Australian Government

BIOREGIONAL ASSESSMENTS

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

Impact and risk analysis for the Gloucester subregion

Product 3-4 for the Gloucester subregion from the Northern Sydney Basin Bioregional Assessment

2018

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

The Bioregional Assessment Programme

The Bioregional Assessment Programme is a transparent and accessible programme of baseline assessments that increase the available science for decision making associated with coal seam gas and large coal mines. A bioregional assessment is a scientific analysis of the ecology, hydrology, geology and hydrogeology of a bioregion with explicit assessment of the potential impacts of coal seam gas and large coal mining development on water resources. This Programme draws on the best available scientific information and knowledge from many sources, including government, industry and regional communities, to produce bioregional assessments that are independent, scientifically robust, and relevant and meaningful at a regional scale.

The Programme is funded by the Australian Government Department of the Environment and Energy. The Department of the Environment and Energy, Bureau of Meteorology, CSIRO and Geoscience Australia are collaborating to undertake bioregional assessments. For more information, visit http://www.bioregionalassessments.gov.au.

Department of the Environment and Energy

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ISBN-PDF 978-1-925315-71-4

Citation

Post DA, Henderson BL, MacFarlane C, Herron N, McVicar TR, Rachakonda PK, Hosack G, Ickowicz A, Hayes KR, Schmidt RK, Lewis S, O'Grady A, Barry S, Brandon C, Zhang YQ, Peeters L, Crosbie R, Viney NR, Dambacher J, Sudholz C, Mount R, Tetreault-Campbell S, Gonzalez D, Marvanek S, Crawford D and Buettikofer H (2018) Impact and risk analysis for the Gloucester subregion. Product 3-4 for the Gloucester subregion from the Northern Sydney Basin Bioregional Assessment. Department of the Environment and Energy, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia.
http://data.bioregionalassessments.gov.au/product/NSB/GLO/3-4.

Authorship is listed in relative order of contribution.

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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

Australian Government
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v20180327

Executive summary

The impact and risk analysis for the Gloucester subregion is a regional overview of potential impact on, and risks to, water resources and water-dependent ecological, economic and sociocultural assets due to coal resource development. Hydrological and ecosystem changes are quantified and impacts that are *very unlikely* (less than 5% chance) are ruled out.

The key finding of the impact and risk analysis indicates that the three proposed new coal mines and one proposed new coal seam gas (CSG) development are predicted to cause minimal impacts on water resources and water-dependent assets in the Gloucester subregion. These findings are explained briefly here and in detail in subsequent sections.

The Gloucester subregion spans an area of 348 km^2 and is the smallest subregion in the Bioregional Assessment Programme. It is located north of the Hunter river basin in NSW. The subregion intersects the northerly flowing Avon and Gloucester rivers of the Manning river basin, which discharge to the Tasman Sea east of Taree, and the south-flowing Karuah River and tributaries, which discharge into Port Stephens. From a groundwater perspective, it is a closed system.

Coal resource developments

Bioregional assessments (BAs) consider two potential coal resource development futures:

- *baseline coal resource development (baseline)*: a future that includes all coal mines and CSG fields that are commercially producing as at December 2012
  - in the Gloucester subregion, the two baseline developments are both open-cut coal mines (Duralie Coal Mine in the south and Stratford Mining Complex in the north)
- *coal resource development pathway (CRDP)*: a future that includes all coal mines and CSG fields that are in the baseline as well as the additional coal resource development (those that are expected to begin commercial production after December 2012)
  - in the Gloucester subregion, the additional coal resource development includes the expansion of the two baseline coal mines (Duralie Coal Mine and Stratford Mining Complex), and a new open-cut coal mine at Rocky Hill in the north of the geological Gloucester Basin. AGL's proposed CSG development, Gloucester Gas Project Stage 1, was included because the CRDP was finalised in October 2015 before AGL withdrew from this project in February 2016.

The difference in results between CRDP and baseline is the change that is primarily reported in a BA. This change is due to the additional coal resource development. Potential hydrological changes due to these coal resource developments have been presented in companion products 2.6.1 (surface water) and 2.6.2 (groundwater); the risks to, and impacts on, water resources and water-dependent ecological, economic and sociocultural assets are summarised.

Zone of potential hydrological change

The zone of potential hydrological change covers an area of 250 km^2 and includes 242 km of stream network. This represents 52% of the area and 70% of the stream length in the entire Gloucester assessment extent. The zone is the union of the groundwater zone of potential hydrological change and the surface water zone of potential hydrological change:

- The *groundwater zone of potential hydrological change* is defined as the area with a greater than 5% chance of exceeding 0.2 m of drawdown due to additional coal resource development in the regional watertable. It covers an area of 100 km^2, comprising 88 km^2 around Stratford mine, Rocky Hill mine and the Gloucester Gas Project Stage 1 and an additional 12 km^2 around Duralie mine.
- The *surface water zone of potential hydrological change* contains those river reaches where a change in any one of the eight hydrological response variables used in the impact and risk analysis for the Gloucester subregion exceeds a specified threshold. The surface water zone covers an area of 187 km^2, with approximately 117 km^2 in the Gloucester river basin and 70 km^2 in the Karuah river basin.

The zone was used to 'rule out' potential impacts on landscape classes and water-dependent assets within the Gloucester assessment extent. Water resources and water-dependent assets outside the zone are *very unlikely* (less than 5% chance) to be impacted. Within the zone, potential impacts due to the hydrological changes were assessed further.

Potential hydrological changes

Groundwater

Results from regional groundwater modelling show drawdown due to additional coal resource development of greater than 0.2 m is *very likely* for an area of almost 20 km^2. This includes 17.2 km^2 in the Gloucester river basin and 2.5 km^2 near the Duralie Coal Mine in the Karuah river basin. It is *very unlikely* that more than 100 km^2 will experience drawdowns of this magnitude due to additional coal resource development. Results for 2 m and 5 m drawdown extents suggest it is:

- *very unlikely* that more than 16 km^2 will experience drawdown exceeding 2 m
- *very unlikely* that more than about 4 km^2 will experience drawdown exceeding 5 m.

The modelled drawdowns close to open-cut mines are considered unreliable because of the very steep hydraulic gradients at the mine pit interface. A 'mine pit exclusion zone' was defined to identify the area of uncertain drawdown results. Within the zone of potential hydrological change, it encompasses an area of 14.5 km^2 (of which 10 km^2 is in the groundwater zone) and includes an area around each of the three mines at Rocky Hill, Stratford and Duralie. Drawdown numbers reported in Section 3.3 include this mine pit exclusion zone, but the area within this zone is not considered when evaluating potential impacts on landscape classes and ecological assets.

Surface water

Within the zone, potential changes to surface water due to additional coal resource development were assessed using three hydrological response variables, chosen to represent low-flow, high-flow and average flow characteristics of streamflow.

The specified threshold for low-flow days is a 5% chance of an increase of three or more low-flow days per year. Low-flow days are likely to increase at a number of locations across the assessment extent. There is at least a 5% chance of increases of more than 3 additional low-flow days per year in Mammy Johnsons and Karuah rivers due to the additional coal resource development at Duralie. Modelled hydrological changes in the Karuah river basin are generally smaller, more localised and of lower likelihood than in the Avon River catchment. At most locations, the modelled increases in low-flow days are less than the interannual variability seen under the baseline. However, results at three model nodes near the Rocky Hill coal mine, indicate at least a 5% chance of increases in number of low-flow days per year that are comparable to or greater than interannual variability, potentially leading to changes in low-flow characteristics outside what has previously been experienced.

The impact on number of high-flow days and annual flow due to additional coal resource development tends to be smaller, but the same streams identified as at risk from changes in the number of low-flow days are likely to be affected.

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. Changes in water quality due to additional coal resource development are considered unlikely in the Gloucester subregion, as none of the proposed developments are licensed to discharge mine water off site and modelled changes in flow regime are relatively small.

Impacts on, and risks to, landscape classes

The vast majority (247 km^2 or 99%) of the zone of potential hydrological change comprises landscape classes from the 'Non-groundwater-dependent ecosystem (GDE)' and 'Economic land use' landscape groups. The 'Non-GDE' landscape group is not considered to be impacted by coal resource development because of a lack of dependence on water other than rainfall. The 'Economic land use' landscape group is considered in impacts on, and risks to, economic assets.

The following are *very unlikely* to be impacted and were not considered further because they are located outside the zone of potential hydrological change:

- the 'Estuarine' landscape group, which includes 38 km^2 in the estuarine reaches of the Karuah River
- the 'Freshwater wetlands' landscape class (1.1 km^2) within the 'GDE' landscape group
- 65 km of perennial – gravel/cobble streams and 3 km of intermittent – gravel/cobble streams, mainly along the Karuah River.

There are 242 km of stream length in the 'Riverine' and 3.3 km^2 extent in the 'GDE' landscape groups in the zone of potential hydrological change that are subject to potential hydrological changes due to additional coal resource development. Results are presented for the potential hydrological changes that may impact the modelled landscape classes within these groups, and using qualitative mathematical models and receptor impact models the associated response of selected ecological indicators is reported.

'Riverine' landscape group

The zone of potential hydrological change includes 76% (133 km) of perennial – gravel/cobble streams and 96% (78 km) of intermittent – gravel/cobble streams in the assessment extent. To investigate ecological changes in these landscape classes, qualitative mathematical models and receptor impact models were constructed. The receptor impact models determined the potential impact of hydrological changes, specifically groundwater drawdown, change in baseflow index and increased zero-flow days per year, using these variables:

- annual mean percent canopy cover of woody riparian vegetation (perennial streams)
- mean number of larvae of the Hydropsychidae family (net-spinning caddisflies) in a 1 m^2 sample of riffle habitat (perennial streams)
- mean number of the eel-tailed catfish (*Tandanus tandanus*) in a 600 m^2 transect whose long axis lies along the mid-point of the stream (perennial streams)
- mean hyporheic invertebrate taxa richness, where hyporheic invertebrate taxa are the organisms found where surface water and groundwater mix below the bed of a stream (intermittent streams).

Overall, the median estimate from modelled changes in the 60-year period (2042 to 2102) showed that there would be no change along any reach in the four receptor impact variables listed above due to additional coal resource development. This is because, at a regional scale, the modelled hydrological changes in these streams are very minor.

'Groundwater-dependent ecosystem (GDE)' landscape group

The 'GDE' landscape group includes those ecosystems that rely on the surface or subsurface expression of groundwater to meet all or some of their life-cycle requirements. There are 3.2 km^2 of the mapped 'GDE' landscape group in the zone of potential hydrological change, including forested wetlands, wet sclerophyll forests, rainforests and dry sclerophyll forests landscape classes. About 0.4 km^2 is in the mine pit exclusion zone.

Of the 2.8 km^2 of GDEs not in the mine pit exclusion zone, there is a 5% chance that 1.1 km^2 will experience drawdown due to additional coal resource development of more than 0.2 m. Most of this coincides with areas of forested wetlands. It is *very unlikely* (less than 5% chance) that any of the GDEs will be subject to more than 2 m of drawdown.

Potential ecological changes are difficult to model because the water requirements of GDEs are poorly understood and there is large uncertainty as to the frequency, timing and duration of groundwater use by GDEs within the Gloucester subregion. Qualitative mathematical models were developed for the 'Forested wetlands', 'Wet sclerophyll forests' and 'Dry sclerophyll forests' landscape classes. The models focus on the role that forest canopies play as a food source and habitat and their response to a simultaneous decrease in shallow and deep groundwater. They reflect the understanding that drawdown has negative impacts on all vegetation-related variables, including overstorey and understorey (ground layer) cover, and recruitment. The models do not represent the magnitude or likelihood of potential impacts due to a change in drawdown. Thus this assessment identifies where these GDEs coincide with areas of modelled drawdown, and what the likely direction of change in ecosystem components is, but not how big an impact the changes will have.

Impacts on, and risks to, water-dependent assets

Ecological assets

The Gloucester subregion has 116 ecological assets in the assessment extent. Of these, 52 are in the zone of potential hydrological change and are therefore subject to potential hydrological changes due to additional coal resource development. They include 17 'Surface water feature' subgroup assets, 3 'Groundwater feature (subsurface)' subgroup assets and 32 'Vegetation' subgroup assets. The vegetation subgroup assets include:

- the habitat (potential species distributions) of 14 threatened ecological species listed under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999*
- 1 threatened ecological community, Lowland Subtropical Rainforest
- 10 point locations of known platypus occurrence
- 7 fish biodiversity hotspot monitoring locations.

Based on regional-scale modelling of hydrological change and associated ecological responses, impacts on ecological assets in the 'Riverine' landscape group due to additional coal resource development are considered *very unlikely*.

There is some potential for impacts on ecological assets associated with GDE landscape classes, although median estimates of areas impacted are less than 1.0 km^2. Species with extensive potential habitat distributions (e.g. regent honeyeater) are more likely to be identified as subject to potential hydrological change because there is greater likelihood their potential distribution will intersect an area of potentially significant hydrological change. However, the magnitude of the impact, if any, is uncertain; it will depend on local-scale factors, including whether or not the species is actually present in the 'at risk' area and the sensitivity of the species to the modelled hydrological changes. It is *very unlikely* that any areas of the Lowland Subtropical Rainforest threatened ecological community are impacted.

Economic assets

There are five surface water sources and two groundwater sources containing 339 bores and surface water extraction points in the zone of potential hydrological change. When non-alluvial bores in the surface water zone and monitoring bores are filtered out, there remain 246 bores and surface water extraction points where the potential for an economic impact cannot be ruled out.

The potential for economic impacts from modelled groundwater changes is assessed in terms of numbers of bores in areas where drawdowns are predicted to exceed minimal impact consideration thresholds. Under the *NSW Aquifer Interference Policy,* if a proposal to extract water from an aquifer is likely to impact a licensed water holder's access to their entitlement, then there is provision for the licence holder to be recompensed. There are five bores outside the mine pit exclusion zone that have at least a 5% chance of experiencing a drawdown greater than 2 m, the minimal impact threshold for aquifers in the Gloucester subregion, due to additional coal resource development. Four are monitoring bores and thus drawdown is unlikely to result in an economic impact; one is a production bore, owned by AGL and considered unlikely to lead to an economic impact.

The impact on water availability in water sources of the Gloucester subregion was assessed in terms of the modelled reductions in mean annual flow due to additional coal resource development. Modelling indicates reductions of less than 1.6 GL/year between 2013 and 2042 in both the Upper Gloucester River and Avon River water sources. These 1% to 2% reductions in mean annual flow from the baseline are less than the interannual variability due to climate.

Potential surface water changes show that the reliability of surface water supply in the Gloucester assessment extent is *very unlikely* to be affected by additional coal resource development. The reliability of water supply to licence holders in the subregion, as indicated by an increase in the number of cease-to-pump days per year, was found to not significantly change in any water source: for the Karuah River water source, where the potential changes are greatest, reductions of more than 3 days are *very unlikely*. Cease-to-pump rules apply to most water sources in NSW to ensure sufficient water is retained in unregulated rivers to meet environmental requirements.

Sociocultural assets

There are 19 water-dependent sociocultural assets identified in the assessment extent. The Washpool at the Karuah River north of the town site of Washpool is the one water-dependent sociocultural asset in the zone of potential hydrological change, but due to very small changes in hydrology at this location, it is not likely to be impacted.

Gaps and opportunities

Any local-scale studies of changes to surface water and groundwater should focus on the northern part of the Gloucester subregion to determine potential impacts of additional coal resource development, specifically the area north-east of Stratford and including Avondale Creek, Dog Trap Creek, Waukivory Creek, Oaky Creek and the Avon River.

Research in the Gloucester subregion should focus on the role of faults, mapping the depth to groundwater, carrying out additional mapping of vegetation, and ground-truthing GDE locations.

Future assessments of the cumulative impacts of coal resource developments on water resources and water-dependent assets and ecosystems in the Gloucester subregion should focus on incorporating the impacts of baseline coal mines, changes in other land uses, and climate variability and climate change.

The full suite of information, including information for individual assets, is provided at www.bioregionalassessments.gov.au. Users can explore detailed results for the Gloucester subregion using a map-based interface at www.bioregionalassessments.gov.au/explorer/GLO.

Contents

Figures

Tables

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Acknowledgements

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Introduction

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

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

The IESC has been involved in the development of *Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources* (the BA methodology; Barrett et al., 2013) and has endorsed it. The BA methodology specifies how BAs should be undertaken. Broadly, a BA comprises five components of activity, as illustrated in Figure 1. Each BA is different, due in part to regional differences, but also in response to the availability of data, information and fit-for-purpose models. Where differences occur, these are recorded, judgments exercised on what can be achieved, and an explicit record is made of the confidence in the scientific advice produced from the BA.

The Bioregional Assessment Programme

The Bioregional Assessment Programme is a collaboration between the Department of the Environment and Energy, the Bureau of Meteorology, CSIRO and Geoscience Australia. Other technical expertise, such as from state governments or universities, is also drawn on as required. For example, natural resource management groups and catchment management authorities identify assets that the community values by providing the list of water-dependent assets, a key input.

The Technical Programme, part of the Bioregional Assessment Programme, has undertaken BAs for the following bioregions and subregions (see http://www.bioregionalassessments.gov.au/assessments for a map and further information):

- the Galilee, Cooper, Pedirka and Arckaringa subregions, within the Lake Eyre Basin bioregion
- the Maranoa-Balonne-Condamine, Gwydir, Namoi and Central West subregions, within the Northern Inland Catchments bioregion
- the Clarence-Moreton bioregion
- the Hunter and Gloucester subregions, within the Northern Sydney Basin bioregion

- the Sydney Basin bioregion
- the Gippsland Basin bioregion.

Technical products (described in a later section) will progressively be delivered throughout the Programme.

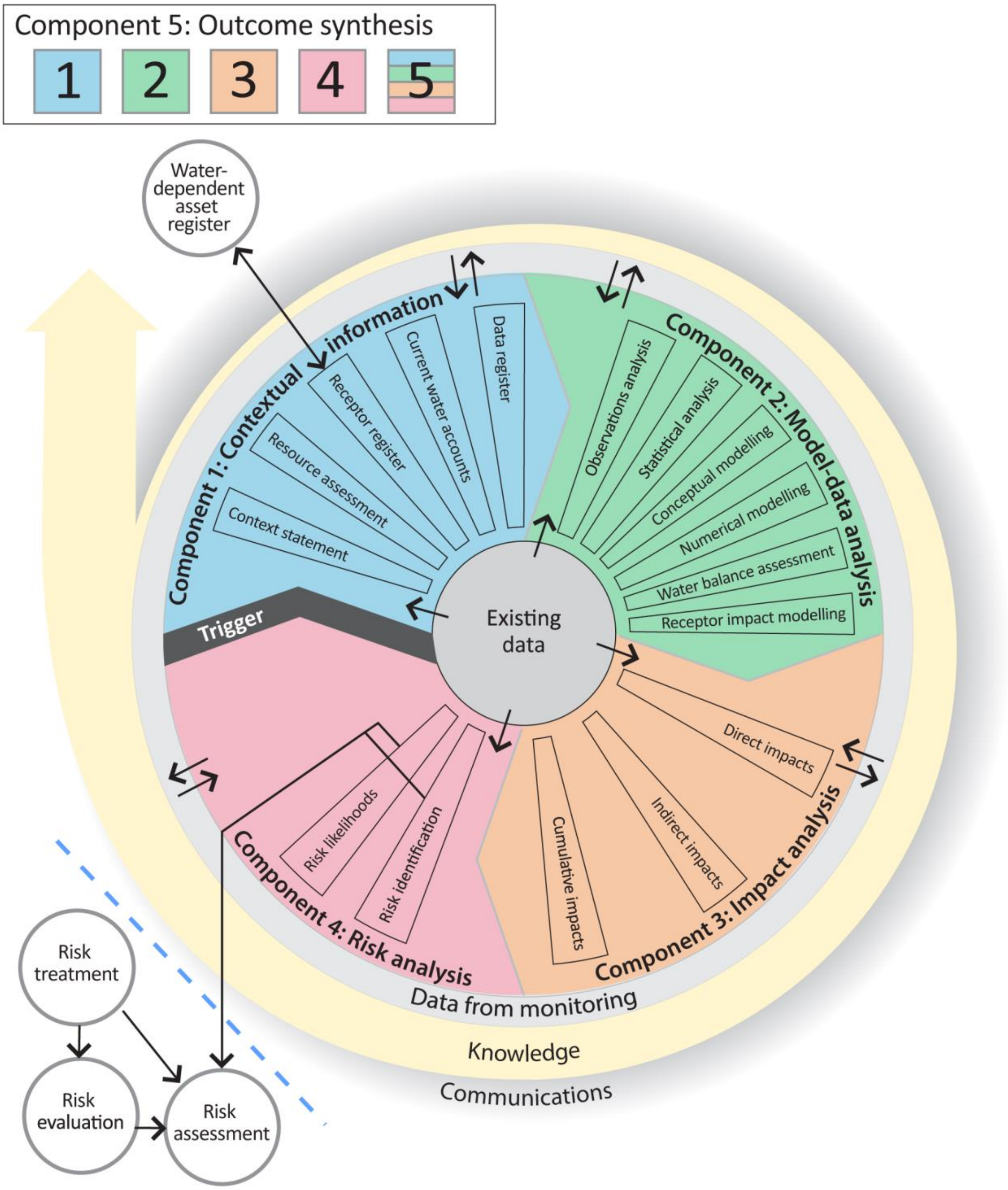

Figure 1 Schematic diagram of the bioregional assessment methodology

The methodology comprises five components, each delivering information into the bioregional assessment and building on prior components, thereby contributing to the accumulation of scientific knowledge. The small grey circles indicate activities external to the bioregional assessment. Risk identification and risk likelihoods are conducted within a bioregional assessment (as part of Component 4) and may contribute activities undertaken externally, such as risk evaluation, risk assessment and risk treatment. Source: Figure 1 in Barrett et al. (2013), © Commonwealth of Australia

Methodologies

The overall scientific and intellectual basis of the BAs is provided in the BA methodology (Barrett et al., 2013). Additional guidance is required, however, about how to apply the BA methodology to a range of subregions and bioregions. To this end, the teams undertaking the BAs have developed and documented detailed scientific submethodologies (Table 1), in the first instance, to support the consistency of their work across the BAs and, secondly, to open the approach to scrutiny, criticism and improvement through review and publication. In some instances, methodologies applied in a particular BA may differ from what is documented in the submethodologies.

