Groundwater numerical modelling, product 2.6.2 (Peeters et al., 2018)

Impact and risk analysis, product 3-4 (Post et al., 2018)

Surface water modelling, submethodology M06 (Viney et al., 2016)

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

Analysing impacts and risks, submethodology M10 (Henderson et al., 2018)

Summary of hydrological response variables from surface water modelling (Dataset 7)

Surface water model (Dataset 8)

Regional watertable (Dataset 22)

Deep groundwater model (Dataset 9)

Shallow groundwater model (Dataset 10)

Summary of groundwater drawdown by assessment unit (Dataset 22)

Groundwater model (Dataset 11)

What are the potential impacts of additional coal resource development on ecosystems?

The impact and risk analysis investigated how hydrological changes due to additional coal resource development may affect ecosystems, such as wetlands, rivers or groundwater-dependent ecosystems. These ecosystems were classified into landscape classes (Box 6; Section 2.3.3 in Dawes et al. (2018)) which were categorised into five landscape groups:

- 'Riverine'
- 'Groundwater-dependent ecosystem (GDE)'
- 'Estuarine'
- 'Non-groundwater dependent ecosystem (Non-GDE)'
- 'Economic land use'.

The impact and risk analysis (Box 7) focused on landscape classes that intersect the zone of potential hydrological change (Box 4). Any ecosystem or asset wholly outside of this zone is considered *very unlikely* to be impacted due to additional coal resource development.

For potentially impacted ecosystems within the zone, receptor impact models (Box 8) were used to translate predicted changes in hydrology into a distribution of ecological outcomes that may arise from those changes. These models used indicators of the health of the ecosystem, such as taxa richness, or canopy cover of vegetation, to assess the potential ecological impacts of hydrological changes.

Box 6 Understanding the landscape classification

The natural and human-modified ecosystems in the subregion were classified into 20 landscape classes (Table 3 and Figure 9 in Dawes et al. (2018)) to enable a systematic and comprehensive analysis of potential impacts on, and risks to, the water-dependent assets nominated by the community. The landscape classification was based on the subregion's geology, geomorphology, hydrogeology, land use and ecology. These landscape classes were aggregated into five landscape groups, based on their likely response to hydrological changes. Definitions for landscape classes and landscape groups for the Gloucester subregion are available online at environment.data.gov.au/def/ba/landscape-classification/gloucester-subregion.

Box 7 Analysing impact and risk

Potential impacts to water-dependent ecosystems and assets were assessed by overlaying their location on the zone of potential hydrological change (Box 4) to identify the hydrological changes that a particular asset or ecosystem might experience.

- **Outside this zone, ecosystems and assets** are ***very unlikely* to be impacted** by hydrological changes due to additional coal resource development.
- **Inside this zone**, ecosystems and assets are **potentially impacted**.

Within the zone, not all water-dependent ecosystems or assets will be affected, as this depends on their reliance on groundwater or surface water. Hydrological changes due to additional coal resource development may be large, but within the range of natural seasonal and climatic variability, and so may not affect water-dependent ecosystems or assets. Alternatively, small changes may affect sensitive ecosystems that have a strong reliance on groundwater or surface water.

For ecological assets, the assessment considered the potential impact to the habitat of the species, not potential impacts to the species themselves.

Ecosystems that fall within the mine pit exclusion zone are likely to be directly impacted, but as estimates of drawdown are unreliable, the degree of impact is not possible to quantify. Similarly, the surface water modelling close to mine pits (Figure 11) cannot quantify the degree of impact on some streams.