The relationship of the submethodologies to BA components and technical products is illustrated in Figure 2. While much scientific attention is given to assembling and transforming information, particularly through the development of the numerical, conceptual and receptor impact models, integration of the overall assessment is critical to achieving the aim of the BAs. To this end, each submethodology explains how it is related to other submethodologies and what inputs and outputs are required. They also define the technical products and provide guidance on the content to be included. When this full suite of submethodologies is implemented, a BA will result in a substantial body of collated and integrated information for a subregion or bioregion, including new information about the potential impacts of coal resource development on water and water-dependent assets.

Table 1 Methodologies

Each submethodology is available online at http://data.bioregionalassessments.gov.au/submethodology/XXX, where 'XXX' is replaced by the code in the first column. For example, the BA methodology is available at http://data.bioregionalassessments.gov.au/submethodology/bioregional-assessment-methodology and submethodology M02 is available at http://data.bioregionalassessments.gov.au/submethodology/M02. Submethodologies might be added in the future.

Code	Proposed title	Summary of content
bioregional-assessment-methodology	*Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources*	A high-level description of the scientific and intellectual basis for a consistent approach to all bioregional assessments
M02	*Compiling water-dependent assets*	Describes the approach for determining water-dependent assets
M03	*Assigning receptors to water-dependent assets*	Describes the approach for determining receptors associated with water-dependent assets
M04	*Developing a coal resource development pathway*	Specifies the information that needs to be collected and reported about known coal and coal seam gas resources as well as current and potential resource developments
M05	*Developing the conceptual model of causal pathways*	Describes the development of the conceptual model of causal pathways, which summarises how the 'system' operates and articulates the potential links between coal resource development and changes to surface water or groundwater
M06	*Surface water modelling*	Describes the approach taken for surface water modelling
M07	*Groundwater modelling*	Describes the approach taken for groundwater modelling
M08	*Receptor impact modelling*	Describes how to develop receptor impact models for assessing potential impact to assets due to hydrological changes that might arise from coal resource development
M09	*Propagating uncertainty through models*	Describes the approach to sensitivity analysis and quantification of uncertainty in the modelled hydrological changes that might occur in response to coal resource development
M10	*Impacts and risks*	Describes the logical basis for analysing impact and risk
M11	*Systematic analysis of water-related hazards associated with coal resource development*	Describes the process to identify potential water-related hazards from coal resource development

Technical products

The outputs of the BAs include a suite of technical products presenting information about the ecology, hydrology, hydrogeology and geology of a bioregion and the potential impacts of CSG and coal mining developments on water resources, both above and below ground. Importantly, these technical products are available to the public, providing the opportunity for all interested parties, including community, industry and government regulators, to draw from a single set of accessible information when considering CSG and large coal mining developments in a particular area.

The information included in the technical products is specified in the BA methodology. Figure 2 shows the relationship of the technical products to BA components and submethodologies. Table 2 lists the content provided in the technical products, with cross-references to the part of the BA methodology that specifies it. The red outlines in both Figure 2 and Table 2 indicate the information included in this technical product.

Technical products are delivered as reports (PDFs). Additional material is also provided, as specified by the BA methodology:

- unencumbered data syntheses and databases
- unencumbered tools, model code, procedures, routines and algorithms
- unencumbered forcing, boundary condition, parameter and initial condition datasets
- lineage of datasets (the origin of datasets and how they are changed as the BA progresses)
- gaps in data and modelling capability.

In this context, unencumbered material is material that can be published according to conditions in the licences or any applicable legislation. All reasonable efforts were made to provide all material under a Creative Commons Attribution 3.0 Australia Licence.

Technical products, and the additional material, are available online at http://www.bioregionalassessments.gov.au.

The Bureau of Meteorology archives a copy of all datasets used in the BAs. This archive includes datasets that are too large to be stored online and datasets that are encumbered. The community can request a copy of these archived data at http://www.bioregionalassessments.gov.au.

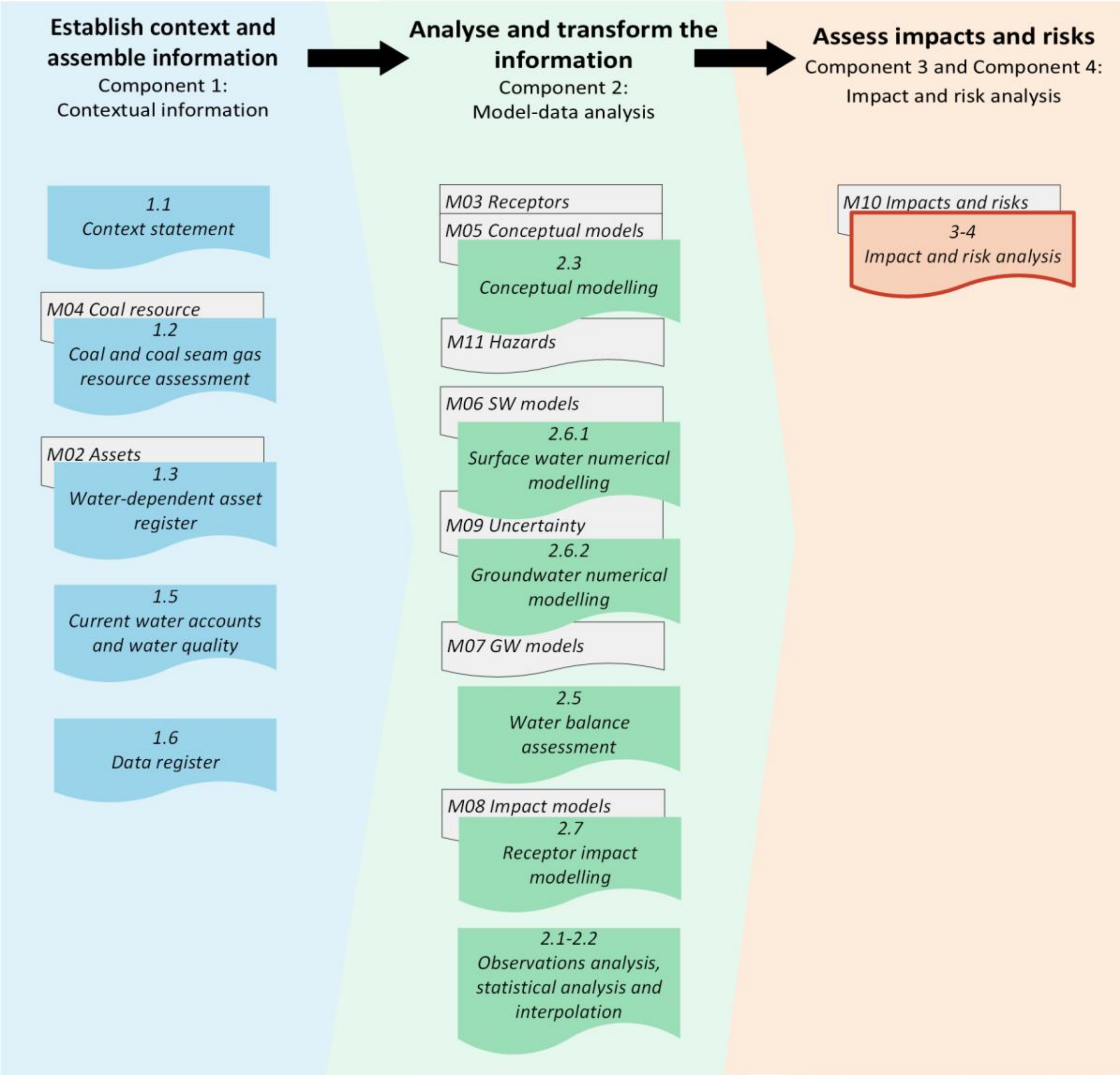

Figure 2 Technical products and submethodologies associated with each component of a bioregional assessment

In each component (Figure 1) of a bioregional assessment, a number of technical products (coloured boxes, see also Table 2) are potentially created, depending on the availability of data and models. The light grey boxes indicate submethodologies (Table 1) that specify the approach used for each technical product. The red outline indicates this technical product. The BA methodology (Barrett et al., 2013) specifies the overall approach.

Table 2 Technical products delivered for the Gloucester subregion

For each subregion in the Northern Sydney Basin Bioregional Assessment, technical products are delivered online at http://www.bioregionalassessments.gov.au, as indicated in the 'Type' column[a]. Other products – such as datasets, metadata, data visualisation and factsheets – are provided online. There is no product 1.4. Originally this product was going to describe the receptor register and application of landscape classes as per Section 3.5 of the BA methodology, but this information is now included in product 2.3 (conceptual modelling) and used in product 2.6.1 (surface water numerical modelling) and product 2.6.2 (groundwater numerical modelling). There is no product 2.4. Originally this product was going to include two- and three-dimensional representations as per Section 4.2 of the BA methodology, but these are instead included in products such as product 2.3 (conceptual modelling), product 2.6.1 (surface water numerical modelling) and product 2.6.2 (groundwater numerical modelling).

Component	Product code	Title	Section in the BA methodology[b]	Type[a]
Component 1: Contextual information for the Gloucester subregion	1.1	Context statement	2.5.1.1, 3.2	PDF, HTML
	1.2	Coal and coal seam gas resource assessment	2.5.1.2, 3.3	PDF, HTML
	1.3	Description of the water-dependent asset register	2.5.1.3, 3.4	PDF, HTML, register
	1.5	Current water accounts and water quality	2.5.1.5	PDF, HTML
	1.6	Data register	2.5.1.6	Register
Component 2: Model-data analysis for the Gloucester subregion	2.1-2.2	Observations analysis, statistical analysis and interpolation	2.5.2.1, 2.5.2.2	PDF, HTML
	2.3	Conceptual modelling	2.5.2.3, 4.3	PDF, HTML
	2.5	Water balance assessment	2.5.2.4	PDF, HTML
	2.6.1	Surface water numerical modelling	4.4	PDF, HTML
	2.6.2	Groundwater numerical modelling	4.4	PDF, HTML
	2.7	Receptor impact modelling	2.5.2.6, 4.5	PDF, HTML
Component 3 and Component 4: Impact and risk analysis for the Gloucester subregion	3-4	Impact and risk analysis	5.2.1, 2.5.4, 5.3	PDF, HTML
Component 5: Outcome synthesis for the Gloucester subregion	5	Outcome synthesis	2.5.5	PDF, HTML

[a]The types of products are as follows:

- 'PDF' indicates a PDF document that is developed by the Northern Sydney Basin Bioregional Assessment using the structure, standards and format specified by the Programme.
- 'HTML' indicates the same content as in the PDF document, but delivered as webpages.
- 'Register' indicates controlled lists that are delivered using a variety of formats as appropriate.

[b]*Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources* (Barrett et al., 2013)

About this technical product

The following notes are relevant only for this technical product.

- All reasonable efforts were made to provide all material under a Creative Commons Attribution 3.0 Australia Licence.
- All maps created as part of this BA for inclusion in this product used the Albers equal area projection with a central meridian of 151.0° East for the Northern Sydney Basin bioregion and two standard parallels of –18.0° and –36.0°.
- Visit http://www.bioregionalassessments.gov.au to access metadata (including copyright, attribution and licensing information) for datasets cited or used to make figures in this product.
- In addition, the datasets are published online if they are unencumbered (able to be published according to conditions in the licence or any applicable legislation). The Bureau of Meteorology archives a copy of all datasets used in the BAs. This archive includes datasets that are too large to be stored online and datasets that are encumbered. The community can request a copy of these archived data at http://www.bioregionalassessments.gov.au.
- The citation details of datasets are correct to the best of the knowledge of the Bioregional Assessment Programme at the publication date of this product. Readers should use the hyperlinks provided to access the most up-to-date information about these data; where there are discrepancies, the information provided online should be considered correct. The dates used to identify Bioregional Assessment Source Datasets are the dataset's published date. Where the published date is not available, the last updated date or created date is used. For Bioregional Assessment Derived Datasets, the created date is used.

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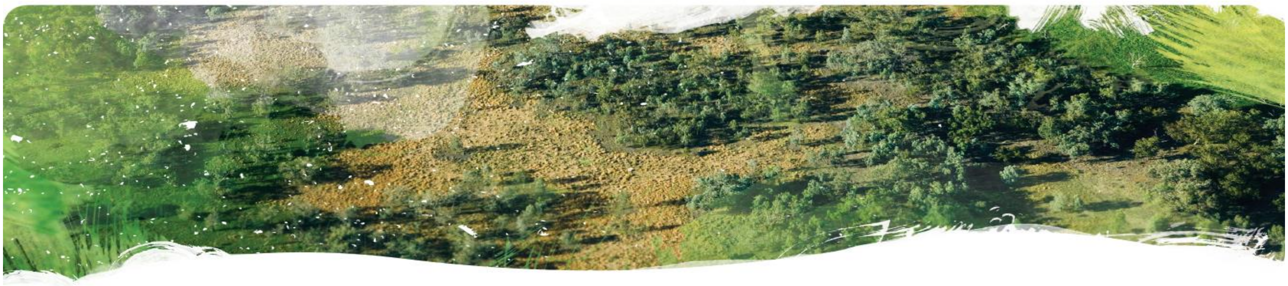

3 Impact and risk analysis for the Gloucester subregion

The impact and risk analysis is the key output of a bioregional assessment (BA). This product presents potential impacts of coal resource development on water resources and water-dependent assets in the Gloucester subregion. Risks are analysed by assessing the magnitude and likelihood of these potential impacts.

The impact and risk analysis (Component 3 and Component 4) builds on the contextual information (Component 1) and knowledge from the model-data analysis (Component 2).

In this impact and risk analysis:

- A zone of potential hydrological change is determined using both the surface water and groundwater numerical hydrological modelling results (from product 2.6.1 (surface water numerical modelling) and product 2.6.2 (groundwater numerical modelling)).
- The zone of potential hydrological change is overlain with the extent of the landscape classes (product 2.3 (conceptual modelling)) and water-dependent assets (product 1.3 (description of water-dependent asset register)) to identify those ecosystems and assets that might be subject to hydrological change.
- Potential impacts to ecological assets are considered via:
  - qualitative mathematical models, which predict (at a high level) how specific ecosystems (represented by landscape classes) might respond to changes in hydrology
  - quantitative receptor impact models (where applicable), which numerically translate the changes in hydrology into changes in ecosystems
- Potential impacts to economic and sociocultural assets are considered via changes to water availability and accessibility.

The product then describes potential impacts for those coal resource developments that cannot be modelled and concludes with key findings, knowledge gaps, how to use the assessment and how to build on this assessment.

3.1 Overview

Summary

The Gloucester subregion covers about 348 km^2, and is defined by the geological Gloucester Basin. It is located north of the Hunter river basin, approximately 85 km north-north-east of Newcastle. About 5000 people live in the subregion, primarily in the towns of Gloucester and Stroud. There are numerous rivers in the subregion that straddle a catchment divide; northern-flowing rivers contribute to the Manning River that discharges to the Tasman Sea beyond Taree and the southern-flowing rivers contribute to the Karuah River, which discharges into Port Stephens. From a groundwater perspective, it is a closed system. The climate is sub-tropical, characterised by summer-dominant precipitation. Grazing is the primary land use (covering over 75% of the subregion) with the dominant pre-European vegetation, eucalypt forests, having been extensively cleared in the subregion since European settlement.

Potential impacts and risks due to additional coal resource development were assessed by comparing the results for two futures: baseline coal resource development (baseline) and the coal resource development pathway (CRDP).

The baseline includes the existing Duralie Coal Mine and Stratford Mining Complex open-cut mines (which commenced in 2003 and 1995, respectively).

The CRDP includes all baseline coal resource developments plus four additional coal resource developments: (i) expansion to the Duralie open-cut mine, (ii) expansion to the Stratford open-cut mine, (iii) establishment of the Rocky Hill Mine, and (iv) establishment of Stage 1 of the Gloucester Gas Project. The Duralie expansion was approved in November 2011, with mining operations of the expansion due to commence in 2013 and cease in 2024. The Stratford expansion was approved in May 2015, with mining operations of the expansion due to commence in 2015 and cease in 2026. As of February 2017, Rocky Hill is still awaiting approval, and in February 2016, AGL Energy Ltd formally announced that they were not pursuing the Gloucester Gas Project.

Section 3.1 first describes the Gloucester subregion. The critical philosophical and operational choices are next outlined to explain the scope and context of bioregional assessments (BAs). These choices include: choice of modelled futures, focus on water quantity and availability, assessment of cumulative developments, increased confidence in modelled predictions, and ruling out impacts. Section 3.1 concludes with an overview of the structure of this product.

3.1.1 Gloucester subregion

The Gloucester subregion covers about 348 km^2, and is defined by the geological Gloucester Basin. It is located just north of the Hunter Valley in NSW, and is approximately 85 km north-north-east of Newcastle, 60 km south-west of Taree and 55 km west of Forster. The subregion extends 55 km north–south (at its longest) and 15 km east–west (at its widest). Elevation in the subregio6 ranges from 10 to 515 m Australian Height Datum (AHD), and it is mostly undulating with relatively low slopes; some steeper slopes are found along the western and eastern flanks of the geological basin.

Pre-European vegetation was dominated by eucalypt forest. Current vegetation cover is mainly persistent vegetation associated with the border forests and grazing (the primary land use, covering over 75% of the subregion). The extent of grazing can be seen in Figure 3, as can the remnant forests on the ridgelines.

There are numerous rivers in the subregion that straddle a catchment divide (Figure 4); northern-flowing rivers contribute to the Manning River and discharge to the Tasman Sea beyond Taree and the southern-flowing rivers contribute to the Karuah River and discharge into Port Stephens. From a groundwater perspective, it is a closed system, with recharge and discharge confined to the syncline structure of the Gloucester geological basin.

Figure 3 View across the Gloucester subregion showing forests on the ridgelines and grazing (the primary land use) in the foreground

Source: Heinz Buettikofer, CSIRO

About 5000 people live in the subregion, primarily in the towns of Gloucester and Stroud. Water for these towns is extracted from local rivers, and there are no major dams or major wetlands in the subregion. Most groundwater-dependent ecosystems and bores access groundwater from the uppermost aquifer, hosted either in near-stream alluvium or shallow, weathered bedrock.

The climate is sub-tropical, characterised by summer-dominant precipitation. Average precipitation over the last 30 years (1982 to 2012) was 1095 mm/year with potential evapotranspiration (PET) of 1587 mm/year.

The Gloucester subregion is underlain by the geological Gloucester Basin, which contains up to 2500 m of faulted, deformed and eroded coal-bearing Permian sedimentary and volcanic rocks that rest unconformably on Carboniferous strata of the Late Paleozoic New England Fold Belt. The Gloucester Basin is interpreted as a fault-bounded depositional trough that was active during the Permian period. The Permian coal measures (Dewrang Group and Gloucester Coal Measures) overlie the Alum Mountain Volcanics. The Dewrang Group includes two coal seams that are mined at the Duralie Coal Mine in the southern closure of the main syncline of the Gloucester Basin. Currently coal mines in the Gloucester subregion extract coal from upper and middle seams of the Gloucester Coal Measures.

An introduction to the geography (physical, human and climate), geology, groundwater, surface water, surface water – groundwater interactions and ecology is provided in companion product 1.1 for the Gloucester subregion (McVicar et al., 2014). The conceptual modelling that underpins the impact and risk analysis for the Gloucester subregion is described in companion product 2.3 (Dawes et al., 2018).

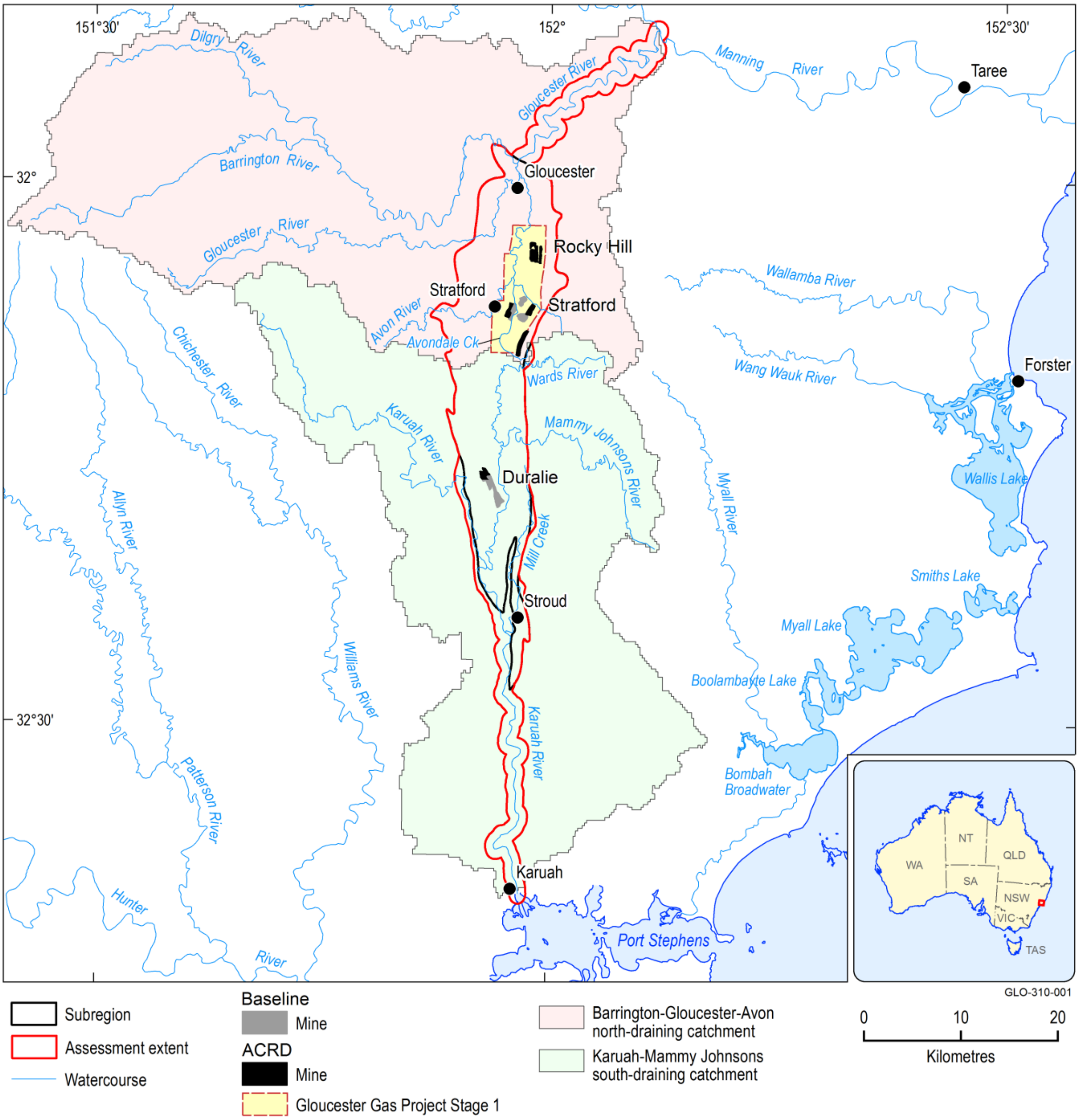

Figure 4 River basins in and around the Gloucester subregion

The extent of the mines in the coal resource development pathway (CRDP) is the union of the extents in the baseline and in the additional coal resource development (ACRD). The area of the Gloucester Gas Project Stage 1 reflects the petroleum tenure and is part of the ACRD.
Data: Bioregional Assessment Programme (Dataset 1, Dataset 2 and Dataset 4); AGL (Dataset 3)

3.1.2 Scope and context

The objective of the Bioregional Assessment Programme is to understand and predict regional-scale cumulative impacts on water resources and water-dependent assets caused by coal resource developments in Australia's major coal-bearing sedimentary basins. The assessments identify areas where water resources and water-dependent assets are *very unlikely* to be impacted (with a less than 5% chance) from those where water resources and water-dependent assets are potentially impacted. Governments, industry and the community can then focus on areas that are potentially impacted when making regulatory, water management and planning decisions.

The impact and risk analysis considered only biophysical consequences, such as changes in hydrology or ecology; fully evaluating consequences requires value judgments and non-scientific information that is beyond the scope of BAs. A full risk assessment (with risk evaluation and risk treatment) was not conducted as part of BAs.

The purpose of this section is to highlight design choices that have steered the direction of this BA and culminated in the impact and risk analysis. Further details about the design choices are provided in companion submethodology M10 (as listed in Table 1) for analysing impacts and risks (Henderson et al., 2018).

3.1.2.1 Choice of modelled futures

A BA is a regional analysis that compares two futures of coal resource development. In BAs, the term 'coal resource development' specifically includes coal mining (both open-cut and underground) as well as CSG extraction. Other forms of coal-related development activity, such as underground coal gasification and microbial enhancement of gas resources, were not within the scope of the assessment.

The two futures considered in the BA for the Gloucester subregion are:

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

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

In the Gloucester subregion, the additional coal resource development (shown in Figure 4) includes: (i) expansion of the Duralie open-cut mine, (ii) expansion of the Stratford open-cut mine, (iii) establishment of the Rocky Hill Mine, and (iv) establishment of Stage 1 of the Gloucester Gas Project.

The Duralie expansion was approved in November 2011, with mining operations due to commence in 2013 and cease in 2024. The Stratford expansion was approved in May 2015, with mining operations due to commence in 2015 and cease in 2026. As of February 2017, Rocky Hill is awaiting approval. In February 2016, AGL Energy Ltd formally announced that they were not pursuing the Gloucester Gas Project. However, despite uncertainties around Rocky Hill, and the Gloucester Gas Project not being developed, both are included in the CRDP for the Gloucester subregion, consistent with the BA approach presented in companion submethodology M04 (as listed in Table 1) for developing a coal resource development pathway (Lewis, 2014).

The CRDP is the most likely future, based on the analysis and expert judgment of the Assessment team in consultation with coal and gas industry representatives, state agencies and the Australian Government. The CRDP was finalised for the Gloucester subregion based on information available in October 2015 (Dawes et al., 2018, Section 2.3.4.1, p. 51) to allow the hydrological numerical modelling to commence. In reality, developments in the CRDP may ultimately be implemented in different ways (e.g. changes to timing), or circumstances of coal resource developments may change (e.g. a proponent may withdraw for some reason, as is the case for the Gloucester Gas Project). This reflects the dynamic nature of resource investment decision making, related to diverse economic, political or social factors. Consequently, the CRDP needs to be viewed as an indicative future that highlights potential changes for water resources and water-dependent assets that may need to be considered further in local analyses or via approval conditions required by regulators. Equally as important, the CRDP plays a role in identifying where changes will not occur, flagging where potential impacts to water resources and water-dependent assets are *very unlikely*.

BAs primarily focus on the potential impacts to water resources and water-dependent assets that are attributable to the additional coal resource development. Potentially important impacts under the baseline may occur in parts of the Gloucester subregion that are not further affected by additional coal resource development, and so are given less attention in the assessment. However, the potential impacts under the baseline may be important in interpreting impacts due to additional coal resource development. For instance, the potential implications to groundwater-dependent ecosystems of an additional 2 m of drawdown in the regional watertable may depend on whether the drawdown under the baseline is 0.10, 1.0 or even 10 m.

Factors such as climate change and land use (such as agriculture) were held constant between the two futures. Although the future climate and/or land use may differ from those assumed in BAs, the effect of this choice is likely small because the focus of BAs is on reporting the difference in results between the baseline and CRDP.

3.1.2.2 Focus on water quantity and availability

BAs focus solely on water-related impacts, and specifically those related to water quantity and availability. Potential water quality hazards were identified through the comprehensive hazard analysis undertaken as part of conceptual modelling for the Gloucester subregion (Dawes et al., 2018), but the analysis, as determined by the BA scope, was limited to salinity and was only addressed qualitatively.

BAs focus on those surface water and groundwater effects that may accumulate, either over extended time frames or as a result of multiple coal resource developments. These typically correspond to changes in surface water and groundwater that are sustained over long periods of time, sometimes decades, and which may create the potential for flow-on effects through the hydrological system.

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 BAs because they are assumed to be adequately managed by site-based risk management and mitigation procedures, and are unlikely to create potential cumulative impacts. Impacts and risks associated with water quality attributes other than salinity that are potentially affected by coal resource development are identified, but not analysed further, in this BA.

3.1.2.3 Assessment of regional-scale cumulative developments

BAs are designed to analyse the cumulative impacts of coal resource developments at a regional-scale, and not focus specifically on individual mines or CSG operations. The baseline and CRDP futures for the Gloucester subregion include a suite of developments, the potential impacts of which may overlap to varying degrees in both time and space.

Regional-scale models are used to predict the cumulative hydrological changes and potential impacts of those developments on landscape classes and water-dependent assets from multiple developments over time. The area of potential impact is expected to be more extensive and extend greater distances downstream of developments than what is predicted from site-scale, single-mine models. In some cases, the spatial or temporal alignment of certain coal resource developments can allow for attribution of potential effects to individual developments, but that occurs because of that alignment rather than by design.

Results of the impact and risk analysis reported in this product do not replace the need for the detailed site- or project-specific investigations that are currently required under existing state and Commonwealth legislation. The hydrological and ecological systems modelling undertaken for a BA are appropriate for assessing the potential impacts and risks to water resources and water-dependent assets at the 'whole-of-basin' scale, whereas the modelling undertaken by a mining proponent for an individual development as part of an environmental assessment, occurs at a much finer scale and makes use of local information. Therefore, results from these detailed mine-specific studies are expected to differ from those from a BA. However, as a range of potential parameter values are considered in a BA, it is expected that the range of possible outcomes predicted by a BA will encompass the results from individual site-specific studies.

3.1.2.4 Focus on predictive uncertainty

In BAs, parameter uncertainty was considered as fully as possible when predicting hydrological outcomes (i.e. changes to surface water or groundwater) and ecological outcomes (i.e. changes to ecologically relevant receptor impact variables). For example, groundwater models were run many thousands of times using a wide range of plausible input parameters for many of the critical hydraulic properties, such as the hydraulic conductivity and storage coefficients of all modelled hydrogeological layers. This differs from the traditional deterministic approach used more routinely for groundwater and surface water modelling and is driven by the risk analysis focus of BAs.

While models are constrained to data, the density of reliable observation data is sparse, so results may not represent local conditions well. However, they do consistently represent the risk and uncertainty at all sites through probability distributions of possible hydrological changes, where the area, depth, timing and assumed pumping rates of each development largely determine the spatial variation, and lack of detail about the physical environment at any given point in the assessment extent define the uncertainty.

Given the wide range of plausible input parameters used in the regional modelling, the hydrological changes due to additional coal resource development at any given location within the assessment extent can be assumed to lie within the distribution of modelled changes. This assumption may not be true near open-cut mines where potentially steep hydraulic gradients at the mine pit interface are poorly resolved in the regional groundwater models. These areas are excluded from the ecological analysis for this reason. Where the BA regional-scale analysis identifies an area as 'at risk' of large hydrological changes and potentially significant impacts on ecological, economic and/or sociocultural values, local-scale information may be necessary to constrain the predictive uncertainty to something more representative of local conditions, and more appropriate for informing the management response.

The quantitative representation of the predictive uncertainty through probability distributions allows BAs to consider the likelihood of impacts with a specified magnitude and underpins the impact and risk analysis. Sources of uncertainty that could not be quantified through numerical modelling were considered qualitatively.

3.1.2.5 A landscape classification

Subregions are complex landscapes with a wide range of human and ecological systems. The systems can be discrete, overlapping or integrated. Because of this complexity, a direct analysis of each and every point, or water-dependent asset, in the landscape across the subregion is not possible. Abstraction and a system-level classification were used to manage the challenges of the dimensionality of the task.

A set of landscape classes was defined that are similar in their physical, biological and hydrological characteristics. This reduced the complexity for each subregion and is appropriate for a regional-scale assessment. The landscape classification focuses on the key processes, functions and interactions for the individual landscape classes and assumes that ecosystems within each landscape class respond similarly to predicted hydrological changes. The landscape classification for the Gloucester subregion built on existing well-accepted classifications and is described in detail in companion product 2.3 for the Gloucester subregion (Dawes et al., 2018). The landscape classification allowed effort to be focused on those landscape classes that are water dependent.

The assessment of impacts on and risks to water-dependent ecological assets relied heavily on the landscape classification. Potential impacts to individual assets were assessed via their constituent landscape classes. For each of those landscape classes, the assessment was based on the qualitative mathematical models for those landscape classes and the indicators of hydrological change or ecosystem change identified as important for that landscape class.

3.1.2.6 Ruling out potential impacts

An important outcome of this BA was to identify areas of the Gloucester subregion that are not likely to be impacted by additional coal resource development. Potential impacts were ruled out where possible, both spatially and in terms of specific groundwater or surface water effects, in order to concentrate the analysis where potential impacts have a higher probability of occurring. This process started with identifying a preliminary assessment extent (PAE) for the subregion that is a conservative spatial boundary, encompassing areas of potential impact based on the most likely coal resource developments within the subregion. The PAE is where assessment effort was preferentially focused, when collating water-dependent assets, creating landscape classes to summarise key surface ecosystems, and constructing numerical surface water and groundwater models.

The results of the hydrological modelling were used to refine the PAE to the 'assessment extent' for this product. The assessment extent (~481.2 km^2) used in this product is only slightly larger than the PAE (~468.2 km^2) identified in companion product 1.3 for the Gloucester subregion (McVicar et al., 2015). This 13.0 km^2 increase was needed to account for small sections of the Karuah River, Mill Creek and Avondale Creek that weave in and out of the PAE boundary (which was defined by the geological Gloucester Basin at that part of the PAE).

Potential impacts were ruled out using a *zone of potential hydrological change*. This zone was defined using probabilities of exceeding thresholds in multiple hydrological response variables. A key role of the zone of potential hydrological change was to identify landscape classes that should be investigated further through qualitative mathematical modelling and receptor impact modelling, and, as required, through use of local information to better define the risk and appropriate management response. Equally as important, this logical and consistently applied process ruled out landscape classes or water-dependent assets where potential impacts due to additional coal resource development are *very unlikely* (less than 5% chance) to occur.

3.1.3 Structure of this product

This product presents the impact and risk analysis for the Gloucester subregion and is a key output of this BA. The structure is as follows:

- Section 3.1 describes the scope of the BA conducted for the Gloucester subregion and summarises the critical philosophical and operational choices.
- Section 3.2 describes the methods for assessing impacts and risks in the Gloucester subregion. It includes details of the databases, tools and geoprocessing that support the impact and risk analysis, and the approach to aggregating potential impacts to landscape classes and assets. The approach is consistent with that outlined in the companion submethodology M10 (as listed in Table 1) for analysing impacts and risks (Henderson et al., 2018), and is in addition to the methods for receptor impact modelling reported in companion product 2.7 for the Gloucester subregion (Hosack et al., 2018).
- Section 3.3 provides a closer look at the spatial extent of hydrological changes within the zone of potential hydrological change, using groundwater drawdown and a subset of the hydrological response variables defined in submethodology M06 (as listed in Table 1) for surface water modelling (Viney, 2016). The surface water hydrological response variables used include changes in low flows, high flows and annual flow due to additional coal resource development. Changes in other hydrological response variables can be accessed online (see www.bioregionalassessments.gov.au/explorer/GLO/hydrologicalchanges). While not explicitly modelled, the potential for additional coal resource development to impact groundwater and surface water quality is reported in this section.

- Section 3.4 considers the impacts on and risks to landscape classes in the zone of potential hydrological change due to additional coal resource development. An aggregated, system-level analysis of potential impacts is possible at the scale of the landscape class. A 'rule-out' process identified potentially impacted landscape classes. The impacts on and risks to landscape classes were assessed either quantitatively using the receptor impact models (Hosack et al., 2018), or qualitatively using the qualitative mathematical models developed through expert elicitation (Hosack et al., 2018). Further details on potential hydrological and ecological impacts on individual landscape classes can be accessed online (see www.bioregionalassessments.gov.au/explorer/GLO/landscapes).
- Section 3.5 considers the impacts on and risks to water-dependent assets (McVicar et al., 2015) in the zone of potential hydrological change due to additional coal resource development. The analysis focuses predominantly on asset groups, not on each individual asset. It includes ecological, economic and sociocultural assets. Profiles of potential impacts for individual assets are available online (see www.bioregionalassessments.gov.au/explorer/GLO/assets).
- Section 3.6 assesses the potential hydrological changes and impacts due to the additional coal resource development that was not modelled, Stage 2 of AGL's Gloucester Gas Project.
- Section 3.7 concludes with key findings and knowledge gaps. Commentary is provided on how to validate and build on this assessment in the future.

The companion product 2.7 Receptor impact modelling for the Gloucester subregion (Hosack et al., 2018) summarises the overarching methodology and development of the Gloucester subregion qualitative mathematical models and receptor impact models used to make predictions about the potential impacts on ecosystems reported in Section 3.4. As such it serves as an appendix to this product.

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Datasets

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Dataset 2 Bioregional Assessment Programme (2015) GLO AEM Model CRDP Mine Footprints v01. Bioregional Assessment Derived Dataset. Viewed 12 April 2017, http://data.bioregionalassessments.gov.au/dataset/e6ded61c-d949-41b3-8d00-a146eac9718b.

Dataset 3 AGL (2014) AGL Gloucester Gas Project AECOM report location map features. Bioregional Assessment Source Dataset. Viewed 12 April 2017, http://data.bioregionalassessments.gov.au/dataset/7fca4f35-6e4e-4d37-bbae-1c1029a93a40.

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3.2 Methods

Summary

The impact and risk analysis for the Gloucester subregion followed the overarching methodology described in companion submethodology M10 (as listed in Table 1) for analysing impacts and risks (Henderson et al., 2018). The impact analysis quantified the magnitude and extent of the potential hydrological or ecosystem changes due to additional coal resource development, including direct, indirect and cumulative impacts. The risk analysis considered not only the magnitude and extent of the potential impact, but also the likelihood of the impact.

Impacts to water-dependent landscapes and assets can be caused by changes in surface water and changes in groundwater in the regional watertable, from which most ecological assets source water. The impact and risk analysis used the conceptual model of causal pathways and probabilistic estimates of hydrological change to identify where potential impacts to landscapes and assets might occur. In some of these locations, receptor impact models were used to translate potential hydrological changes to potential ecosystem changes.

For bioregional assessment (BA) purposes, the regional watertable is the upper groundwater level within the unconfined, near-surface aquifer (not perched), where pore water pressure is equal to atmospheric pressure. It is constructed by combining the watertable from all the near-surface geological units (or layers) in which it occurs. Within the Gloucester subregion, the regional watertable exists in the alluvia of the Gloucester and Karuah river systems and in the weathered and fractured zone outside these alluvia. The change in drawdown at the regional watertable was obtained from the analytic element groundwater model for the weathered and fractured zone and combined with the change in drawdown in the alluvia from the MODFLOW groundwater model.

Surface water modelling was undertaken using the Australian Water Resources Assessment landscape model (AWRA-L). Results for eight hydrological response variables were reported for 34 model nodes across the subregion and extrapolated to stream links to better represent changes in surface water across the assessment extent.

The results from the groundwater and surface water modelling were used to define the zone of potential hydrological change due to additional coal resource development. Potential impacts to landscapes and assets were then assessed by overlaying their location on the zone of potential hydrological change. Outside this zone, landscapes and assets were ruled out from potential impacts and not analysed further. Inside this zone, potential impacts were summarised for each landscape class or asset using indicators of hydrological change (hydrological response variables) and ecosystem change (receptor impact variables).

The databases, tools and geoprocessing that supported the impact and risk analysis are summarised in this section.

3.2.1 Impact and risk analysis

The *Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources* (the BA methodology) (Barrett et al., 2013) states:

> The central purpose of BAs is to analyse the impacts and risks associated with changes to water-dependent assets that arise in response to current and future pathways of CSG and coal mining development.

The impact and risk analysis for the Gloucester subregion (Component 3 and Component 4) followed the logic described in companion submethodology M10 (as listed in Table 1) for analysing impacts and risks (Henderson et al., 2018), and is summarised diagrammatically in Figure 5. It built on, and was only possible because of, the contextual information (Component 1) and knowledge from the conceptual models of causal pathways, numerical groundwater and surface water modelling, and data analysis (Component 2). These components are described in detail in preceding products for the Gloucester subregion. The impact and risk analysis represents the culmination of efforts to improve the knowledge base around the coal resource development, and to understand how water resources and water-dependent assets may be affected by hydrological changes caused by additional coal resource development in the Gloucester subregion.