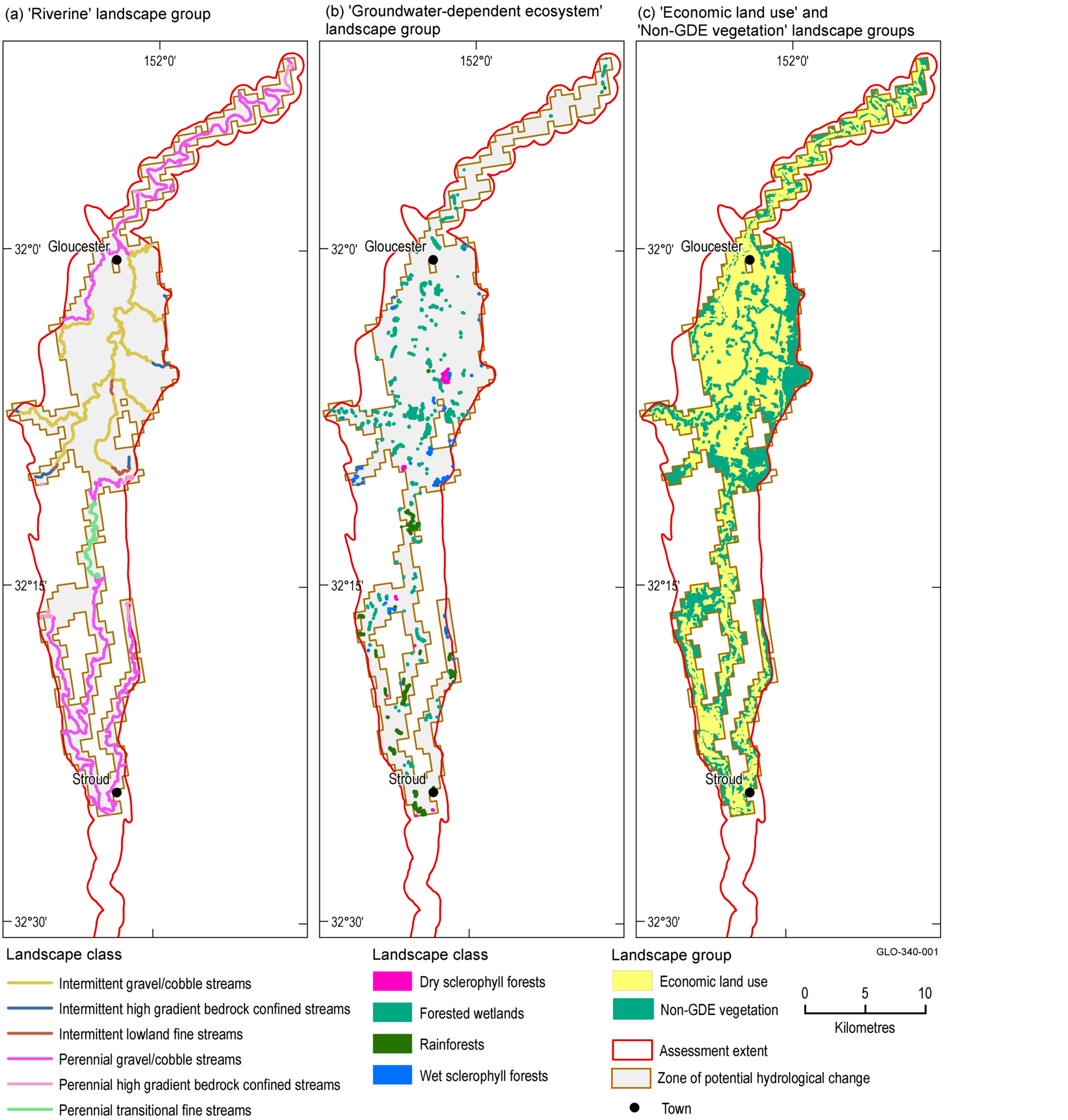

Figure 13 Landscape classes in the zone of potential hydrological change

Groundwater-dependent ecosystems (GDEs) are exaggerated (not to scale) for clarity. Landscape classes in the 'Estuarine' landscape group are not shown because they are not water dependent.

Data: Bioregional Assessment Programme (Dataset 12, Dataset 13, Dataset 15); NSW Office of Water (Dataset 14); ABARES (Dataset 16)

Ecosystems

Which ecosystems are *very unlikely* to be impacted?

Key finding 5: Potential impacts due to additional coal resource development are ruled out for all of the 139 km^2 of 'Native vegetation' landscape class in the assessment extent, as it is not groundwater dependent. All estuarine ecosystems, 7.05 km^2 of the 10.3 km^2 of groundwater-dependent ecosystems, and 67 km of the 344 km of streams lie outside the zone of potential hydrological change, and so are *very unlikely* to be impacted.

Most ecosystems in the zone of potential hydrological change (246 km^2 or 99%, see Table 14 in Post et al. (2018)) are classified as non-groundwater-dependent vegetation and economic land use (Figure 13). Non-groundwater-dependent vegetation is not considered water dependent for the purposes of bioregional assessments. While some economic land use classes such as irrigated agriculture are water dependent, impacts on economic assets are not evaluated by landscape class. Instead, economic assets are assessed by analysing changes in the availability of groundwater or surface water, and against specific management thresholds. This is explained further in Section 3.5 of Post et al. (2018) and in 'What are the potential impacts of additional coal resource development on water-dependent assets?' on page 22 of this synthesis.

The following ecosystems in the south of the assessment extent are outside the zone of potential hydrological change and thus impacts are *very unlikely*:

- the estuarine reaches of the Karuah River
- 1.1 km^2 of freshwater wetlands
- 65 km of perennial streams and 3 km of intermittent streams, mainly along the Karuah River.

There are no springs in the Gloucester subregion.

Which ecosystems are potentially impacted?

Key finding 6: There are 242 km of streams and 3.3 km^2 of groundwater-dependent ecosystems in the zone of potential hydrological change (Table 1). Modelled hydrological changes are likely to lead to minimal ecological impacts in intermittent and perennial gravel/cobble streams. It is *very likely* that modelled drawdown under the 3.3 km^2 of groundwater-dependent ecosystems is less than 2 m.

Riverine ecosystems

Receptor impact models (Box 8) were built to predict how hydrological changes (as measured by a suite of hydrological response variables) might result in changes to the ecological condition of intermittent and perennial gravel/cobble streams, which make up about 75% of the subregion's streams. The zone of potential hydrological change includes 78 km of the 81 km of intermittent gravel/cobble streams and 133 km of the 175 km of perennial gravel/cobble streams in the assessment extent (Table 1). Perennial gravel/cobble streams are found along the Gloucester River in the north, and along the Karuah and Mammy Johnsons rivers in the south. Most intermittent gravel/cobble streams are found in the Avon River, a major tributary of the Gloucester River, and its tributaries. Within the zone, only 3% of perennial streams and 2% of intermittent streams were reported as being in good condition (Figure 31 of Post et al. (2018)).

Overall, modelling suggests it is unlikely that perennial gravel/cobble streams will experience large changes in groundwater drawdown, changes in baseflow index, or increased zero-flow days (averaged over 30 years) as a result of additional coal resource development. Small-decreases in the frequency of overbench and overbank flows are possible for short reaches. An increase in zero-flow days (averaged over 30 years) may occur in short sections of intermittent gravel/cobble streams due to additional coal resource development but large lengths of stream are not expected to experience changes.

Outputs of receptor impact models suggest that these modelled hydrological changes will have a minimal impact on the chosen indicators of ecological condition (Box 8). Details can be found in Section 3.4.3.3 of the impact and risk analysis (Post et al., 2018).

Groundwater-dependent ecosystems

The water requirements of groundwater-dependent ecosystems in the subregion are poorly understood and the frequency, timing and duration of groundwater use are uncertain. Therefore, receptor impact models were not developed. Instead, qualitative models were developed for forested wetlands, wet sclerophyll forests and dry sclerophyll forests. These models predicted that groundwater drawdown would have negative impacts on all vegetation-related variables, including overstorey and understorey (ground layer) cover, and recruitment.

There are 3.3 km^2 of groundwater-dependent ecosystems in the zone of potential hydrological change (Table 1), of which 0.4 km^2 is in the mine pit exclusion zone (Table 23 in Post et al. (2018)). Modelling of the additional coal resource developments indicated a 5% chance of about 1.1 km^2 of groundwater-dependent ecosystems being subject to a drawdown of between 0.2 and 2 m. Most of the impact would be in forested wetlands. No groundwater-dependent ecosystems were modelled to be subject to more than 2 m of drawdown. These qualitative models did not, however, predict the magnitude or likelihood of potential ecological impacts.