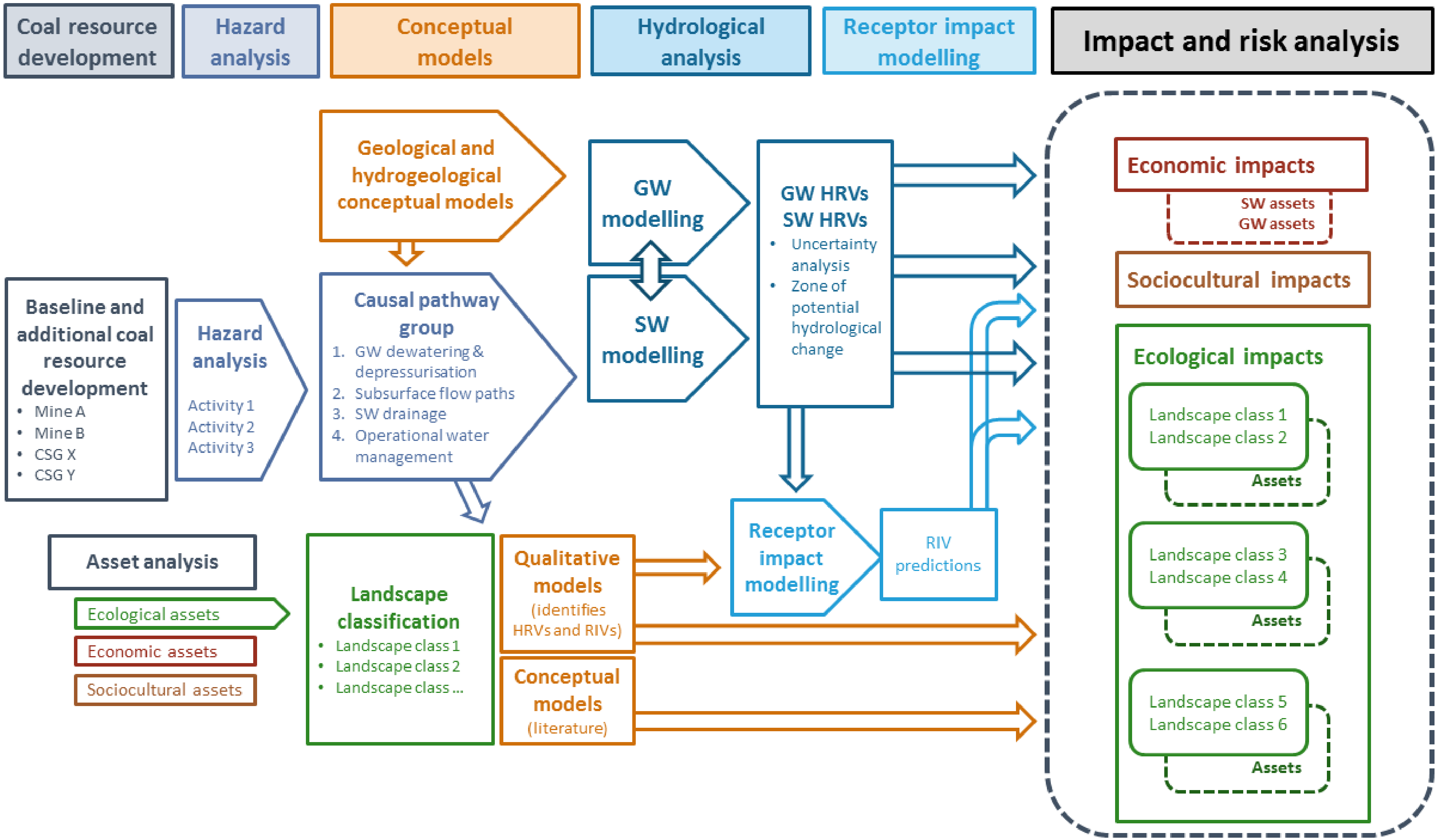

Figure 5 Overarching methodology for impact and risk analysis in bioregional assessments

CSG = coal seam gas, GW = groundwater, HRV = hydrological response variable, RIV = receptor impact variable, SW = surface water

The impact analysis quantified the magnitude and extent of the potential hydrological and ecosystem changes due to additional coal resource development. This included:

- *direct impacts*: a change in water resources and water-dependent assets resulting from coal seam gas (CSG) and coal mining developments without intervening agents or pathways
- *indirect impacts*: a change in water resources and water-dependent assets resulting from CSG and coal mining developments with one or more intervening agents or pathways
- *cumulative impacts*: the total change in water resources and water-dependent assets resulting from CSG and coal mining developments when all past, present and reasonably foreseeable actions that are likely to impact on water resources are considered.

The risk analysis is related, but considered not only the magnitude and extent of the potential impact but also the likelihood of that impact. This is often framed as 'consequence multiplied by the likelihood'. The quantification of the likelihood was underpinned by an uncertainty analysis that allowed probabilistic statements about events or impacts occurring. Within BAs, the uncertainty analysis stochastically propagated uncertainties in underlying hydrological parameters through hydrological models to produce distributions of potential surface water and groundwater changes. These in turn were input to receptor impact models to produce distributions of receptor impact variables which were chosen as indicators of potential ecosystem impacts.

BAs identified risks through a hazard analysis and analysed those risks by estimating the magnitude and likelihood of specific impacts. The risk assessment, risk evaluation and risk treatment that occur as part of broader risk management (see, for example, ISO 31000:2009 Risk Management Standards) are beyond the scope of BAs because they require careful consideration of a number of non-scientific matters and value judgments; these are roles of proponents and government regulators in the first instance.

This product first describes the hydrological changes, and then the potential impacts of those changes on landscape classes and water-dependent assets, which contain ecological, economic and sociocultural values. These regional-scale results do not replace the need for detailed site or project specific studies, nor should they be used to pre-empt the results of detailed studies that may be required under NSW legislation. Where potentially significant impacts are identified from the regional scale analysis, local scale information can be used to better define the risk.

BAs present the likelihood of certain impacts occurring, for example, the percent chance of exceeding 0.2 m of drawdown in a particular aquifer and location. The underpinning data and information is available at www.bioregionalassessments.gov.au for others to use in their own targeted risk assessments. Users can choose thresholds of impact that may threaten the specific values they are trying to protect and calculate the corresponding likelihood of occurrence. More details about hydrological changes and potential impacts in the Gloucester subregion are available at www.bioregionalassessments.gov.au/explorer/GLO.

3.2.2 Causal pathways

The conceptual model of causal pathways describes the logical chain of events – either planned or unplanned – that link coal resource development to potential impacts on water and water-dependent assets. The causal pathways provide the logical and transparent foundation for the impact and risk analysis.

A systematic hazard analysis, using the Impact Modes and Effects Analysis method (described in companion submethodology M11 (as listed in Table 1) for hazard analysis (Ford et al., 2016)), was undertaken for the Gloucester subregion to identify the activities that occur as part of coal resource development that might result in a change in the quality or quantity of surface water or groundwater. Hazards were prioritised according to the likelihood, severity and detectability of potential impacts (Dataset 1). It is important to ensure that all hazards are addressed for the impact and risk analysis to meet the necessary quality criteria. This does not mean that all causal pathways need to be assessed in the same way, only that they are all addressed in some way.

The many individual 'hazards' themselves were not represented directly in the hydrological models, but instead they were grouped into four causal pathway groups, which reflect the main hydrological pathways via which the effects of a hazard can propagate from its origin. These simplified pathways were broadly represented in the BA hydrological models. These causal pathway groups are:

- 'Subsurface depressurisation and dewatering'
- 'Subsurface physical flow paths'
- 'Surface water drainage'
- 'Operational water management'.

Figure 6 illustrates these causal pathways and Table 3 provides a more detailed list of the potential hazards arising from coal resource development in the Gloucester subregion, grouped into the four causal pathway groups. Further details about hazards, their identified effects and their link to causal pathway groups are in companion product 2.3 for the Gloucester subregion (Dawes et al., 2018).

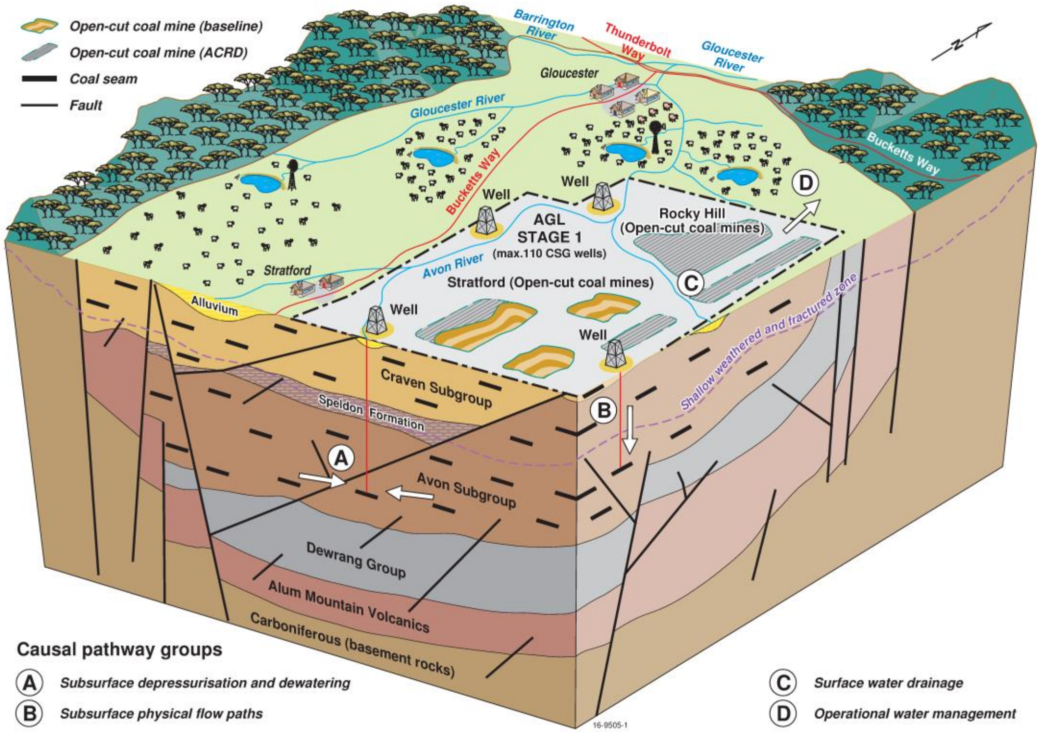

Figure 6 Conceptual diagram of the causal pathway groups associated with coal seam gas operations and open-cut coal mines for the Avon River basin in the Gloucester subregion

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

The hydrological models represent causal pathways through their conceptualisations and parameterisations. The outputs from the hydrological models do not identify individual causal pathways but integrate the various possible causal pathways into the predicted hydrological response at particular points in space and time.

The effects of some hazards were not modelled. Some cannot be modelled due to scale or complexity and were addressed qualitatively using the current conceptual understanding and knowledge base. Changes in water quality due to coal resource development activities were considered only through potential effects on stream salinity (Section 3.3.4). Some identified hazards were deemed to be local in scale and addressed by existing site-based management, whereas some were considered knowledge gaps (e.g. because the means of disposal for co-produced water extracted during CSG production is unknown). Others were considered of such low likelihood and/or consequence for broader cumulative impacts at the regional scale that they were not included.

While the causal pathway groups are generic, the physical characteristics of a subregion, such as its geological, geophysical and topographic architecture, and related surface water and groundwater networks, will influence the hydrological connectivity across the subregion. The Assessment team’s conceptual understanding of the dominant geological and topographic influences on surface water and groundwater connectivity in the Gloucester subregion are described in companion product 2.3 (Dawes et al., 2018).

Table 3 Causal pathways in the Gloucester subregion and their associated hazards, hydrological effects, system components and temporal context

Each causal pathway is listed in a chain of logic from the hazard and associated hydrological effects to system components that may contain assets or ecosystems that may be subject to potential hydrological changes.

Causal pathway group – Causal pathway	Hazards (impact mode)	Hydrological effects	System components	Temporal context
Subsurface depressurisation and dewatering – Groundwater pumping enabling coal seam gas extraction Groundwater pumping enabling open-cut coal mining Groundwater pumping of target aquifer	Aquifer depressurisation Aquifer depressurisation (coal seam) Groundwater extraction (groundwater supply bore) Localised watertable reduction Reduction in pressure head (pump testing) Very localised watertable reduction	Groundwater flow (reduction) Groundwater level Groundwater pressure	Target aquifer	Short term Long term
Subsurface depressurisation and dewatering – Unplanned groundwater changes in non-target aquifers	Aquifer depressurisation (fault-mediated) Aquifer depressurisation (non-target, non-reservoir) Deliberate dewatering (pit wall stabilisation) Mis-perforation of target aquifer	Surface water flow Groundwater direction Groundwater flow (reduction) Groundwater pressure Groundwater quality Groundwater quantity/volume	Non-target aquifer Alluvium and watercourses within and downstream of coal resource developments	Medium to long term Long term
Subsurface physical flow paths – Failure of well integrity	Bore leakage between aquifers Bore leakage to surface Fluid loss to aquifer Incomplete seal Incomplete/compromised cementing/casing (gas leakage) Incomplete/compromised cementing/casing (linking aquifers) Intersection of artesian aquifer Mis-perforation of target aquifer (connecting aquifers) Mud pressure imbalance Seal integrity loss	Surface water quality Groundwater quality Groundwater composition Groundwater pressure	Aquifers within coal resource developments Watercourses within and downstream of coal resource developments	Short term Long term

Causal pathway group – Causal pathway	Hazards (impact mode)	Hydrological effects	System components	Temporal context
Subsurface physical flow paths – Hydraulic fracturing	Accidental intersection of fault Changing non-target aquifer properties (physical or chemical) Changing target aquifer properties (physical or chemical) Connecting aquifers (too much pressure) Contaminate non-target aquifer (chemical) Contaminate target aquifer (chemical) Intersection of aquifer	Aquifer properties Groundwater composition Groundwater pressure Groundwater quality	Target aquifers within coal resource developments Non-target aquifers within coal resource developments	Long term
Subsurface physical flow paths – Extracting overburden to access coal	Artificial point of recharge Enhanced aquifer interconnectivity Groundwater sink Linking aquifers, preferential drainage	Surface water flow Change in zero-flow days Groundwater direction Groundwater pressure Groundwater quality Groundwater quantity/volume	Alluvium and watercourses within and downstream of coal resource developments Aquifers within coal resource developments	Medium to long term Long term
Surface water drainage – Altering surface water system	Change to natural surface drainage Disruption of natural surface drainage	Surface water direction Surface water quality Surface water volume Groundwater quantity/volume	Alluvium and watercourses within and downstream of coal resource developments	Medium to long term
Operational water management – Processing and using extracted water	Increase discharge to rivers following irrigation Raise watertable following irrigation Soil salt mobilisation following irrigation	Surface water flow Surface water quality Groundwater level Groundwater quality	Alluvium and watercourses within and downstream of coal resource developments	Short term
Operational water management – Storing extracted water	Change to natural surface drainage Disruption of natural surface drainage (freshwater storage) Disruption of natural surface drainage (mine water storage) Disruption of natural surface drainage (tailings water storage) Excessive runoff during closure (water management structures)	Surface water direction Surface water flow Surface water quality Surface water volume Groundwater quality Groundwater quantity/volume	Alluvium and watercourses within and downstream of coal resource developments	Medium to long term

Full descriptions of the causal pathways and causal pathway groups are available in companion submethodology M05 (as listed in Table 1) for developing a conceptual model of causal pathways (Henderson et al., 2016).

3.2.3 Hydrological analysis

The Gloucester surface water and groundwater models were designed to quantify potential changes in hydrology caused by activities undertaken at multiple coal resource developments. This enabled an assessment of the cumulative impacts of coal resource development at a regional scale. This analysis focused on the zone of potential hydrological change, outside of which potential impacts from additional coal resource development are *very unlikely* (less than 5% chance). See Section 3.3.1 for more details.

3.2.3.1 Groundwater

A deeper analytic element model was coupled to a shallow numerical alluvial model to estimate spatially explicit probabilities of hydrological changes due to coal resource development. Potential hydrological changes were calculated for two futures considered in BAs: the baseline and the coal resource development pathway (CRDP). The difference in results between CRDP and baseline is the change that is primarily reported in a BA. This change is due to the additional coal resource development, which in the Gloucester subregion comprises three open-cut coal mines and one CSG field (Section 3.1.2.1).

The deeper analytic element model was developed using TTim (Bakker, 2015) to predict the response in the weathered zone to coal resource development. The bottom of the weathered zone is the lower boundary of the alluvium (where present) and the land surface layer outside of the alluvium. The analytic element model stochastically simulated the representation of faults and hydraulic properties, thus incorporating both conceptual and parameter uncertainty in the predictions. The numerical model of the alluvium was developed in MODFLOW (Harbaugh et al., 2000). It propagated the drawdown from the weathered zone below to the watertable and also predicted the change in surface water – groundwater flux to the stream network. Results were generated at model nodes across the modelling domain. Hydrological response variables representing maximum drawdown and the year of maximum drawdown were defined for summarising model results. The details of the groundwater modelling are reported in companion product 2.6.2 for the Gloucester subregion (Peeters et al., 2018).

Groundwater modelling results are reported for the regional watertable, from which most ecological assets source water. For BA purposes, the regional watertable is the upper groundwater level within the unconfined, near-surface aquifer (not perched), where pore water pressure is equal to atmospheric pressure. It was constructed by combining the watertable from all the near-surface geological units (or layers) in which it occurs. Within the Gloucester subregion, the regional watertable exists in the alluvia of the Gloucester and Karuah river systems and in the weathered and fractured zone outside these alluvia. The change in drawdown in the regional watertable was obtained from the analytic element model for the weathered and fractured zone and combined with the change in drawdown in the alluvia from the MODFLOW models.

Drawdown from the groundwater model nodes was spatially interpolated to obtain valid posterior distributions at all assessment units across the modelling domain. A Delaunay Triangulation was generated in the R package 'tripack' (Renka et al., 2015). For each assessment unit, the quantiles of maximum drawdown at the nodes of the triangle enclosing the assessment unit were linearly interpolated to the new location. A forward-backward cubed-root transform was applied during the interpolation to improve performance over potentially non-linear surfaces.

Section 3.3.1.1 describes how the groundwater modelling results were used to define the groundwater zone of potential hydrological change.

3.2.3.2 Surface water

Surface water modelling for the Gloucester subregion was undertaken using the Australian Water Resources Assessment landscape model (AWRA-L). Details of the application of this model to the Gloucester subregion are reported in companion product 2.6.1 (Zhang et al., 2018). No river modelling was carried out because the rivers in the subregion are unregulated and their catchments are relatively small. Instead, streamflow was predicted by accumulating output from a spatially explicit streamflow model (AWRA-L). Coal resource development affects surface water hydrology directly through disruption of surface water drainage and some aspects of operational water management, and indirectly through changes in surface water – groundwater fluxes in response to aquifer depressurisation from mine dewatering and CSG wells.

Results for eight hydrological response variables were reported for 34 model nodes across the Gloucester subregion. The locations of these model nodes are shown in Figure 7. In order to carry out the impact and risk analysis, results from these model nodes needed to be extrapolated to stream links. Extrapolating these changes is important in order to get some sense of the changes in surface water across the entire assessment extent.

The process for extrapolating hydrological response variable values from model nodes to stream links is shown schematically in Figure 8. The schematic includes a number of stream links with no model nodes (dashed lines) for which model results were not generated, but were important for doing the extrapolations. The junctions of these non-modelled streams with the modelled network correspond to significant changes in streamflow and hence represent limits to extrapolation from the nearest upstream or downstream model node. Extrapolations were also not undertaken for stream links potentially affected by changes in runoff from open-cut coal mine operations (e.g. Avondale Creek, the reach between nodes 14 and 16 on Dog Trap Creek, and the reach between nodes 12 and 13 on Waukivory Creek). Because the impact of a mine on streamflow diminishes with increasing distance downstream of the mine, it is difficult to know how far along the reach it is reasonable to extrapolate from the nearest model node before the hydrological changes at that node are no longer representative of the hydrological changes at that point in the reach. Thus, they were classified as potentially impacted and included in the zone of potential hydrological change.

Section 3.3.1.2 describes how the surface water modelling results were used to define the surface water zone of potential hydrological change.

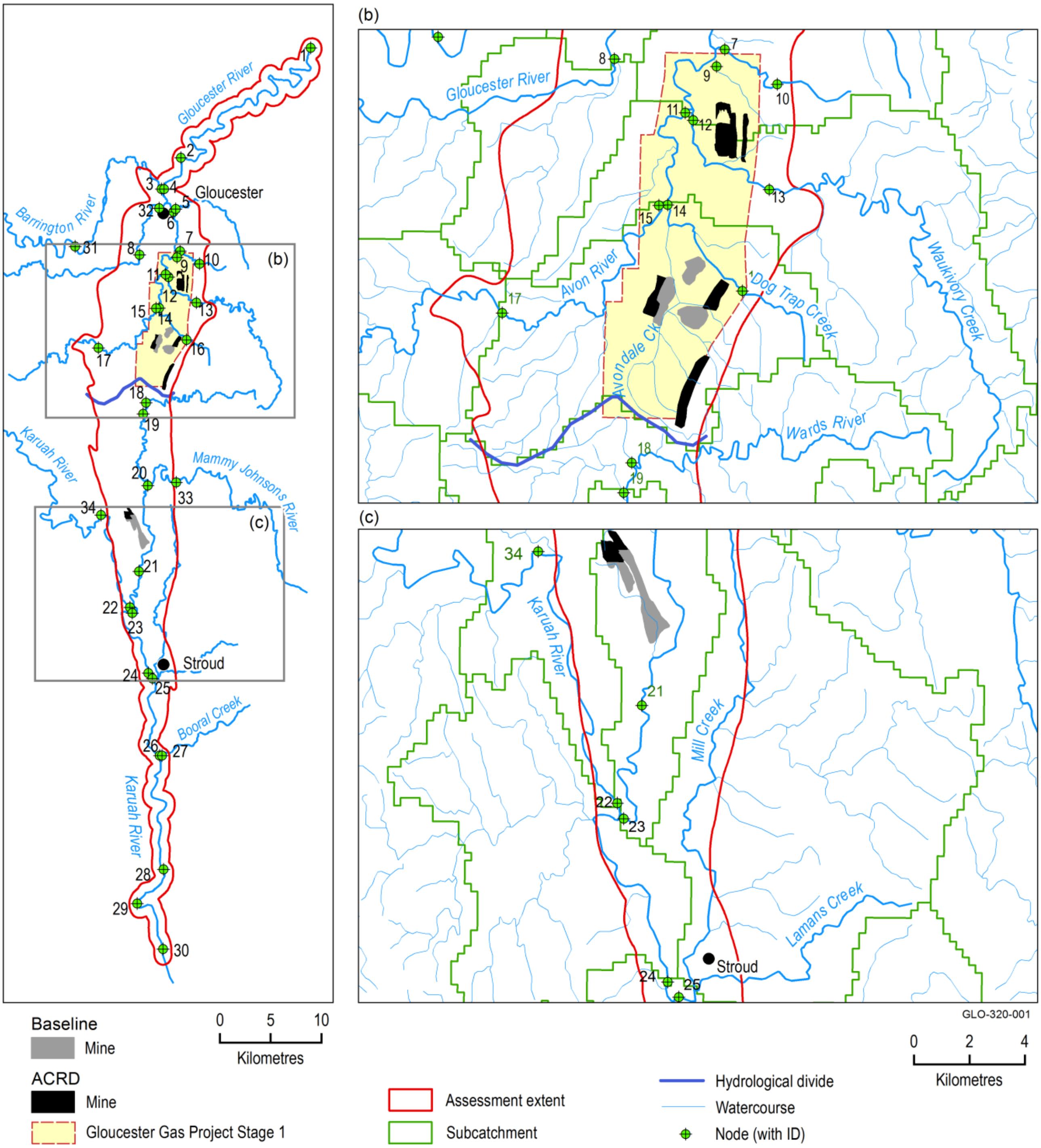

Figure 7 Surface water model nodes in the Gloucester subregion

Data: Bioregional Assessment Programme (Dataset 6, Dataset 7, Dataset 8); AGL (Dataset 5)

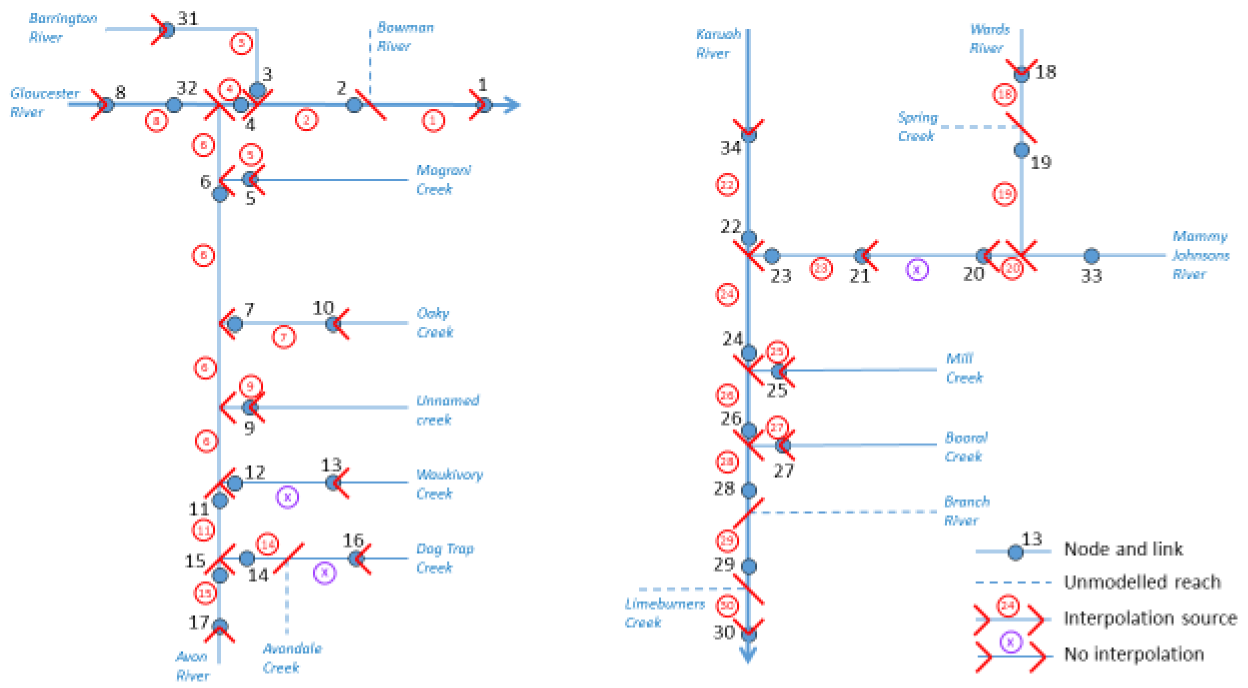

Figure 8 Scheme for interpolating hydrological response variables from model nodes to stream links for the northern-flowing (left) and the southern-flowing river basins

3.2.3.3 Representing predictive uncertainty

The models used in the assessment produced a large number of predictions of groundwater drawdown and streamflow characteristics rather than a single number. This results in a range or distribution of predictions, which are typically reported as probabilities – the percent chance of something occurring (Figure 9). This approach allowed an assessment of the likelihood of exceeding a given magnitude of change, and underpinned the assessment of the risk.

Groundwater models require information about physical properties such as the thickness of geological layers, how porous aquifers are, and whether faults are present. As the exact values of these properties are not always known, modellers used a credible range of values, which are based on various sources of data (commonly point-scale) combined with expert knowledge. The groundwater model was run thousands of times using a different set of plausible values for those physical properties each time. Historical observations, such as groundwater level and changes in water movement and volume, were used to constrain and validate the model runs.

The complete set of model runs produced a range or distribution of predictions (Figure 9) that are consistent with available observations and the understanding of the modelled system. The range conveys the confidence in model results, with a wide range indicating that the expected outcome is less certain, while a narrow range provides a stronger evidence base for decision making. The distributions created from these model runs are expressed as probabilities that drawdown or a change in streamflow will exceed relevant thresholds, as there is no single 'best' estimate of change.

In this assessment, the estimates of drawdown or streamflow change are shown as 95th, 50th or 5th percentile results, corresponding to a 5%, 50% or 95% chance of exceeding thresholds. Figure 10 illustrates this predictive uncertainty within a spatial context.

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

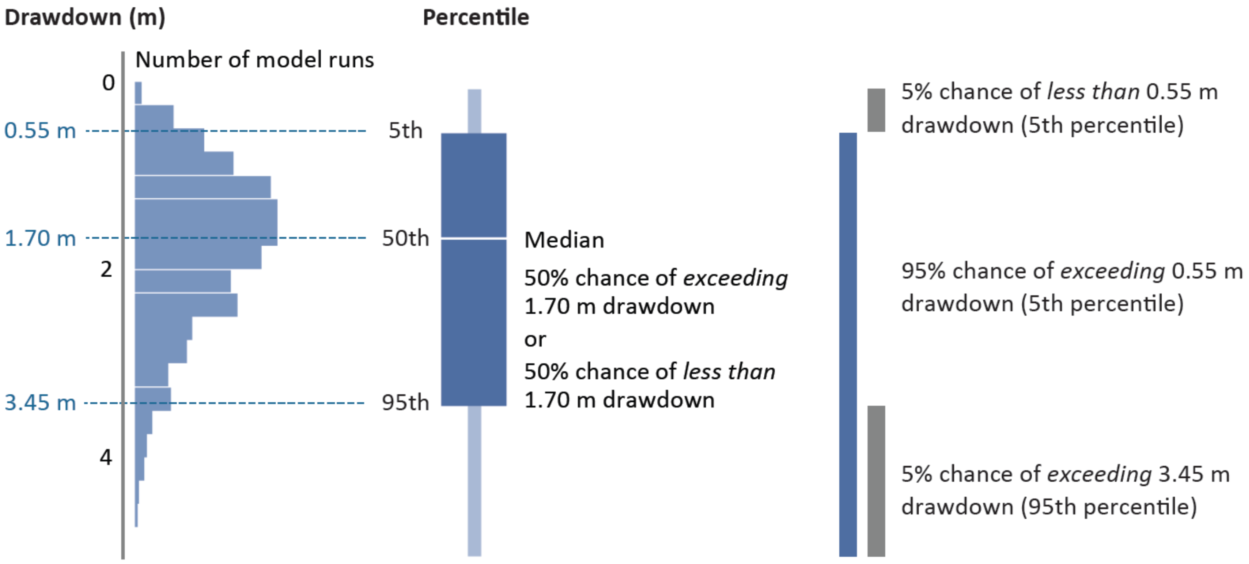

Figure 9 Illustrative example of probabilistic drawdown results using percentiles and percent chance

The chart on the left shows the distribution of results for drawdown, obtained from an ensemble of thousands of model runs that use many sets of parameters. These generic results are for illustrative purposes only and are not actual results from the Gloucester subregion.

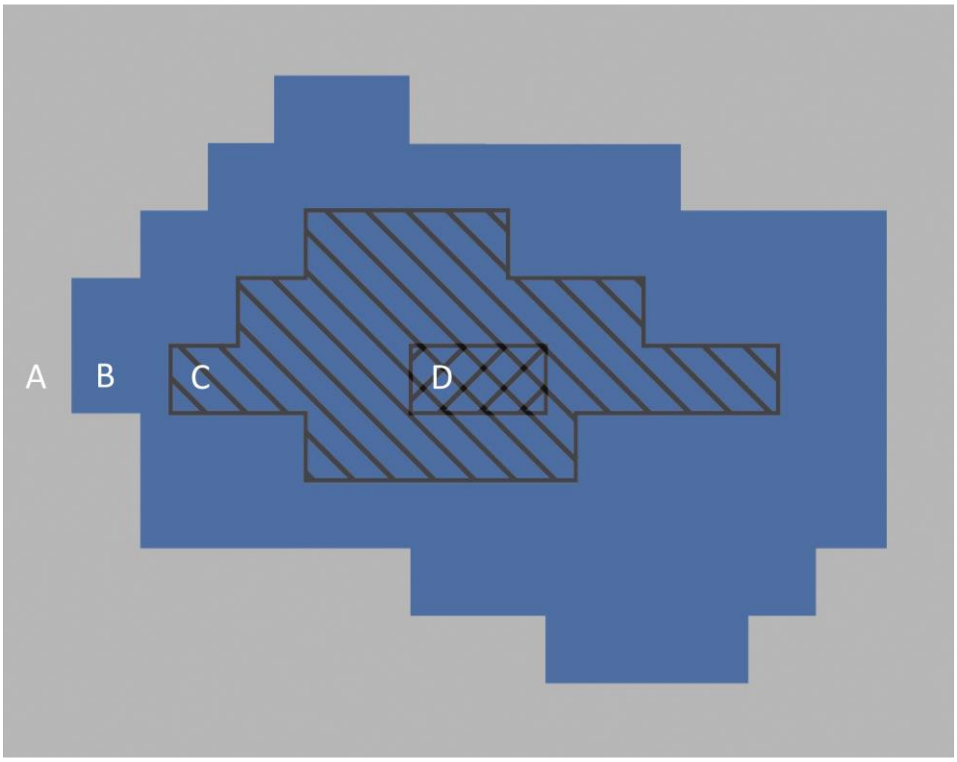

Figure 10 Illustrative example of key areas in the landscape defined by probabilistic results

The assessment extent was divided into smaller square assessment units (see Section 3.2.4.1) and the probability distribution (Figure 9) was calculated for each. In this product results are reported with respect to the following key areas:
A. outside the zone of potential hydrological change, where hydrological changes (and hence impacts) are *very unlikely* (defined by maps showing the 95th percentile)
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 95th percentile). Further work is required to determine whether the hydrological changes in the zone translate into impacts for water-dependent assets and landscapes
C. with at least a 50% chance of exceeding the threshold (i.e. the assessment units where the median is greater than the threshold; defined by maps showing the 50th percentile)
D. with at least a 95% chance of exceeding the threshold (i.e. the assessment units where hydrological changes are *very likely*; defined by maps showing the 5th percentile).

3.2.4 Assessing potential impacts for landscape classes and assets

The approach for assessing potential impacts for landscape classes and water-dependent assets is discussed in companion submethodology M10 (as listed in Table 1) for analysing impacts and risks (Henderson et al., 2018). The zone of potential hydrological change focuses the attention of the analysis on areas where there may be changes in surface water and/or groundwater that are attributable to additional coal resource development.

The principal focus of BAs is water-dependent assets that are nominated by the community. These assets may have a variety of values, including ecological, sociocultural and economic values. The water-dependent asset register (companion product 1.3 for the Gloucester subregion (McVicar et al., 2015); Bioregional Assessment Programme, 2017; Bioregional Assessment Programme, Dataset 2) provides a simple and authoritative listing of the assets within the assessment extent. The register is a compilation of assets identified in local land services (formerly catchment management authorities) databases and Commonwealth and state databases, and through the Gloucester assets workshop. To be included in the register, assets must have spatial information, intersect the assessment extent for the subregion and have a water-dependency. These assets are considered in the impact and risk analysis reported in this product.

Landscape classification discretised the heterogeneous landscape into a manageable number of landscape classes for impact and risk analysis. Landscape classes represent key surface ecosystems that have broadly similar physical, biological and hydrological characteristics. They were used to reduce the complexity inherent in assessing impacts on a large number of water-dependent assets by focusing on the hydrological drivers and interactions relevant to a regional-scale assessment. The landscape classes provide a meaningful scale for understanding potential ecosystem impacts and communicating them through their more aggregated system-level view. The landscape classification for the Gloucester subregion is described in companion product 2.3 (Dawes et al., 2018) and the methodology that underpins it is described in companion submethodology M05 (as listed in Table 1) for developing a conceptual model of causal pathways (Henderson et al., 2016).

Potential hydrological changes were assessed by overlaying the extent of a landscape class or asset on the zone of potential hydrological change due to additional coal resource development. For the landscape classes or assets that lie outside the zone, hydrological changes (and hence potential impacts due to coal resource development) are *very unlikely*, and are thus ruled out in terms of further assessment. Section 3.4.2 identifies landscape classes in the Gloucester subregion that can be ruled out on this basis.

Where an asset or landscape class wholly or partially intersects the zone of potential hydrological change, there is the potential for impact. This does not mean there will be an impact, but rather, based on the magnitude of the hydrological change, the possibility of an impact cannot be ruled out and further investigation is required. The nature of the water dependency of the landscape class can be important for informing the assessment. For example, if the water dependence of a landscape class relies on overbank flows to support seedling establishment, but the significant hydrological changes in the nearby stream relate only to low-flow variables (i.e. flows that are contained within the streambanks), then it is possible to rule the landscape class out of further consideration because it is unlikely to be impacted.

Four receptor impact models were built, representing two landscape classes in the Gloucester subregion (Table 4), and were used to quantitatively predict the impact of the predicted hydrological changes on one or more receptor impact variables within the receptor impact model (companion product 2.7 for the Gloucester subregion (Hosack et al., 2018b)). Ecological meaningful hydrological response variables and receptor impact variables (Table 4) were elicited from experts (listed in Table 3 in companion product 2.7 for the Gloucester subregion (Hosack et al., 2018b)) during qualitative and receptor impact model building workshops and subsequent follow-up by email. A full description of receptor impact modelling is described in companion submethodology M08 (as listed in Table 1) (Hosack et al., 2018a).

Table 4 Landscape classes, receptor impact models and their model variables

Landscape class	Receptor impact variable (with associated sample units)	Hydrological response variables
Perennial – gravel/cobble streams	**Annual mean percent canopy cover of woody riparian vegetation** (predominately *Casuarina cunninghamiana, Melia azedarach, Eucalyptus amplifolia* and *Angophora subvelutina*) in a transect 20 m wide and 100 m long covering the bottom of the stream bench to the high bank	dmaxRef tmaxRef EventsR0.3 EventsR3.0
Perennial – gravel/cobble streams	**Mean number of larvae of the family Hydropsychidae (net-spinning caddisflies)** in a 1 m^2 sample of riffle habitat	ZQD
Perennial – gravel/cobble streams	**Mean abundance of the eel-tailed catfish** (*Tandanus tandanus*) in a 600 m^2 transect whose long axis lies along the mid-point of the stream	ZQD QBFI
Intermittent – gravel/cobble streams	**Mean richness of hyporheic invertebrate taxa** in 6 L of water pumped from a depth of 40 cm below the streambed (riffle and gravel bars)	ZQD

dmaxRef = maximum drawdown, tmaxRef = year of maximum drawdown, EventsR3.0 = overbank events, EventsR0.3 = overbench events, ZQD = zero-flow days (averaged over 30 years), QBFI = baseflow index

Potential impacts are reported in Section 3.4 for landscape classes and in Section 3.5 for assets.

In addition, impact profiles for landscape classes and assets are available at www.bioregionalassessments.gov.au. Each profile summarises the hydrological changes and potential impacts that pertain to that landscape class or asset (e.g. increase in the number of low-flow days for the streams in the 'Perennial – gravel/cobble streams' landscape class in the zone of potential hydrological change). Users can aggregate and consider potential impacts for their own scale of interest.

Users can also explore the results for landscape classes and assets using a map-based interface at www.bioregionalassessments.gov.au/explorer/GLO/landscapes and www.bioregionalassessments.gov.au/explorer/GLO/assets.

3.2.4.1 Information management and processing

A very large number of multi-dimensional and multi-scaled datasets were used in the impact and risk analysis for each BA, including hydrological model outputs, and ecological, economic and sociocultural asset data from a wide range of sources. Part of the approach used to manage these datasets and produce meaningful results was to adopt a clear spatial framework as an organising principle. While the inherently spatial character of every BA is important and must be addressed, it is also essential that the temporal and other dimensions of the analysis do not lose resolution during data processing. For example, knowing where a potential impact may take place is obviously important, but so is knowing when, which hydrological response variables may change, which assets may be affected, and what level of impact may result.

The datasets for this BA were organised into an *impact and risk analysis database* (Bioregional Assessment Programme, Dataset 3) to enable efficient management. The purpose of the database is to produce result datasets that integrate the available modelling and other evidence across the assessment extent of the BA. These databases are required to support three types of BA analyses: analysis of hydrological changes, impact profiles for landscape classes, and impact profiles for assets. The results of these analyses are summarised in this product, with more detailed information available on www.bioregionalassessments.gov.au. The impact and risk analysis database is also available on data.gov.au (Bioregional Assessment Programme, Dataset 3).

The datasets used in the impact and risk analysis database (Bioregional Assessment Programme, Dataset 3) include the assets, landscape classes, modelling results (groundwater, surface water and receptor impact modelling), coal resource development 'footprints' and other relevant geographic datasets, such as the boundaries of the subregion, assessment extent and zone of potential hydrological change. All data in the impact and risk analysis database (and the results derived from it) meet the requirements for transparency.

The impact and risk assessment requires the geoprocessing of complex queries on very large spatial datasets. To overcome the computational overload associated with this task a relational, rather than geospatial approach was utilised. All dataset geometries are split against a universal grid of assessment units that exhaustively cover the assessment extent (Figure 11). An assessment unit is a geographic area represented by a square polygon with a unique identifier. The spatial resolution of the assessment units is closely related to that of the BA groundwater modelling and is typically 1 km x 1 km, though due to the small size of the Gloucester subregion and the resolution of the groundwater modelling it is 0.5 km x 0.5 km. Assessment units were used to partition asset and landscape class spatial data for impact analysis. The gridded data can be combined and recombined into any aggregation supported by the conceptual modelling, causal pathways and model data.

The gridded data were normalised and loaded into the impact and risk analysis database (Bioregional Assessment Programme, Dataset 3). Impact area, length and counts are calculated for individual features (e.g. stream reaches, individual assets, groups of assets or landscape classes) at the assessment unit level. An individual analysis result is executed by selecting the assessment units of interest and summing the pre-calculated values of area, length or count for the required dataset. This approach of front-loading the geospatial analysis through grid base attribution is fundamental to enabling the volume of calculations required to complete the assessment. The approach uses the source geometries in calculation and hence does not impact on the analysis calculations. In a few cases, source geometries were found to create geospatial errors and were removed from the analysis. The removing of invalid geometries did not in any case, affect the analysis results more than a combined total area of one assessment unit per geospatial item.

The interpolated modelled groundwater drawdowns (see Section 3.2.3.1) are at the same resolution as the assessment unit and contain a single value per assessment unit. However, the surface water modelling generated results at points that are extrapolated to links (see Section 3.2.3.2), which were then mapped to assessment units. An example of this can be seen in Figure 11, where the assessment units containing nodes 14 and 15 are assigned the value associated with that node.

However, where the assessment unit contains multiple stream reaches (e.g. at the confluence of the two streams shown in Figure 11), it was necessary to prioritise which stream reach was used to inform the value of the assessment unit for representing the surface water modelling results. The general rules for prioritising a stream reach take into account:

- whether the modelled reaches show a hydrological change (i.e. a reach with a potential hydrological change takes priority over a reach predicted to have no significant change)
- whether the stream reach is represented in the model (i.e. modelled reaches take priority)
- the stream order of each reach (i.e. a higher order stream (e.g. main channel) takes priority over a lower order stream (e.g. tributary))
- reach length (i.e. where two streams in an assessment unit are of equally high stream order, priority is given to the longer of the two).

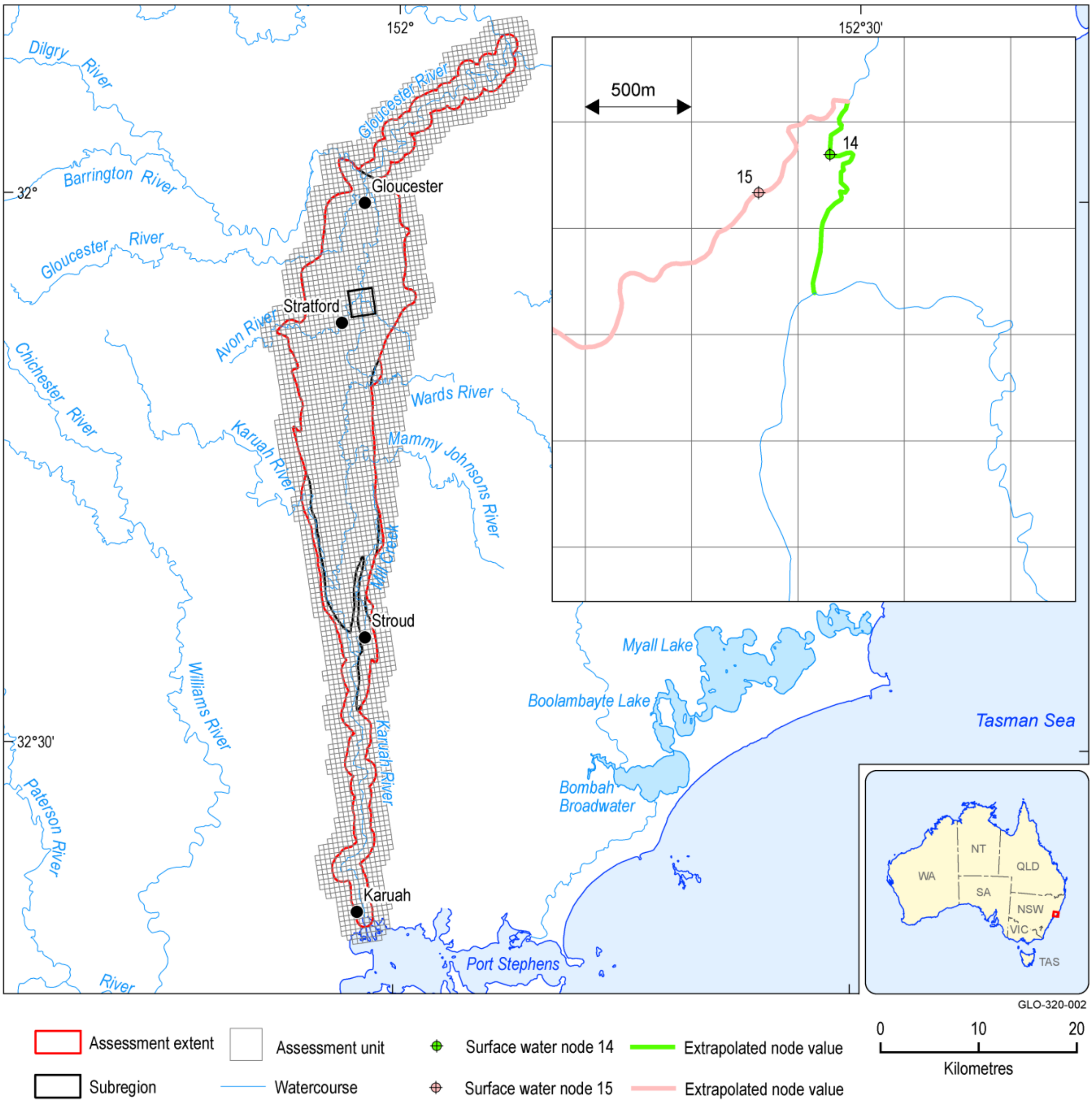

Figure 11 Assessment units and interpolation of surface water nodes across the assessment extent

Data: Bioregional Assessment Programme (Dataset 7, Dataset 8)

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3.3 Potential hydrological changes

Summary

Potential hydrological changes were derived for the two futures considered in bioregional assessments (BAs): the baseline and the coal resource development pathway (CRDP).