Table 1 Extent of each landscape class in the assessment extent and in the zone of potential hydrological change, and the landscape classes that have qualitative and/or receptor impact models

The extent of each landscape class is either an area of vegetation (km^2) or length of stream network (km). See Table 14 in Post et al. (2018) for results for the 'Non-GDE' and 'Economic land use' landscape groups.

Landscape group	Landscape class[a]	Extent in assessment extent	Extent in zone of potential hydrological change	Qualitative model	Receptor impact model
Riverine	Intermittent – gravel/cobble streams (km)	81	78	Yes	Yes
	Intermittent – high gradient bedrock confined streams (km)	5	5	No	No
	Intermittent – lowland fine streams (km)	4	4	No	No
	Perennial – gravel/cobble streams (km)	175	133	Yes	Yes
	Perennial – high gradient bedrock confined streams (km)	28	9	No	No
	Perennial – lowland fine streams (km)	1	0	No	No
	Perennial – transitional fine streams (km)	17	13	No	No
	Subtotal (km)	**311**	**242**	**na**	**na**
Groundwater-dependent ecosystem (GDE)	Dry sclerophyll forests (km^2)	1.4	0.2	Yes	No
	Forested wetlands (km^2)	5.2	1.9	Yes	No
	Freshwater wetlands (km^2)	1.1	0	No	No
	Rainforests (km^2)	2.2	1.0	No	No
	Wet sclerophyll forests (km^2)	0.4	0.15	Yes	No
	Subtotal (km^2)	**10.3**	**3.25**	**na**	**na**
Estuarine	Barrier river (km)	33	0	No	No
	Saline wetlands (km^2)	5.4	0	No	No
	Total (all lengths of stream network, km)	**344**	**242**	**na**	**na**
	Total (all areas of vegetation, km^2)	**15.7**	**3.25**	**na**	**na**

[a]Definitions for landscape classes and landscape groups for the Gloucester subregion are available at http://environment.data.gov.au/def/ba/landscape-classification/gloucester-subregion.
na = not applicable
Data: Bioregional Assessment Programme (Dataset 1)

FIND MORE INFORMATION

Explore potential impacts on ecosystems in more detail on the BA Explorer, at www.bioregionalassessments.gov.au/explorer/GLO/landscapes.

Conceptual modelling, product 2.3 (Dawes et al., 2018)

Impact and risk analysis, product 3-4 (Post et al., 2018)

Assigning receptors to water-dependent assets, submethodology M03 (O'Grady et al., 2016)

Receptor impact modelling, submethodology M08 (Hosack et al., 2018a)

Analysing impacts and risks, submethodology M10 (Henderson et al., 2018)

Impact and risk analysis database (Dataset 1)

Landscape classification (Dataset 17)

Landscape class spatial overlay by assessment unit (Dataset 18)

Box 8 Receptor impact models

Receptor impact models translate predicted changes in hydrology into ecological outcomes that may arise from those changes. Applying receptor impact models across ecosystems allows a better understanding of how changed hydrological conditions may impact water-dependent assets within those ecosystems at specified points in time.

To assess potential ecological outcomes:

1. Experts first choose **receptor impact variables**, characteristics that serve as indicators of the ecological condition of an ecosystem. These are specifically chosen to be representative of a landscape class. For each indicator, experts also choose one or more hydrological response variables, chosen because the indicator is sensitive to changes in those hydrological response variables.

   For example, in the Gloucester subregion, for perennial gravel/cobble streams three indicators (bolded) were chosen to predict changes that are sensitive to the following hydrological response variables:

   - **percent canopy cover**: overbench flow, overbank flow, groundwater drawdown
   - **mean abundance of caddisfly larvae**: baseflow index, number of zero-flow days (averaged over 30 years)
   - **mean abundance of eel-tailed catfish per 100 m of stream length**: baseflow index, number of zero-flow days (averaged over 30 years).

   For intermittent gravel/cobble streams in the Gloucester subregion, the indicator (bolded) and hydrological response variable were:

   - **richness of hyporheic taxa in a 6 L sample of stream water**: number of zero-flow days (averaged over 30 years). (Hyporheic taxa are the organisms found where surface water and groundwater mix below the bed of a stream.)

2. Hydrological models are used to quantify changes in the hydrological response variables.

3. Receptor impact models are used to predict changes in the indicator for a landscape class that result from the changes in hydrological response variables. The changes in the indicator reflect the magnitude of potential ecological impacts for that ecosystem.

What are the potential impacts of additional coal resource development on water-dependent assets?

The impact and risk analysis investigated how hydrological changes due to additional coal resource development may affect water-dependent assets, such as bores, heritage sites or habitats of species.

A total of 108 water-dependent assets listed in the asset register (Dataset 19; Bioregional Assessment Programme, 2017; McVicar et al., 2015) were analysed for the subregion. They include:

- **67 ecological assets**, including the Karuah River and Port Stephens estuaries; 23 river or stream reaches, tributaries, anabranches or bends; three groundwater features (Karuah Alluvium, Manning Alluvium and New England Fold Belt); and 39 habitats of species
- **22 economic assets**, including water source areas, monitoring bores, water access licences and basic water rights, represented by groundwater production bores and surface water extraction points
- **19 sociocultural assets.**

Key finding 7: Of the 108 water-dependent assets nominated for the subregion, 30 are *very unlikely* to be impacted, because they lie outside the zone of potential hydrological change.

Ecological assets

Which ecological assets are *very unlikely* to be impacted?

Fifteen ecological assets fall outside the zone of potential hydrological change and so are *very unlikely* to be impacted. These include the Karuah River and Port Stephens estuaries; seven river or stream reaches, tributary anabranch or bends; and seven habitats of species.

The potential for impacts on ecological assets associated with riverine ecosystems is assessed as *very unlikely* (Section 3.5 in Post et al. (2018)).

It is *very unlikely* that more than 6 ha of a threatened ecological community (Lowland Subtropical Rainforest) are impacted (Table 28 in Post et al. (2018)).