The groundwater zone of potential hydrological change is defined as the area with a greater than 5% chance of exceeding 0.2 m of drawdown in the regional watertable due to additional coal resource development (as predicted by numerical groundwater modelling). It consists of an area of 88 km^2 around Stratford mine, Rocky Hill mine and the Gloucester Gas Project Stage 1, and an additional 12 km^2 around Duralie mine.

The surface water zone of potential hydrological change is defined as the area in which the change in any one of the eight surface water hydrological response variables exceeds the specified threshold. It includes all modelled reaches that are within the assessment extent except for those in the Barrington River, Booral Creek and the Karuah River below Booral Creek. Additionally, it includes three unmodelled reaches in the Gloucester river basin: Sandy Creek (a tributary of the Gloucester River), Avondale Creek (a tributary of the Avon River), and an unnamed tributary of the Avon River.

The combined groundwater and surface water zone of potential hydrological change in the Gloucester assessment extent covers an area of 250 km^2 and 242 km of stream network.

It is *very likely* that an area of 19 km^2 will experience at least 0.2 m of drawdown, and it is *very unlikely* that more than 100 km^2 will experience drawdowns of this magnitude, due to additional coal resource development. It is *very unlikely* that more than 16 km^2 exceeds 2 m of drawdown, and *very unlikely* that more than about 4 km^2 exceeds 5 m of drawdown.

The potential impacts due to additional coal resource development on surface water flow regimes are summarised using three hydrological response variables: low-flow days, high-flow days and annual flow. Low-flow days are likely to increase at a number of locations across the assessment extent. The median change is less than the interannual variability observed under the baseline; however, there is at least a 5% chance that changes will be comparable to or greater than the interannual variability seen under the baseline. Similar, although slightly smaller in both area and magnitude, reductions in the number of high-flow days are modelled. The reduction in annual flow is smaller again in both area and magnitude and is unlikely to move the system out of the range of interannual variability seen under the baseline.

Potential changes in hydrology could lead to changes in water quality (although water quality was not modelled). Several regulatory requirements are in place in NSW to minimise potential water quality impacts from coal resource development. Potential impacts on water quality

due to additional coal resource development are considered unlikely in the Gloucester subregion, as no development is permitted to discharge mine water off site. Modelled predictions of baseflow reductions are small and, if anything, are expected to result in small decreases in stream salinity.

Potential hydrological changes due to additional coal resource development are summarised using hydrological response variables based on results from regional-scale surface water and groundwater modelling, reported in companion product 2.6.1 (Zhang et al., 2018) and companion product 2.6.2 (Peeters et al., 2018) for the Gloucester subregion. These hydrological response variables have been defined to represent the maximum difference between the CRDP and baseline for groundwater drawdown and a range of streamflow characteristics. They have also been used to define the zone of potential hydrological change – the focal extent for the impact and risk analysis (Section 3.3.1).

Potential changes in groundwater and surface water within the zone of potential hydrological change are presented in Section 3.3.2 and Section 3.3.3, respectively. Areas more at risk of hydrological changes, and hence potentially adverse impacts, due to additional coal resource development are identified. Local scale information is needed to refine the assessment of risk and determine the appropriate management response in these areas. While changes in water quality were not part of the hydrological modelling, the potential for changes in water quality due to additional coal resource development in the Gloucester subregion is considered in Section 3.3.4.

Additional hydrological response variables have been defined for input into the landscape class qualitative models and receptor impact models (companion product 2.7 for the Hunter subregion (Hosack et al., 2018b)), and for quantifying potential impacts on economic assets. They represent key water dependencies in these systems and are based on average differences over 30-year and 90-year periods. Changes in these variables are presented as part of the impact and risk analysis in Section 3.4 and Section 3.5.

3.3.1 Defining the zone of potential hydrological change

The zone of potential hydrological change is the area within the subregion where changes in hydrology due to additional coal resource development exceed defined thresholds for groundwater and surface water changes. The impact and risk analysis presented in the remainder of this product focuses on landscape classes and assets that intersect this zone. Any landscape class or asset wholly outside of the zone of potential hydrological change is considered *very unlikely* (less than 5% chance) to experience hydrological changes due to additional coal resource development, and thus is ‘ruled out’ from any further analysis as part of this BA.

The zone of potential hydrological change is defined as the union of the groundwater zone of potential hydrological change (Section 3.3.1.1) and the surface water zone of potential hydrological change (Section 3.3.1.2), clipped to the assessment extent. It is further described in Section 3.3.1.3.

3.3.1.1 Groundwater

The groundwater zone of potential hydrological change is defined as the area with a greater than 5% chance of exceeding 0.2 m of drawdown in the regional watertable due to additional coal resource development. This 5% chance is determined based on an uncertainty analysis as described in Section 2.6.2.8 of companion product 2.6.2 for the Gloucester subregion (Peeters et al., 2018). It means that 95% of groundwater model runs exceeded this level of drawdown. Groundwater impacts due to coal mines and CSG projects are regulated under state legislation and state regulatory and management frameworks. The 0.2 m drawdown threshold adopted in BAs is consistent with the most conservative minimal impact threshold in the *NSW Aquifer Interference Policy* (DPI, 2012) and Queensland's *Water Act 2000*.

Figure 12 shows the areas with a greater than 5% chance of drawdown exceeding 0.2 m under the baseline, under the CRDP and due to additional coal resource development. Under the baseline, this corresponds to an area of 140 km^2 (29% of the 481 km^2 assessment extent). It increases to 206 km^2 (42% of assessment extent) under the CRDP, which represents the combined effect of drawdown under the baseline and due to additional coal resource development. However, it is the area with a greater than 5% chance of drawdown exceeding 0.2 m due to additional coal resource development (Figure 12c) that forms the basis of the groundwater zone of potential hydrological change and this covers an area of 100 km^2. Of this, 52 km^2 also experiences greater than 0.2 m of drawdown under the baseline. It is this area of overlap where there is potential for cumulative impacts due to baseline and additional coal resource developments.

The groundwater zone of potential hydrological change for the Gloucester subregion is shown in Figure 12c. It consists of an area of 88 km^2 in the Gloucester river basin, and 12 km^2 north-west of Stroud in the Karuah river basin. These two areas are around the proposed Rocky Hill Coal Project, Stratford expansion and the Gloucester Gas Project Stage 1 CSG field in the north, and the proposed Duralie expansion in the south.

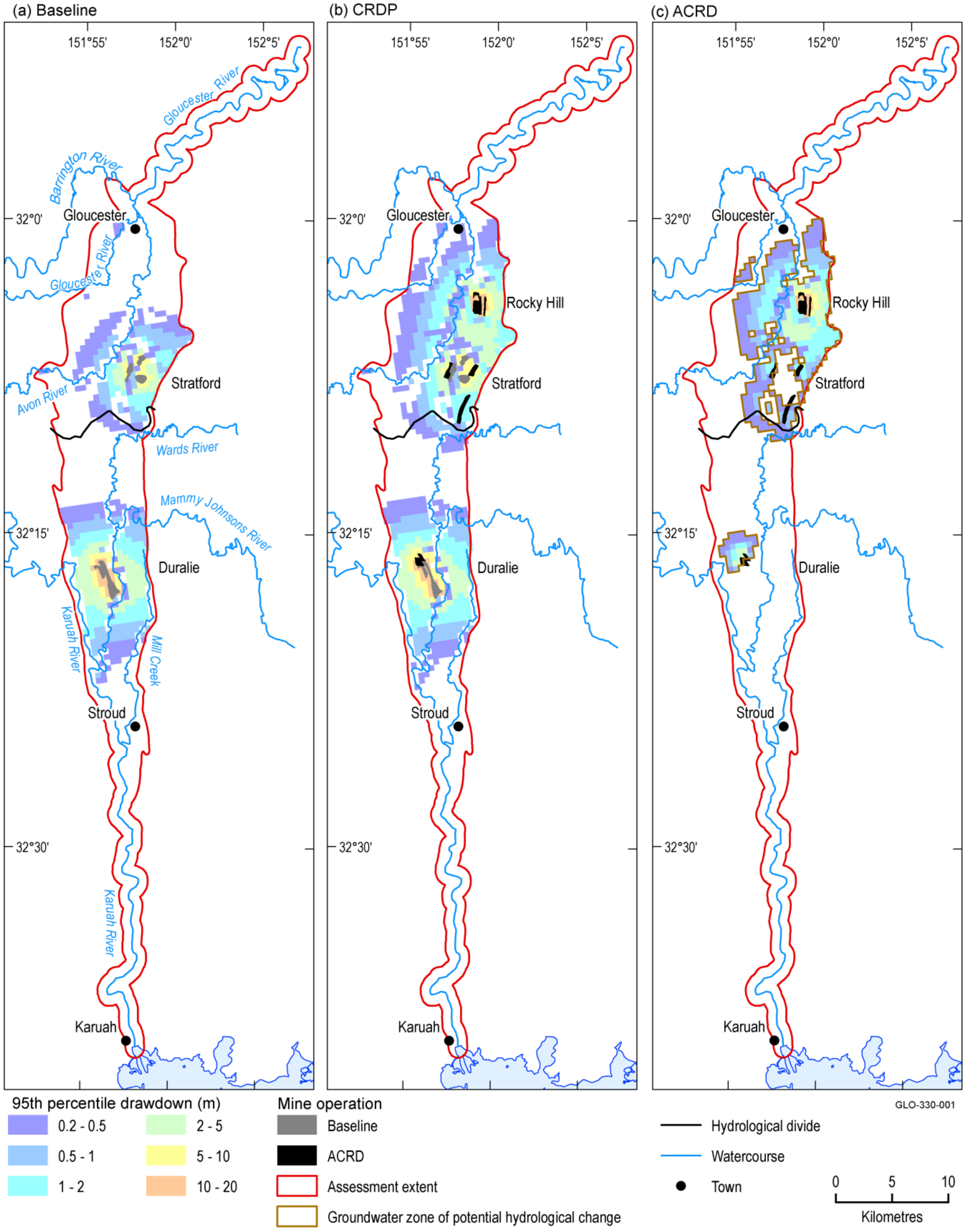

Figure 12 95th percentile of drawdown exceeding 0.2 m (a) under the baseline, (b) under the coal resource development pathway (CRDP) and (c) due to additional coal resource development (ACRD), which defines the groundwater zone of potential hydrological change

The difference in drawdown between CRDP and baseline is due to the ACRD. Drawdowns under the baseline and CRDP are relative to drawdown with no coal resource development.
Data: Bioregional Assessment Programme (Dataset 1)

3.3.1.2 Surface water

In companion product 2.6.1 for the Gloucester subregion (Zhang et al., 2018), the potential hydrological changes in surface water are summarised by eight hydrological response variables listed in Table 5, as per submethodology M06 (as listed in Table 1) for surface water modelling (Viney, 2016). These hydrological response variables were chosen to represent potential changes across the full flow regime: from low flows (P01, LFD, LFS, LLFS) to high flows (P99 and FD), including two hydrological response variables to represent changes in flow volume (AF) and variability (IQR). All hydrological response variables were calculated at annual time steps. The hydrological response variable, zero-flow days (ZFD) was not used in assessing hydrological changes because the vast majority of streams in the Gloucester subregion are perennial (see companion product 2.6.1 (Zhang et al., 2018)). Additional hydrological response variables have been defined for receptor impact modelling (see companion submethodology M08 (as listed in Table 1) (Hosack et al., 2018a)) and assessing economic impacts, and are considered further in the impacts on landscape classes and assets sections (Section 3.4 and Section 3.5, respectively) of this product. While maximum change in zero-flow days (ZFD) was not used to describe hydrological changes, the variable ZQD representing the average change in zero-flow days over a 30-year time period was used as an input into the receptor impact modelling. Results for this hydrological response variable are presented in Section 3.4.

Table 5 Surface water hydrological response variables and the thresholds used to define the zone of potential hydrological change

Hydrological response variable[a]	Units	Description	Threshold
AF	GL/year	The volume of water that discharges past a specific point in a stream in a year. This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102).	≥5% chance of ≥1% change in AF
P99	ML/day	Daily flow rate at the 99th percentile. This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102).	≥5% chance of ≥1% change in P99
IQR	ML/day	Interquartile range in daily flow; that is, the difference between the daily flow rate at the 75th percentile and at the 25th percentile. This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102).	≥5% chance of ≥1% change in IQR
FD	days	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'.	≥5% chance of a change in FD ≥3 days in any year
P01	ML/day	Daily flow rate at the 1st percentile. This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102).	≥5% chance of ≥1% change in P01 and change in runoff depth >0.0002 mm
LFD	days	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 (2013 to 2102).	≥5% chance of a change in LFD ≥3 days in any year
LFS	number	Number of low-flow spells 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). A spell is defined as a period of contiguous days of streamflow below the 10th percentile threshold.	≥5% chance of a change in LFS ≥2 spells in any year
LLFS	days	Length of the longest low-flow spell each year. This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102).	≥5% chance of a change in LLFS ≥3 days in any year

[a]ZFD is not used in assessing hydrological changes because the vast majority of streams in the Gloucester subregion are perennial (see product 2.6.1 for the Gloucester subregion (Zhang et al., 2018)).

The definitions of the thresholds for each variable that were adopted for defining the zone of potential hydrological change are also given in Table 5. A location is deemed to be potentially impacted by hydrological changes due to additional coal resource development if the change in at least one of the eight variables exceeds its specified threshold. Probability estimates are derived from the predictions of 1000 model replicates – each of which uses a unique set of model parameter values. The 5% threshold means that at least 5% (i.e. 50) of the 1000 replicates have modelled changes that exceed the relevant change threshold. Conversely, if fewer than 5% of the replicates have modelled changes that exceed the threshold at a particular location, then the change in that hydrological response variable at that location is considered *very unlikely* (less than 5% chance) to have an impact.

As well as some of the reaches that make up the AWRA-L surface water network, the surface water zone of potential hydrological change includes some small stream reaches that are not represented in the model. The methods for extending the modelled network to include other streams potentially impacted by hydrological changes are as follows:

1. Stream reaches in the groundwater zone of potential hydrological change that were not modelled were classified as 'potentially impacted' on the assumption that any streams connected to regional groundwater could potentially be affected by changes in baseflow due to additional coal resource development.
2. Stream reaches that flowed beyond the groundwater zone of potential hydrological change were extended downstream to where they joined a reach already in the surface water zone of potential hydrological change.

The surface water zone of potential hydrological change is shown in Figure 13. It comprises potentially impacted reaches and adjoining areas from the associated assessment units. It covers an area of 187 km^2, with approximately 117 km^2 in the Gloucester river basin and 70 km^2 in the Karuah river basin. The resulting surface water zone of potential hydrological change includes all modelled reaches shown in Figure 8 (Section 3.2) that are within the assessment extent except for those in the Barrington River, Booral Creek and the Karuah River below Booral Creek. Additionally, it includes three unmodelled reaches in the Gloucester river basin: Sandy Creek (a tributary of the Gloucester River), Avondale Creek (a tributary of the Avon River), and an unnamed tributary of the Avon River.

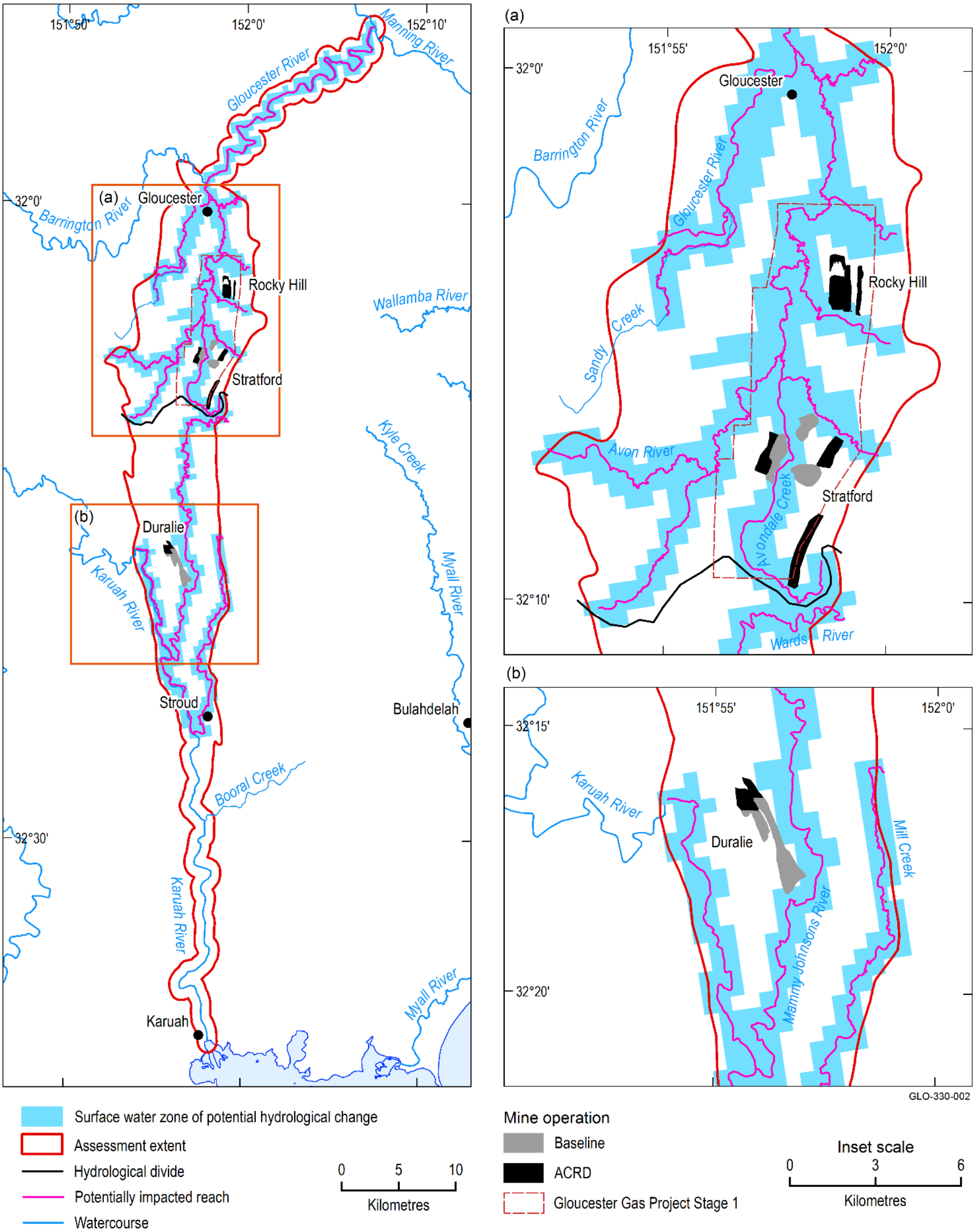

Figure 13 Surface water zone of potential hydrological change

The extent of the mines in the CRDP is the union of the extents in the baseline and in the additional coal resource development (ACRD).

The surface water zone of potential hydrological change is the area where a change in any one of eight surface water hydrological response variables exceeds the specified thresholds (Table 5).

Data: Bioregional Assessment Programme (Dataset 1)

3.3.1.3 Zone of potential hydrological change

The zone of potential hydrological change (Figure 14) represents the union of the groundwater zone of potential hydrological change (Figure 12) with the surface water zone of potential hydrological change (Figure 13), clipped to the assessment extent. The Gloucester zone covers an area of 250 km^2 and has 242 km of stream network. A graphical summary of the areas (km^2) of the zone and its surface and groundwater components is provided in Figure 15.

Mill Creek is included in the zone of potential hydrological change, even though it is not particularly close to the additional coal resource development at Duralie. This could be an artefact of the modelling as the pumping point in the groundwater model was moved from the middle of the baseline pit in the baseline model run to the middle of the additional pit in the CRDP run. This resulted in slight increases in groundwater levels in the CRDP run compared to the baseline run, which are reflected as changes in baseflow to the surface water model. It is unlikely that Mill Creek is impacted due to additional coal resource development.

Figure 14 also shows the mine pit exclusion zone defined for the Gloucester subregion based on open-cut mine footprints under the CRDP in the zone of potential hydrological change. The mine pit exclusion zone identifies areas in the zone of potential hydrological change that are within or near open-cut mine pits, and where:

- modelled drawdowns are highly uncertain due to the very steep hydraulic gradients at the mine pit interface
- changes in drawdown are inevitable where the mine pit intersects the regional watertable
- 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
- impacts are predominantly site-scale, assumed to be adequately addressed through existing development approval processes, and hence not the primary focus of BAs.

The modelled estimates of drawdown in this zone are considered unreliable for use in the receptor impact modelling. Local-scale groundwater models are expected to give better estimates of drawdown around mine pits than is possible using a regional-scale model.

The Gloucester mine pit exclusion zone covers an area of 14.5 km^2 (10 km^2 of which is in the groundwater zone of potential hydrological change; Figure 15) and includes an area around each of the three mines at Rocky Hill, Stratford and Duralie. There is no exclusion zone identified for CSG wells or infrastructure associated with the Gloucester Gas Project.

It is worth noting that some of the area defined by the mine pit exclusion zone around the baseline Duralie mine as well as the area immediately south of this are outside the zone of potential hydrological change. Groundwater levels in this area are subject to drawdown due to the baseline mine as shown in Figure 12a, but the small expansion (relative to the baseline area) of this mine pit, modelled as part of the additional coal resource development, does not have a big effect on drawdown over much of this area.

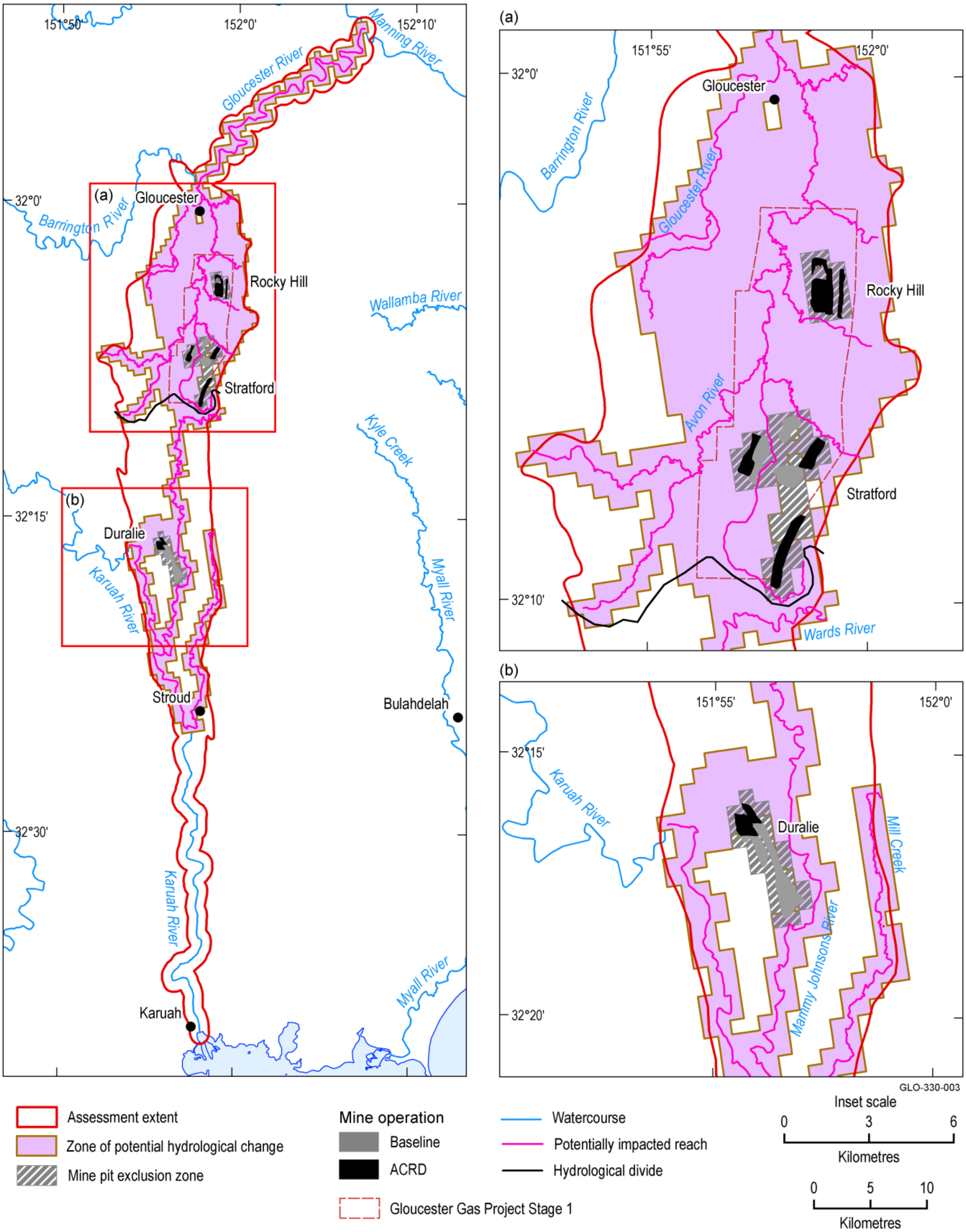

Figure 14 Zone of potential hydrological change

The zone of potential hydrological change is the union of the groundwater zone of potential hydrological change and the surface water zone of potential hydrological change.
ACRD = additional coal resource development
Data: Bioregional Assessment Programme (Dataset 1)

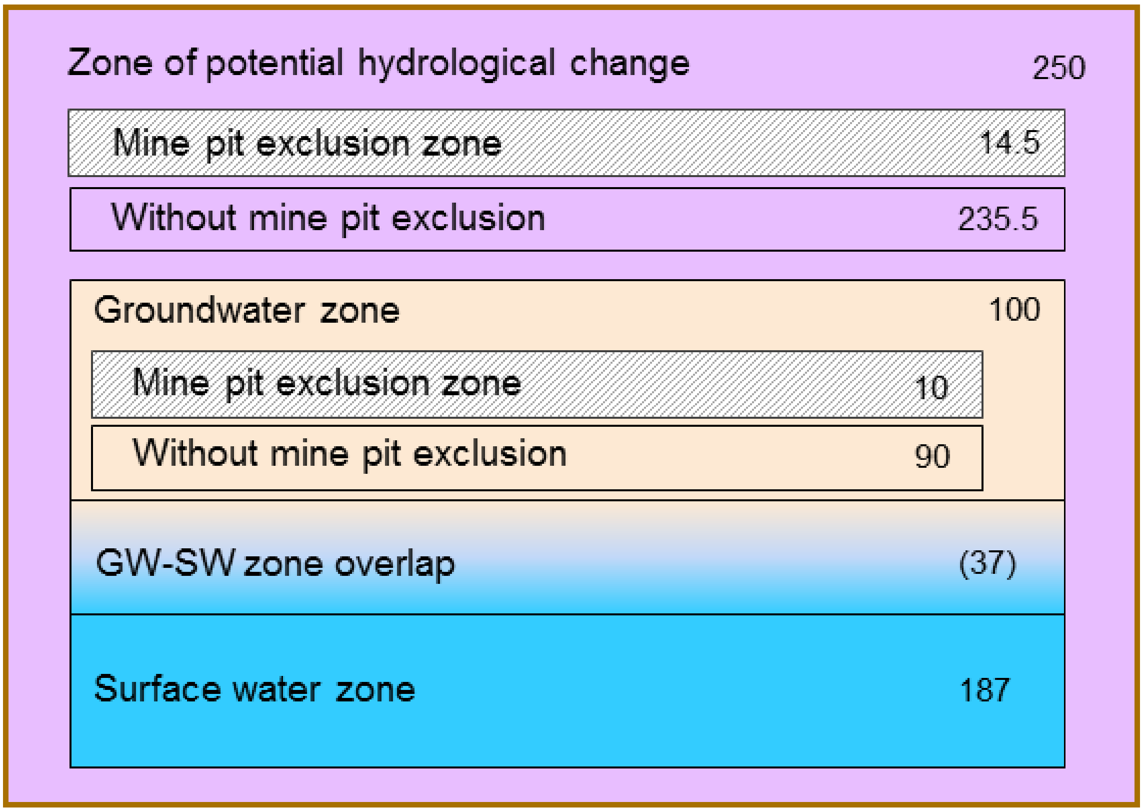

Figure 15 Areas (km^2) of the zone of potential hydrological change and its surface water and groundwater components for the Gloucester subregion

GW = groundwater, SW = surface water
Data: Bioregional Assessment Programme (Dataset 1)

In the impacts on landscape classes and assets sections (Section 3.4 and Section 3.5, respectively), the initial 'rule-out' assessment determines what is in the zone of potential hydrological change and, within that, what is in the mine pit exclusion zone. Features that have a groundwater dependency and occur in the mine pit exclusion zone do not have receptor impact modelling results generated for them; they are assumed to be 'potentially impacted but not quantified'.

Changes in surface water were analysed on an individual stream link basis. Stream links, where it was determined that the change in hydrology for that stream link could not be interpolated from a nearby model node are labelled as 'potential hydrological change' in the maps presented in this section, and are reported in results tables under the header 'potentially impacted but not quantified'.

3.3.2 Potential groundwater changes

In assessing potential impacts on groundwater, changes are summarised by the hydrological response variable *dmax* – the maximum difference in drawdown, obtained by choosing the maximum of the time series of differences between two futures. Drawdowns are reported for a single regional watertable, which spans the alluvial, weathered rock and fractured rock units represented in the groundwater model.

In Figure 16, the panels show maximum predicted depth of drawdown due to the additional coal resource development for the 5th, 50th and 95th percentiles to illustrate the variation in model predictions due to parameter uncertainty. Additional drawdown occurs in two areas, the first area in the Gloucester river basin, centred on the Rocky Hill mine; the second in the Karuah river basin around the Duralie mine. Table 6 summarises the areas where the additional drawdown is greater than 0.2 m, greater than 2 m and greater than 5 m for the 5th, 50th and 95th percentiles in these two river basins and as a subregion total. For additional drawdown greater than 0.2 m, the area associated with the 5th percentile (19.7 km^2) can be interpreted as representing the extent of drawdown when the model parameters reflect lower pumping rates and/or lower hydraulic conductivities. Conversely, the area of drawdown associated with the 95th percentile (100 km^2) also includes the predictions based on higher pumping rates and relatively conductive geological layers. This is a general guide only as the influences of the different parameters can be complex and produce a range of drawdown responses. Groundwater drawdown predictions indicate that drawdowns of greater than 2 m are *very likely* (greater than 95% chance; 5th percentile) due to the additional coal resource developments at Duralie and around Rocky Hill (Figure 16a). Generally drawdowns exceeding 5 m due to the additional coal resource development are *very unlikely*, although the 95th percentile map indicates the possibility of >5 m drawdowns around the Rocky Hill development (Figure 16c).

The spatial distribution of drawdown under the baseline is shown in Figure 17, providing a visual comparison to the potential groundwater drawdown due to additional coal resource development in Figure 16. Under the baseline, the area with at least a 5% chance of drawdown greater than 0.2 m is about 140 km^2. The areas of drawdown are associated with the baseline workings at the Duralie mine and the Stratford mine. The area of overlap with the groundwater zone is 53 km^2 and represents the area where drawdowns due to baseline and additional coal resource developments potentially accumulate. Another 30 km^2 overlaps with the surface water zone and defines the area where lagged groundwater drawdown responses from baseline developments could coincide with more instantaneous changes in streamflow due to the additional coal resource development. Table 7 summarises the area (km^2) of baseline drawdown in the zone of potential hydrological change.

Figure 18 and Figure 19 summarise the modelled drawdowns due to the additional coal resource development and under the baseline as log-transformed cumulative exceedance plots by area for the 5th, 50th and 95th percentile drawdown distributions. The mine pit exclusion areas are not included here so the total area of drawdown is less than what is included in Table 6. It can be seen that there is a median probability of drawdown of at least 2 m due to the additional coal resource development over about 1.2 km^2, but *very unlikely* to occur over an area exceeding 10 km^2 outside the mine pit exclusion zone. Because the data are not classified, details within the classes can be discerned: drawdowns of at least 1 m due to baseline development have a median probability of occurring over about 3 km^2 and due to additional coal resource development over about 8 km^2; outside the mine pit exclusion zone, drawdowns greater than 5 m are *very unlikely* under the baseline and due to additional coal resource development.

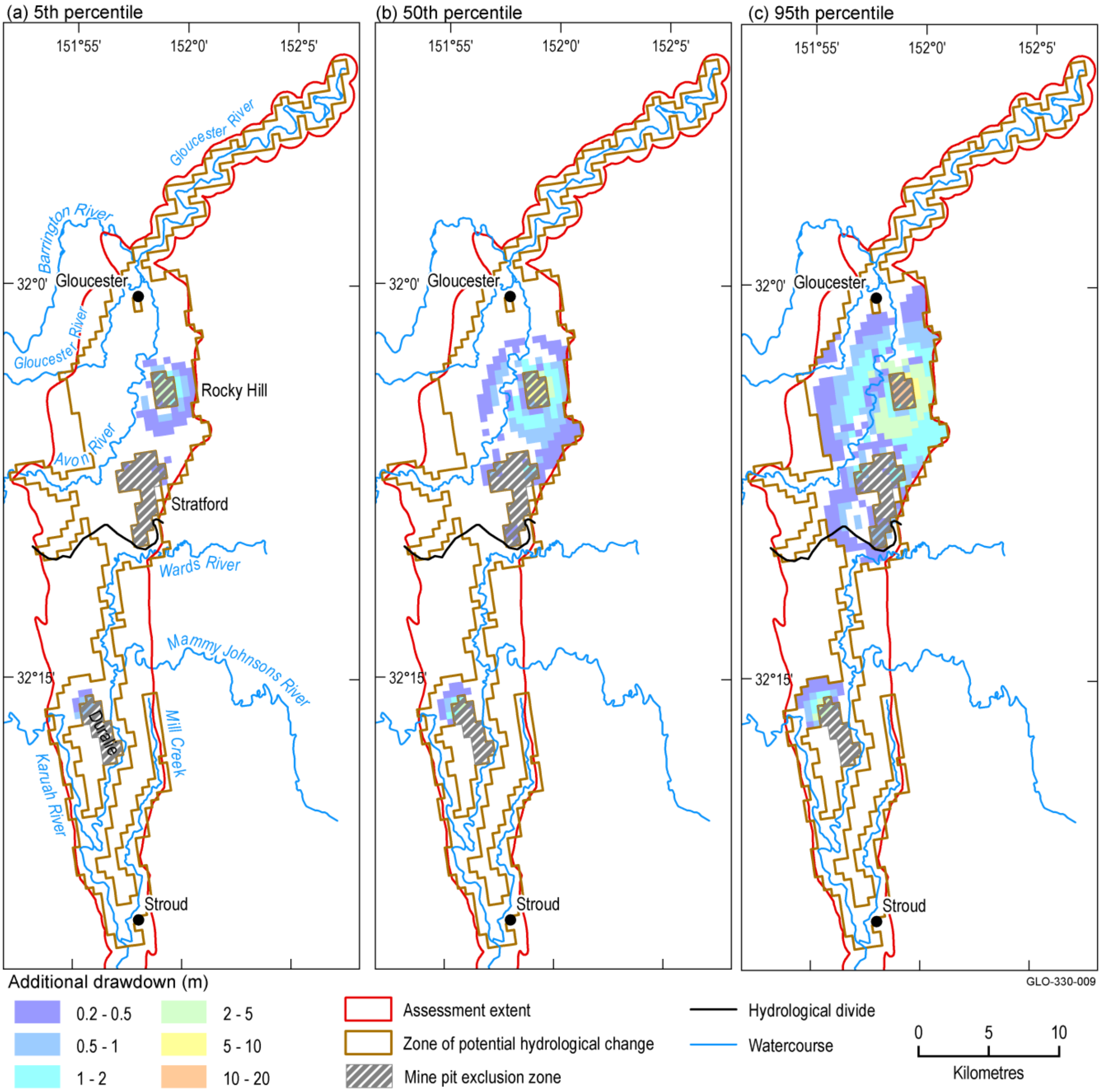

Figure 16 Additional drawdown (m) in the regional watertable (5th, 50th and 95th percentiles)

Additional drawdown is the maximum difference in drawdown (*dmax*) between the coal resource development pathway (CRDP) and baseline, due to additional coal resource development.
Data: Bioregional Assessment Programme (Dataset 1)

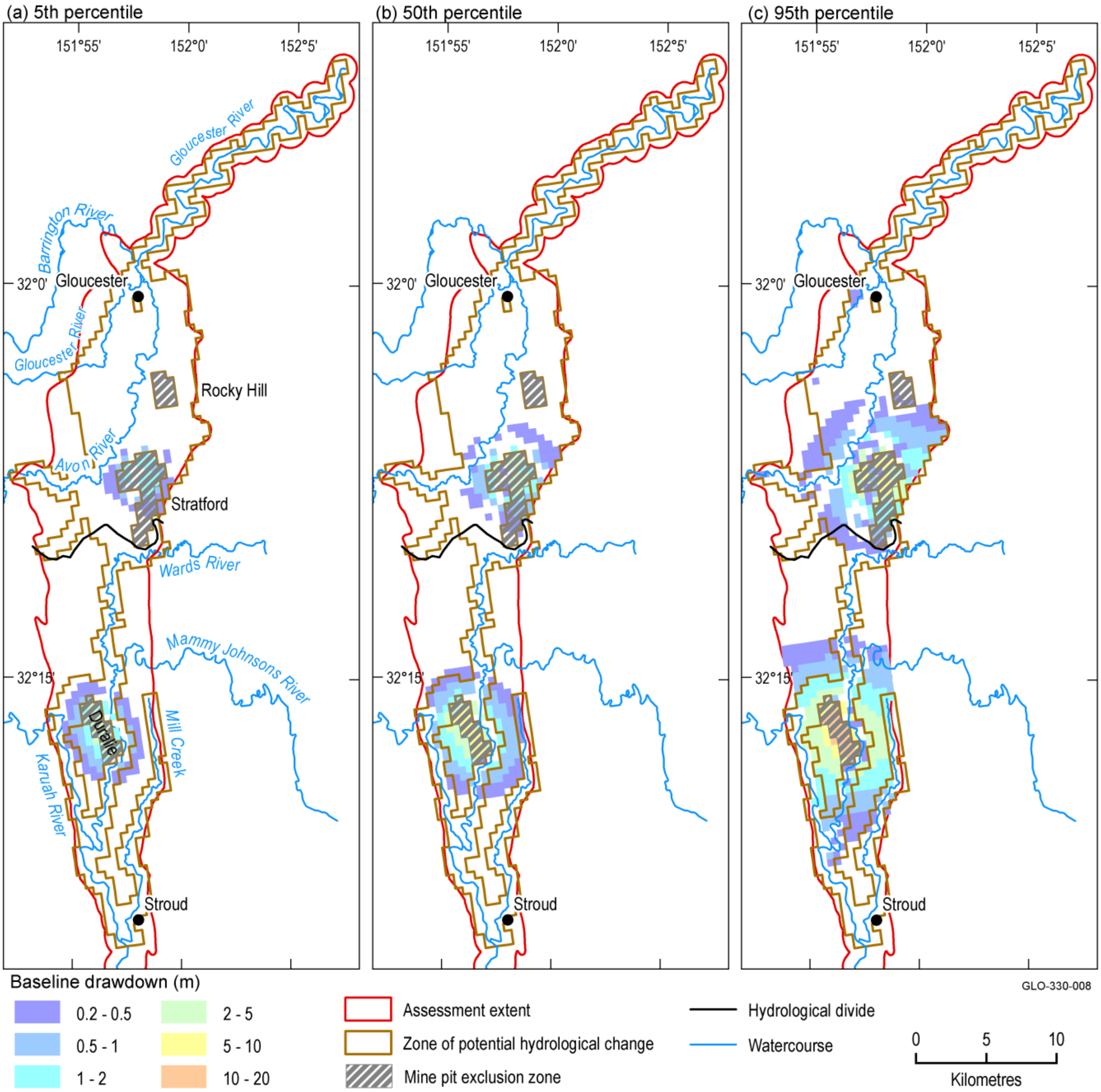

Figure 17 Baseline drawdown (m) in the regional watertable (5th, 50th and 95th percentiles)

Baseline drawdown is the maximum difference in drawdown (*dmax*) under the baseline relative to no coal resource development. Data: Bioregional Assessment Programme (Dataset 1)

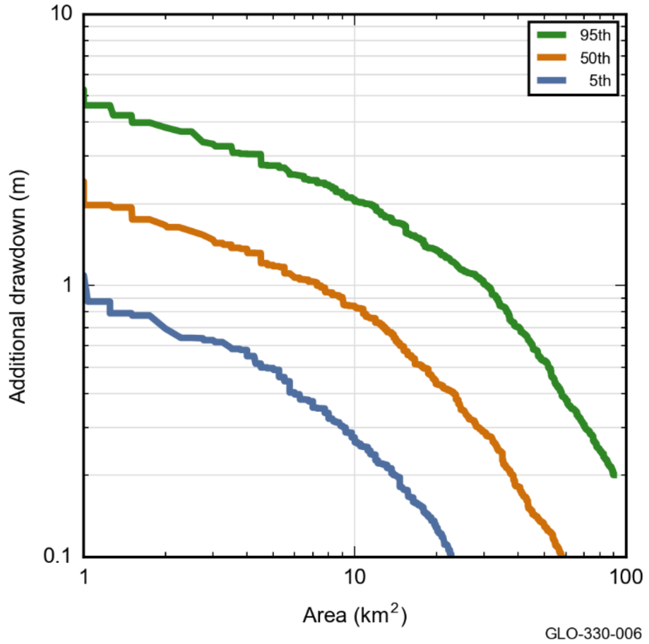

Figure 18 Cumulative exceedance plot of area of drawdown in the zone of potential hydrological change due to additional coal resource development for 5th (blue), 50th (orange) and 95th (green) percentiles