Which ecological assets are potentially impacted?

Key finding 8: No detectable impacts are likely for ecological assets in the southern part of the subregion, given the limited additional coal resource development in this area. In the northern part of the subregion, potential impacts on ecological assets are expected to be minor and localised due to the small magnitude of modelled hydrological changes.

Out of the 67 ecological water-dependent assets in the subregion's assessment extent, 52 assets are subject to potential hydrological change due to additional coal resource development because they are both water-dependent and within the zone of potential hydrological change. However, only 1.1 km^2 associated with groundwater-dependent ecosystems is predicted to have potential for impacts on ecological assets (Table 24 in Post et al. (2018)).

Qualitative modelling predicted that groundwater drawdown negatively impacts on the potential habitat for koalas. An area of 0.6 km^2 is the median estimate of potential koala habitat that overlaps with groundwater-dependent ecosystems experiencing drawdown greater than 0.2 m. Note that the chance of impact to potential habitats is often highly uncertain based on qualitative modelling.

Plant species and the threatened ecological community (Lowland Subtropical Rainforest) have very small areas (from 0 to 6 ha) of associated landscape classes within the zone of potential hydrological change (Figure 50 in Post et al. (2018)). Habitats where animal species are known to live range from 15 ha for the stuttering frog to 400 ha for the grey-headed flying fox and spot-tailed quoll.

Information about known habitats associated with species in groundwater-dependent ecosystems, and predictions about the occurrence of species within the assessment extent, are sourced from the BioNet database (NSW Office of Environment and Heritage, 2017).

The presence of potential habitats within the zone of potential hydrological change does not mean species are associated with particular landscape classes. For example, Guthrie's grevillea is known to be associated with the 'Wet sclerophyll forests' landscape class but not with any of the other groundwater-dependent ecosystem (GDE) landscape classes. The Australasian bittern is only known to be associated with landscape classes that lie outside the zone, which are freshwater wetlands and saline wetlands. Also, not all habitat with potential to house certain species are known to occur within the Gloucester assessment extent. For example, the Australasian bittern, eastern bristlebird, red goshawk and Hastings River mouse are not known to occur within the Karuah-Manning Interim Biogeographic Regionalisation for Australia (IBRA) subregion which encompasses the Gloucester subregion.

Economic assets

Which economic assets are *very unlikely* to be impacted?

The Lower Manning River water source is outside the zone of potential hydrological change and thus *very unlikely* to be impacted. Thirty-six groundwater bores and 58 surface water extraction points in the Gloucester water-dependent asset register (Dataset 19; Bioregional Assessment Programme, 2017) are outside the zone of potential hydrological change and are thus *very unlikely* to be impacted.

A further 93 bores in the zone are unlikely to be impacted because they are monitoring bores or in fractured rock aquifers outside the area where there is at least a 5% chance that drawdown will be greater than 0.2 m.

Which economic assets are potentially impacted?

Five unregulated and alluvial water sources and two groundwater sources are potentially impacted by hydrological changes due to additional coal resource development.

Of the 339 bores and surface water extraction points in the zone, 304 are potentially impacted due to additional coal resource development. As the 58 monitoring bores in the zone are not used to pump water for beneficial use, impacts on these of changes in hydrology were not considered further for these bores. There is therefore a potential for impacts due to additional coal resource development at 246 bores and surface water extraction points in the zone of potential hydrological change (Figure 54, Table 32 and Table 33 in Post et al. (2018)).

The Gloucester Basin and New England Fold Belt groundwater sources are potentially impacted by groundwater drawdown due to additional coal resource development. The Avon River, Bowman River, Karuah River, Lower Barrington/Gloucester River and Upper Gloucester River unregulated and alluvial water sources are potentially impacted surface water economic assets (Figure 14).

Surface water economic assets

Key finding 9: The reliability of surface water supply in the Gloucester assessment extent is *very unlikely* to be affected by additional coal resource development. No change in cease-to-pump days is seen in the Upper Gloucester River and Karuah River (upper management zone) water sources. It is *very likely* that there will be fewer than 3 additional low-flow days per year in the Avon River, with an even smaller or no impact on cease-to-pump days.

Cease-to-pump rules apply to most water sources in NSW to ensure sufficient water is retained in unregulated rivers to meet environmental requirements. In the Avon River water source, pumping must cease when there is no visible flow into or out of the pumping pool; in the upriver management zone of the Karuah River, pumping must cease when flows are equal to or less than 3.5 ML per day at the Booral stream gauge; and in the Upper Gloucester River, when flows are equal to or less than 1 ML per day at the Gloucester River gauge.

Under the baseline for the 2013 to 2102 period, surface water modelling indicates a 5% chance that cease-to-pump days in the Karuah River (upriver management zone) and the Upper Gloucester water sources could exceed 50 days per year and 35 days per year, respectively. For the Avon River water source, there is a 5% chance of 80 or more days of flows per year below 1 ML per day, which is not the cease-to-pump threshold, but an indicator of the low-flow regime for the 90-year climate sequence modelled. This number of cease-to-pump days is *very unlikely* to increase by more than 3 days per year in the Avon River and 1 day per year in the Karuah and Upper Gloucester rivers.

It is *very unlikely* that reduction in water availability due to additional coal resource development, as assessed by a change in mean annual flows, will exceed 1.6 GL per year in either the Upper Gloucester River or Avon River water sources. This is well within the interannual variability due to climate, and corresponds to 1% and 2% changes relative to the assessment baseline (Table 34 in Post et al. (2018)).

Groundwater economic assets

Key finding 10: Five bores have a 5% chance of drawdown exceeding 2 m. Four are monitoring bores and therefore unlikely to lead to an economic impact; the one production bore is owned by AGL.

For more information see Table 37 in Post et al. (2018).

The *NSW Aquifer Interference Policy* (NSW Office of Water, 2012) requires that any proposal to extract water from an aquifer must address minimal impact considerations. Generally, if drawdown at a water supply work exceeds 2 m, then 'make good' provisions should apply.

Sociocultural assets

Which sociocultural assets are *very unlikely* to be impacted?

As of February 2016, 19 sociocultural assets in the subregion were identified as water dependent. Eighteen of them are located outside the zone of potential hydrological change, and are therefore *very unlikely* to be impacted.

Fifteen Indigenous assets were included in the sociocultural assets registered, including 11 assets for which locations were not provided. Based on the association of these assets with marine and estuarine environments, they are almost certainly located outside the zone of potential hydrological change and therefore not likely to be impacted. Information on Indigenous water assets is also available in Constable and Love (2015).

Which sociocultural assets are potentially impacted?

Key finding 11: The Washpool in the Karuah River, north of the town of Washpool, is the only sociocultural asset in the zone of potential hydrological change. However, due to the very small hydrological changes at this location, it is unlikely to be impacted by additional coal resource development.

The Washpool (Figure 49 in Section 3.5 of Post et al. (2018)) is a locally significant heritage site along the Karuah River north of the town site of Washpool at the Stroud Hill Road bridge. Although it is located within the zone of potential hydrological change, the small alterations to flow predicted at this location are unlikely to result in any change in water level at the Washpool, and are not expected to affect the social amenity provided by the site.

FIND MORE INFORMATION

Explore assets in more detail on the BA Explorer, at www.bioregionalassessments.gov.au/explorer/GLO/assets.

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

Water-dependent asset register, list for product 1.3 (Bioregional Assessment Programme, 2017)

Impact and risk analysis, product 3-4 (Post et al., 2018)

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

Analysing impacts and risks, submethodology M10 (Henderson et al., 2018)

Impact and risk analysis database (Dataset 1)
Asset database (Dataset 19)

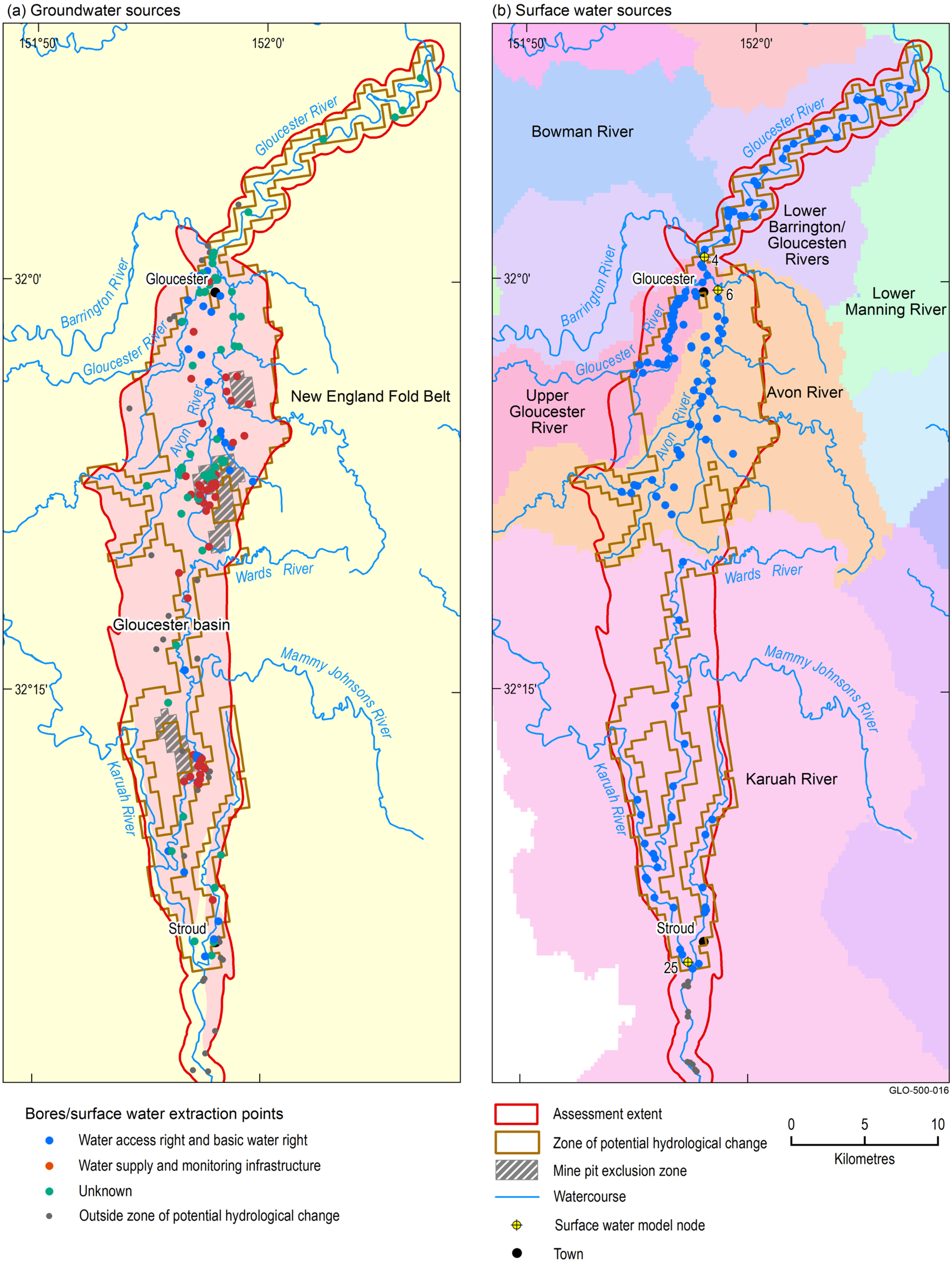

Figure 14 Economic assets in the zone of potential hydrological change

Pastel colours in background represent different water source areas.
Data: Bioregional Assessment Programme (Dataset 19, Dataset 20, Dataset 21)

How to use this assessment

Findings from bioregional assessments 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 achieved through the rule-out process, which directs focus onto areas where hydrological changes are predicted. This process has 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 predicted the likelihood of exceeding levels of potential hydrological change at a **regional scale**. 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 describe the environmental values that may be affected by coal resource development, and to adopt strategies to avoid, mitigate or manage the predicted impacts. These assessments do not investigate the social, financial or human health impacts of coal resource development, nor do they consider risks of fugitive gases and non-water-related impacts.

Bioregional assessments are not a substitute for careful assessment of proposed coal mine or coal seam gas 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, including information for individual assets, is provided at www.bioregionalassessments.gov.au. Access to underpinning datasets, including geographic data and modelling results, can assist decision makers at all levels to review the work undertaken to date; to explore the results using different thresholds; and to extend or update the assessment if new models or data become available. Additional guidance about how to apply the Programme's methodology is also documented in 11 detailed scientific submethodologies (as listed in 'References and further reading' on page 28).

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

If new coal resource developments emerge in the future, the data, information, analytical results and models from this assessment would provide a comprehensive basis for bioregion-scale re-assessment of potential impacts under an updated coal resource development pathway. For example, new coal resource developments could be incorporated in the groundwater model. Components such as the water-dependent asset register (Bioregional Assessment Programme, 2017; Dataset 19) remain relevant for future assessments. The information and approach may also be applicable for assessing other types of resource development.

Assessing impacts on ecosystems

Assessment of impacts on water-dependent assets would be improved by additional vegetation mapping and ongoing research to identify groundwater-dependent ecosystems in the subregion. This will improve understanding of the interactions between changes in groundwater availability and the health of terrestrial vegetation that relies on groundwater.

As actual water requirements of different plant communities is only approximately known, future assessments would be assisted by more work to identify suitable indicators of ecosystem condition, or alternative methods of assessing the condition of water-dependent ecosystems.

Groundwater data and mapping

Groundwater data available from state databases include primarily monitoring data for shallow groundwater systems and aquifers used for irrigation, stock and domestic purposes. These data are usually in the form of water level measurements and major ion analyses, which support understanding of groundwater recharge processes and interactions between rivers and groundwater. However, they provide limited understanding of the deeper groundwater systems that are relevant for coal and coal seam gas development. This has been factored into the assessment's uncertainty analysis and modelling. Future assessments would be assisted by improved information on deeper groundwater systems.

Future investigations of the mapping of depth to groundwater would improve confidence in assessment predictions. Interactions between changes in groundwater availability and the health and persistence of terrestrial groundwater-dependent vegetation remain uncertain due, in part, to sparse mapping of groundwater depths outside of alluvial layers.

Drawdown predictions are very sensitive to hydraulic properties of the deeper sedimentary basin, especially predictions of the surface weathered and fractured rock layer. Improved knowledge of the hydraulic properties of the surface weathered and fractured rock layer and storage is needed to better understand changes at different depths.

Geology

Groundwater modelling conducted in this assessment demonstrates that it is unlikely that faults connect shallow groundwater systems with groundwater systems associated with coal measures. However, there remains a knowledge gap in the geological understanding of the Gloucester Basin regarding the number of faults present, their orientation and other characteristics.

The modelling highlighted that the predictive uncertainty would reduce with improved characterisation of hydraulic properties of the surface weathered and fractured rock layer and more detailed information of local geology around developments.

Climate change and land use

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

Future monitoring

Future monitoring to confirm predictions made in this assessment should focus on the northern part of the subregion, specifically the area north-east of Stratford and including Avondale Creek, Dog Trap Creek, Waukivory Creek, Oaky Creek and the Avon River.

FIND MORE INFORMATION
See sections titled 'Gaps' in:

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

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

Conceptual modelling, product 2.3 (Dawes et al., 2018)

Groundwater numerical modelling, product 2.6.2 (Peeters et al., 2018)

Impact and risk analysis, product 3-4 (Post et al., 2018)

See www.bioregionalassessments.gov.au for links to information about all datasets used or created, most of which can be downloaded from data.gov.au.

References and further reading

The information presented in this product for the Gloucester subregion 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 Gloucester subregion are listed here. Also listed are the submethodologies that describe the key approaches used to undertake the assessments.

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Datasets

Key datasets are listed here. The web version of this synthesis at data.bioregionalassessments.gov.au/product/NSB/GLO/5 links to metadata for all datasets, most of which can be downloaded from data.gov.au.

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Dataset 11 Bioregional Assessment Programme (2016) GLO AEM Model v02. Bioregional Assessment Derived Dataset. Viewed 16 August 2017, http://data.bioregionalassessments.gov.au/dataset/e76e05a1-3d3c-4014-a163-66a342278ea2.

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Dataset 13 Bioregional Assessment Programme (2016) GLO subregion boundaries for Impact and Risk Analysis 20160712 v01. Bioregional Assessment Derived Dataset. Viewed 12 April 2017, http://data.bioregionalassessments.gov.au/dataset/b1fa8214-ceec-47d8-b074-8539e94f728f.

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Glossary

The register of terms and definitions used in the Bioregional Assessment Programme is available online at environment.data.gov.au/def/ba/glossary. Definitions for landscape classes and landscape groups for the Gloucester subregion are available online at environment.data.gov.au/def/ba/landscape-classification/gloucester-subregion.

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

additional drawdown: the maximum difference in drawdown (dmax) between the coal resource development pathway (CRDP) and baseline, due to additional coal resource development

annual flow (AF): the volume of water that discharges past a specific point in a stream in a year, commonly measured in GL/year. This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102).

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

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.

baseflow: the portion of streamflow that comes from shallow and deep subsurface flow, and is an important part of the groundwater system

baseflow index: the ratio of baseflow to total streamflow over a long period of time (years)

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

baseline drawdown: the maximum difference in drawdown (*dmax*) under the baseline relative to no coal resource development

bioregion: a geographic land area within which coal seam gas (CSG) and/or coal mining developments are taking place, or could take place, and for which bioregional assessments (BAs) are conducted

bioregional assessment: a scientific analysis of the ecology, hydrology, geology and hydrogeology of a bioregion, with explicit assessment of the potential direct, indirect and cumulative impacts of coal seam gas and coal mining development on water resources. The central purpose of bioregional assessments is to analyse the impacts and risks associated with changes to water-dependent assets that arise in response to current and future pathways of coal seam gas and coal mining development.

bore: a narrow, artificially constructed hole or cavity used to intercept, collect or store water from an aquifer, or to passively observe or collect groundwater information. Also known as a borehole or piezometer.

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

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)

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.

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

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

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

groundwater: water occurring naturally below ground level (whether stored in or flowing through aquifers or within low-permeability aquitards), or water occurring at a place below ground that has been pumped, diverted or released to that place for storage there. This does not include water held in underground tanks, pipes or other works.

groundwater-dependent ecosystem: ecosystems that rely on groundwater - typically the natural discharge of groundwater - for their existence and health

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

groundwater system: see water system

groundwater zone of potential hydrological change: outside this extent, groundwater drawdown (and hence potential impacts) is *very unlikely* (less than 5% chance). It is the area with a greater than 5% chance of exceeding 0.2 m of drawdown due to additional coal resource development in the relevant aquifers.

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

high-flow days (FD): the number of high-flow days per year. This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102). The threshold for high-flow days is the 90th percentile from the simulated 90-year period. In some early products, this was referred to as 'flood days'.

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

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

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

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. Note that there is expected to be less heterogeneity in the response within a landscape class than between landscape classes. 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.

landscape group: for the purposes of bioregional assessments (BAs), a set of landscape classes grouped together based on common ecohydrological characteristics that are relevant for analysis purposes

likelihood: probability that something might happen

low-flow days (LFD): the number of low-flow days per year. This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102). The threshold for low-flow days is the 10th percentile from the simulated 90-year period.

mine pit exclusion zone: areas in the zone of potential hydrological change that are within or near open-cut mine pits, and where (i) modelled drawdowns are highly uncertain due to the very steep hydraulic gradients at the mine pit interface; (ii) changes in the drawdown are inevitable where the mine pit intersects the regional watertable; (iii) other factors, such as physical removal of a wetland or creek, may have a larger impact on a landscape class than the predicted decrease in groundwater level; and (iv) impacts are predominantly site-scale, assumed to be adequately addressed through existing development approval processes, and hence not the primary focus of bioregional assessments. The modelled estimates of drawdown in the mine pit exclusion zone are considered unreliable for use in the receptor impact modelling.

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.

overbank flow: an extremely high-flow rate condition, when the water level stage just begins to spill out of the channel into the floodplain. Bank erosion is accentuated, with the effectiveness of these erosional forces being a function of bank condition, the health of riparian vegetation, particle shape, density, packing and biological activity such as algal growth

overbench flow: high-flow condition where a river channel is partially or completely filled for a period of weeks to months. All habitats within the river channel will be wet including boulders, logs and lateral benches, and the entire length of the channel is connected with relatively deep water, allowing biota to move freely along the river.

permeability: the measure of the ability of a rock, soil or sediment to yield or transmit a fluid. The magnitude of permeability depends largely on the porosity and the interconnectivity of pores and spaces in the ground.

receptor impact model: a function that translates hydrological changes into the distribution or range of potential ecosystem outcomes that may arise from those changes. Within bioregional assessments, hydrological changes are described by hydrological response variables, ecosystem outcomes are described by receptor impact variables, and a receptor impact model determines the relationship between a particular receptor impact variable and one or more hydrological response variables. Receptor impact models are relevant to specific landscape classes, and play a crucial role in quantifying potential impacts for ecological water-dependent assets that are within the landscape class. In the broader scientific literature receptor impact models are often known as 'ecological response functions'.

receptor impact variable: a characteristic of the system that, according to the conceptual modelling, potentially changes due to changes in hydrological response variables (for example, condition of the breeding habitat for a given species, or biomass of river red gums)

recharge: see groundwater recharge

regional watertable: the upper groundwater level within the unconfined, near-surface aquifer (not perched), where pore water pressure is equal to atmospheric pressure. For bioregional assessment (BA) purposes, the regional watertable is developed by combining, at the subregion or bioregion scale, the watertable from all the near-surface geological units (or layers) in which it occurs, so that impacts to water-dependent assets and ecosystems can be assessed. As the regional watertable is not a contiguous geological layer, water may not move freely through it.

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.

spring: a naturally occurring discharge of groundwater flowing out of the ground, often forming a small stream or pool of water. Typically, it represents the point at which the watertable intersects ground level.

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

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

surface water zone of potential hydrological change: outside this extent, changes in surface water hydrological response variables due to additional coal resource development (and hence potential impacts) are very unlikely (less than 5% chance). The area contains those river reaches where a change in any one of nine surface water hydrological response variables exceeds the specified thresholds. (Note that for the Gloucester subregion, only eight hydrological response variables were used to define the surface water zone.) For the four flux-based hydrological response variables (annual flow (AF), daily flow rate at the 99th percentile (P99), interquartile range (IQR) and daily flow rate at the 1st percentile (P01)), the threshold is a 5% chance of a 1% change in the variable. That is, if 5% or more of model runs show a maximum change in results under coal resource development pathway (CRDP) of 1% relative to baseline. For four of the frequency-based hydrological response variables (high-flow days (FD), low-flow days (LFD), length of longest flow-flow spell (LLFS) and zero-flow days (ZFD)), the threshold is a 5% chance of a change of 3 days per year. For the final frequency-based hydrological response variable (low-flow spell (LFS)), the threshold is a 5% chance of a change of 2 spells per year.

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

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

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

well: typically a narrow diameter hole drilled into the earth for the purposes of exploring, evaluating or recovering various natural resources, such as hydrocarbons (oil and gas) or water. As part of the drilling and construction process the well can be encased by materials such as steel and cement, or it may be uncased. Wells are sometimes known as a ‘wellbore’.

zero-flow days (ZFD): the number of zero-flow days per year. This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102).

zero-flow days (averaged over 30 years, ZQD): the number of zero-flow days per year, averaged over a 30-year period. This is typically reported as the maximum change due to additional 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 using probabilities of exceeding thresholds for 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 due to additional coal resource development 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 due to additional coal resource development).

Contributors to the Technical Programme

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

Role or team	Contributor(s)
Assistant Secretary	Department of the Environment and Energy: Matthew Whitfort
Programme Director	Department of the Environment and Energy: John Higgins, Anthony Swirepik
Technical Programme Director	Bureau of Meteorology: Julie Burke
Projects Director	CSIRO: David Post
Principal Science Advisor	Department of the Environment and Energy: Peter Baker
Science Directors	CSIRO: Brent Henderson Geoscience Australia: Steven Lewis
Integration	Bureau of Meteorology: Richard Mount (Integration Leader) CSIRO: Becky Schmidt
Programme management	Bureau of Meteorology: Louise Minty CSIRO: Paul Bertsch, Warwick McDonald Geoscience Australia: Stuart Minchin
Project Leaders	CSIRO: Alexander Herr, Kate Holland, Tim McVicar, David Rassam Geoscience Australia: Tim Evans Bureau of Meteorology: Natasha Herron
Assets and receptors	Bureau of Meteorology: Richard Mount (Discipline Leader) Department of the Environment and Energy: Glenn Johnstone, Wasantha Perera, Jin Wang
Bioregional Assessment Information Platform	Bureau of Meteorology: Lakshmi Devanathan (Team Leader), Derek Chen, Trevor Christie-Taylor, Melita Dahl, Angus MacAulay, Christine Price, Paul Sheahan, Kellie Stuart CSIRO: Peter Fitch, Ashley Sommer Geoscience Australia: Neal Evans
Communications	Bureau of Meteorology: Jessica York CSIRO: Clare Brandon Department of the Environment and Energy: John Higgins, Miriam McMillan, Milica Milanja Geoscience Australia: Aliesha Lavers
Coordination	Bureau of Meteorology: Brendan Moran, Eliane Prideaux, Sarah van Rooyen CSIRO: Ruth Palmer Department of the Environment and Energy: Anisa Coric, Lucy Elliott, James Hill, Andrew Stacey, David Thomas, Emily Turner
Ecology	CSIRO: Anthony O'Grady (Discipline Leader), Caroline Bruce, Tanya Doody, Brendan Ebner, Craig MacFarlane, Patrick Mitchell, Justine Murray, Chris Pavey, Jodie Pritchard, Nat Raisbeck-Brown, Ashley Sparrow
Geology	CSIRO: Deepak Adhikary, Emanuelle Frery, Mike Gresham, Jane Hodgkinson, Zhejun Pan, Matthias Raiber, Regina Sander, Paul Wilkes Geoscience Australia: Steven Lewis (Discipline Leader)
Geographic information systems	CSIRO: Jody Bruce, Debbie Crawford, Dennis Gonzalez, Mike Gresham, Steve Marvanek, Arthur Read Geoscience Australia: Adrian Dehelean
Groundwater modelling	CSIRO: Russell Crosbie (Discipline Leader), Tao Cui, Warrick Dawes, Lei Gao, Sreekanth Janardhanan, Luk Peeters, Praveen Kumar Rachakonda, Wolfgang Schmid, Saeed Torkzaban, Chris Turnadge, Andy Wilkins, Binzhong Zhou

Role or team	Contributor(s)
Hydrogeology	Geoscience Australia: Tim Ransley (Discipline Leader), Chris Harris-Pascal, Jessica Northey, Emily Slatter
Information management	Bureau of Meteorology: Brendan Moran (Team Leader), Christine Panton CSIRO: Qifeng Bai, Simon Cox, Phil Davies, Geoff Hodgson, Brad Lane, Ben Leighton, David Lemon, Trevor Pickett, Shane Seaton, Ramneek Singh, Matt Stenson Geoscience Australia: Matti Peljo
Information model and impact analysis	Bureau of Meteorology: Carl Sudholz (Project Manager), Mark Dyall, Michael Lacey, Brett Madsen, Eliane Prideaux Geoscience Australia: Trevor Tracey-Patte
Products	CSIRO: Becky Schmidt (Products Manager), Maryam Ahmad, Helen Beringen, Clare Brandon, Heinz Buettikofer, Sonja Chandler, Siobhan Duffy, Karin Hosking, Allison Johnston, Maryanne McKay, Linda Merrin, Sally Tetreault-Campbell, Catherine Ticehurst Geoscience Australia: Penny Kilgour
Risk and uncertainty	CSIRO: Simon Barry (Discipline Leader), Jeffrey Dambacher, Rob Dunne, Jess Ford, KeithHayes, Geoff Hosack, Adrien Ickowicz, Warren Jin, Dan Pagendam
Surface water hydrology	CSIRO: Neil Viney and Yongqiang Zhang (Discipline Leaders), Santosh Aryal, Mat Gilfedder, Fazlul Karim, Lingtao Li, Dave McJannet, Jorge Luis Peña-Arancibia, Tom Van Niel, Jai Vaze, Bill Wang, Ang Yang

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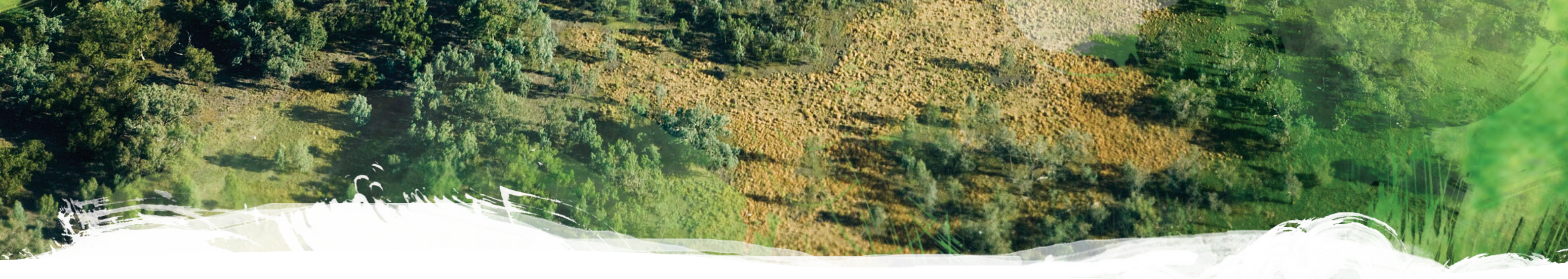

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