Data: Bioregional Assessment Programme (Dataset 1)

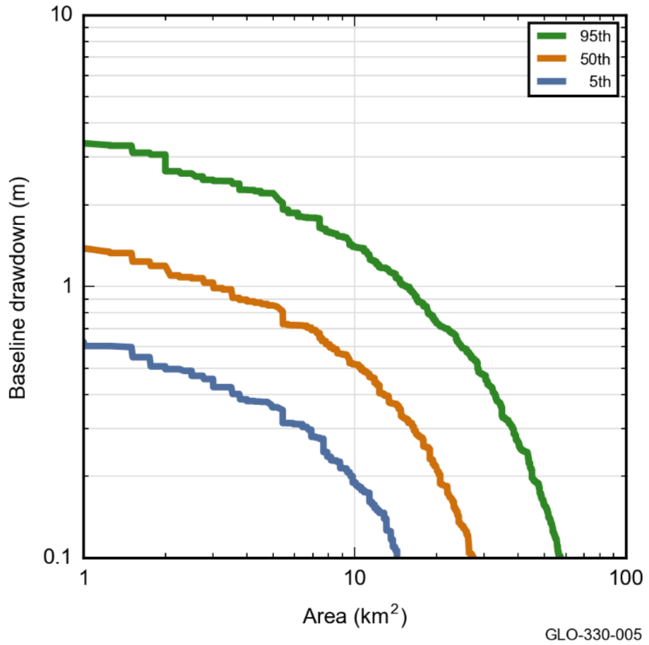

Figure 19 Cumulative exceedance plot of area of drawdown in the zone of potential hydrological change under the baseline for 5th (blue), 50th (orange) and 95th (green) percentiles

Data: Bioregional Assessment Programme (Dataset 1)

Table 6 Area (km^2) potentially exposed to varying levels of drawdown due to additional coal resource development in the Gloucester and Karuah river basins

Basin	Area of zone of potential hydrological change	Area with additional drawdown ≥0.2 m			Area with additional drawdown ≥2 m			Area with additional drawdown ≥5 m		
		5th	50th	95th	5th	50th	95th	5th	50th	95th
Gloucester River	170	17.2	41.4	88.1	2.5	4.3	14.3	0	2.3	4.3
Karuah River	80	2.5	4.8	12.0	0	0.5	1.5	0	0	0
Total	**250**	**19.7**	**46.2**	**100.1**	**2.5**	**4.8**	**15.8**	**0**	**2.3**	**4.3**

The area potentially exposed to ≥0.2, ≥2 and ≥5 m additional drawdown is shown for the 5th, 50th and 95th percentiles. Additional drawdown is the maximum difference in drawdown (*dmax*) due to additional coal resource development relative to the baseline.
Data: Bioregional Assessment Programme (Dataset 1)

Table 7 Area (km^2) in the zone of potential hydrological change potentially exposed to varying levels of drawdown under the baseline in the Gloucester and Karuah river basins

Basin	Area of zone of potential hydrological change	Area with baseline drawdown ≥0.2 m			Area with baseline drawdown ≥2 m			Area with baseline drawdown ≥5 m		
		5th	50th	95th	5th	50th	95th	5th	50th	95th
Gloucester River	170	10.1	20.9	50.2	0	2.8	7.2	0	0	2.5
Karuah River	80	11.3	17.3	31.6	1.0	4.0	10.0	0	0.5	3.5
Total	**250**	**21.3**	**38.1**	**81.8**	**1.0**	**6.8**	**17.2**	**0**	**0.5**	**6.0**

The area potentially exposed to ≥0.2, ≥2 and ≥5 m of baseline drawdown is shown for the 5th, 50th and 95th percentiles. Baseline drawdown is the maximum difference in drawdown (*dmax*) under the baseline relative to no coal resource development.
Data: Bioregional Assessment Programme (Dataset 1)

3.3.3 Potential surface water changes

The hydrological response variables modelled in the Gloucester subregion are shown in Table 5. Of these, three were chosen to represent the potential impacts due to additional coal resource development on the low-flow (low-flow days (LFD)) and high-flow (high-flow days (FD)) components of the flow regime and the average change in streamflow (annual flow (AF)).

The following maps and tables include streams with 'potential hydrological change'. These are reaches where results from the model nodes cannot be extrapolated to the reach, but where the downstream node indicates an above threshold change in that hydrological response variable (as defined in Table 5). Some reaches show potential hydrological change because they are in the same catchment as the additional coal resource development and are thus likely to be impacted. Some reaches show potential hydrological change because they are within the area of greater than 0.2 m drawdown. Since the extent of the greater than 0.2 m drawdown area varies from the 5th to 50th to 95th percentiles (see Figure 16), streams that show potential hydrological change at the 95th percentile do not necessarily show potential hydrological change at the 50th or 5th percentiles.

The potential changes in streamflow due to the baseline coal resource development are not presented spatially because of difficulties in interpolating baseline values from nodes to links and because baseline values of the hydrological response variables are only available for the year in which the maximum change in each hydrological response variable due to the additional coal resource development occurs. A spatial map might therefore have annual flow from 2021 at one location and 2067 at another location, rendering comparisons meaningless. As a result of this, changes due to additional coal resource development are considered in the context of the interannual variability under the baseline, a far more robust and meaningful measure. Unlike groundwater, streamflow characteristics are extremely sensitive to climate, particularly the variability in rainfall over relatively short time-scales.

A number of hydrological response variables were defined to represent changes in ecologically important components of the flow regime for the purposes of the receptor impact modelling (see companion submethodology M08 (as listed in Table 1) for receptor impact modelling (Hosack et al., 2018b)). Changes in these variables due to additional coal resource development are presented in Section 3.4 in the context of impacts on landscape classes. The risk to water-dependent landscape classes and assets from hydrological changes due to the additional coal resource development is related in large part to their resilience to a variable climate. Hydrological changes that push the flow regime beyond its 'natural' range are more likely to have an impact on these water-dependent systems than changes that are well within that 'natural' range.

3.3.3.1 Low-flow days

The increases in the number of low-flow days due to additional coal resource development in the Gloucester subregion are shown in Figure 20. A cumulative exceedance plot of these increases in low-flow days is shown in Figure 21, while the underlying data are presented in Table 8.

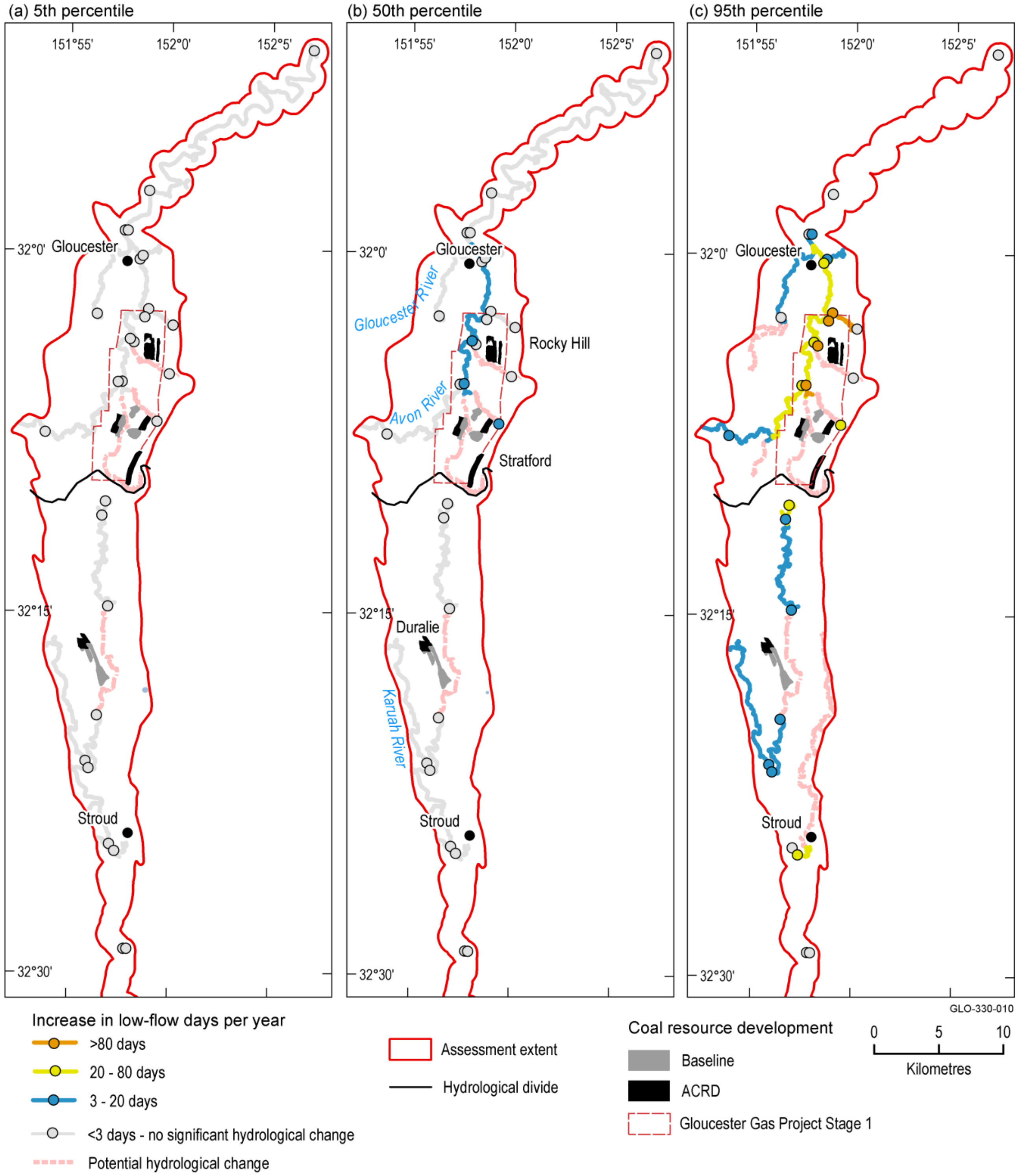

Figure 20 Increase in the number of low-flow days (LFD) due to additional coal resource development (ACRD)

The extent of the mines in the CRDP is the union of the extents in the baseline and in the ACRD.
Data: Bioregional Assessment Programme (Dataset 1)

Figure 20 shows that at the 5th percentile, it is unlikely that there are increases of at least 3 low-flow days per year anywhere in the assessment extent, although there are a couple of streams that pass close to the Rocky Hill, Stratford and Duralie mines where potential impacts are unable to be ruled out. At the 50th percentile, there are streams near the Rocky Hill mine that experience an extra 3 to 20 low-flow days per year, and there are other streams where potential impacts are unable to be ruled out. At the 95th percentile there are large increases in the number of low-flow days near Rocky Hill and Stratford mines, and smaller increases due to the mine extension at Duralie. Note that any potential impacts due to the Gloucester Gas Project would be limited to the area around Rocky Hill and Stratford, as this is the proposed Stage 1 CSG field area.

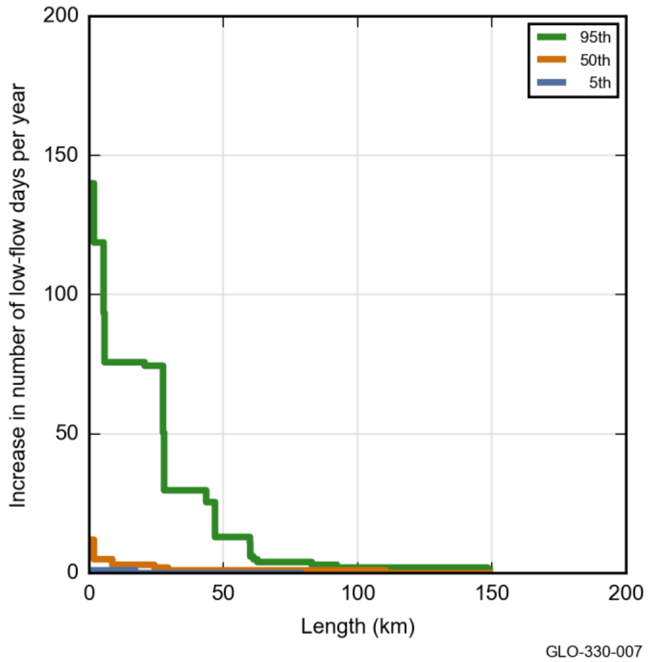

Figure 21 Cumulative exceedance plot of the increase in the number of low-flow days (LFD) due to additional coal resource development for 5th (blue), 50th (orange) and 95th (green) percentiles

Data: Bioregional Assessment Programme (Dataset 1)

Table 8 Stream length (km) potentially exposed to varying increases in low-flow days due to additional coal resource development in the Gloucester and Karuah river basins

Basin	Length in zone of potential hydrological change	Length potentially impacted but not quantified			Length with increases of ≥3 low-flow days per year			Length with increases of ≥20 low-flow days per year			Length with increases of ≥80 low-flow days per year		
		5th	50th	95th	5th	50th	95th	5th	50th	95th	5th	50th	95th
Gloucester River	143.6	25.2	33.1	47.9	0	24.2	54.1	0	0	43.1	0	0	5.7
Karuah River	98.9	11.6	11.6	44.8	0	0	38.2	0	0	3.7	0	0	0
Total	**242.5**	**36.8**	**44.7**	**92.7**	**0.0**	**24.2**	**92.3**	**0**	**0**	**46.8**	**0**	**0**	**5.7**

The stream length potentially exposed to increases in low-flow days (LFD) is shown for the 5th, 50th and 95th percentiles. The increase due to additional coal resource development is obtained by subtracting the results under the baseline from the results under the coal resource development pathway (CRDP).
Data: Bioregional Assessment Programme (Dataset 1)

To understand the significance of the modelled increases in low-flow days, it is useful to look at them in the context of the interannual variability in low-flow days due to climate. In other words, are the modelled increases due to additional coal resource development within the natural range of variability of the longer-term flow regime, which would suggest the system is adapted to the range of possible increases, or are they potentially moving the system outside the range of hydrological variability it experiences under the baseline? The maximum increase in the number of low-flow days due to additional coal resource development relative to the interannual variability in low-flow days under the baseline has been adopted to put some context around the modelled changes. This ratio is shown qualitatively for each surface water model node in Figure 22. Table 9 provides the ratio ranges for LFD, FD and AF adopted for each qualitative ratio class shown in Figure 22. It is important to be aware that the changes shown in Figure 22 represent the maximum change due to additional coal resource development in a single year relative to the interannual variability across 90 years under the baseline. Thus, it is not a comparison of distributions, but an assessment of whether the change due to additional coal resource development, in the year of maximum difference between the CRDP and the baseline, is within the range of natural variability. If the maximum change is small relative to the interannual variability due to climate (e.g. an increase of 3 days relative to a baseline range of 20 to 50 days; ratio of 0.1), then the risk of impacts from the changes in low-flow days is likely to be low. If the maximum change is comparable to or greater than the interannual variability due to climate (e.g. an increase of 200 days relative to a baseline range of 20 to 50 days; ratio of 6.7), then there is a greater risk of impact on the landscape classes and assets that rely on this water source. Here, changes comparable to or greater than interannual variability are interpreted as presenting a considerable risk. However, since the change due to the additional coal resource development is additive, even a 'less than interannual variability' change is not free from risk, and the results of this analysis should be viewed as indicators of risk.

Table 9 Ratio of increase in the number of low-flow days (LFD), high-flow days (FD) and annual flow volume (AF) due to additional coal resource development to the interannual variability in low-flow days under the baseline

Qualitative ratio class	Ratio range
No significant change	LFD <3 days FD ≥3 days AF ≥ 1%
Less than interannual variability	<0.5
Comparable to interannual variability	0.5–1.5
Greater than interannual variability	>1.5

FD = high-flow days – in previous products, this is referred to as 'flood days'

Figure 22 indicates that at the 5th percentile, the increase in the number of low-flow days is not significant and unlikely to impact the interannual variability. At the 50th percentile, changes around and downstream of the Stratford, Rocky Hill and Gloucester Gas Project developments are less than interannual variability, but flag a potential risk. At the 95th percentile, the change in number of low-flow days is either comparable to or greater than interannual variability in this area, indicating potentially large changes in the low-flow regime, with some risk further downstream on the Avon River and in the Karuah River basin also. Section 3.4 and Section 3.5

provide an assessment of the potential impacts of the modelled hydrological changes on ecosystems and assets.

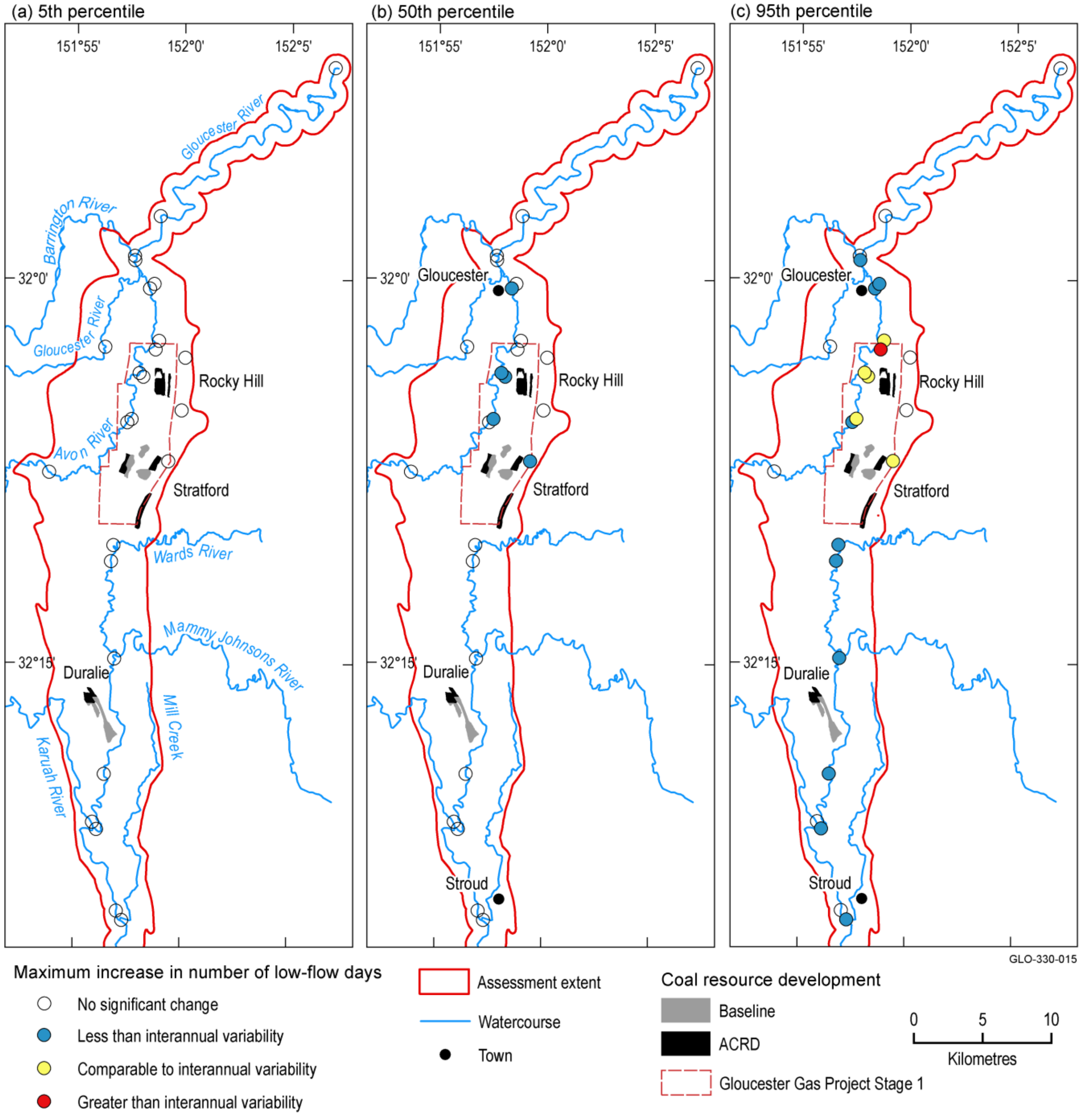

Figure 22 Ratio of increase in the number of low-flow days due to additional coal resource development (ACRD) to the interannual variability in the number of low-flow days

The extent of the mines in the CRDP is the union of the extents in the baseline and in the ACRD.
Data: Bioregional Assessment Programme (Dataset 1)

3.3.3.2 High-flow days

The decrease in the number of high-flow days due to additional coal resource development in the Gloucester subregion is shown in Figure 23. A cumulative exceedance plot of these decreases in high-flow days is shown in Figure 24, while the underlying data are presented in Table 10.

Figure 23 shows that at the 5th percentile, there are only 1.7 km of stream downstream of the Stratford mine where there is a decrease of 3 to 10 high-flow days per year. There are also two streams that pass close to the Stratford and Rocky Hill mines where potential impacts are unable to be ruled out. At the 50th percentile, downstream of the Stratford mine there are 8.5 km of stream that may experience 3 to 10 fewer high-flow days per year, and there are other streams where potential impacts are unable to be ruled out. At the 95th percentile, there are large decreases in the number of high-flow days downstream of the Stratford and Rocky Hill mines, and smaller decreases in the stream flowing southwards in the Karuah river basin. Changes in this stream are due to potential impacts from the Stratford mine and the Gloucester Gas Project crossing the catchment divide into the Karuah river basin.

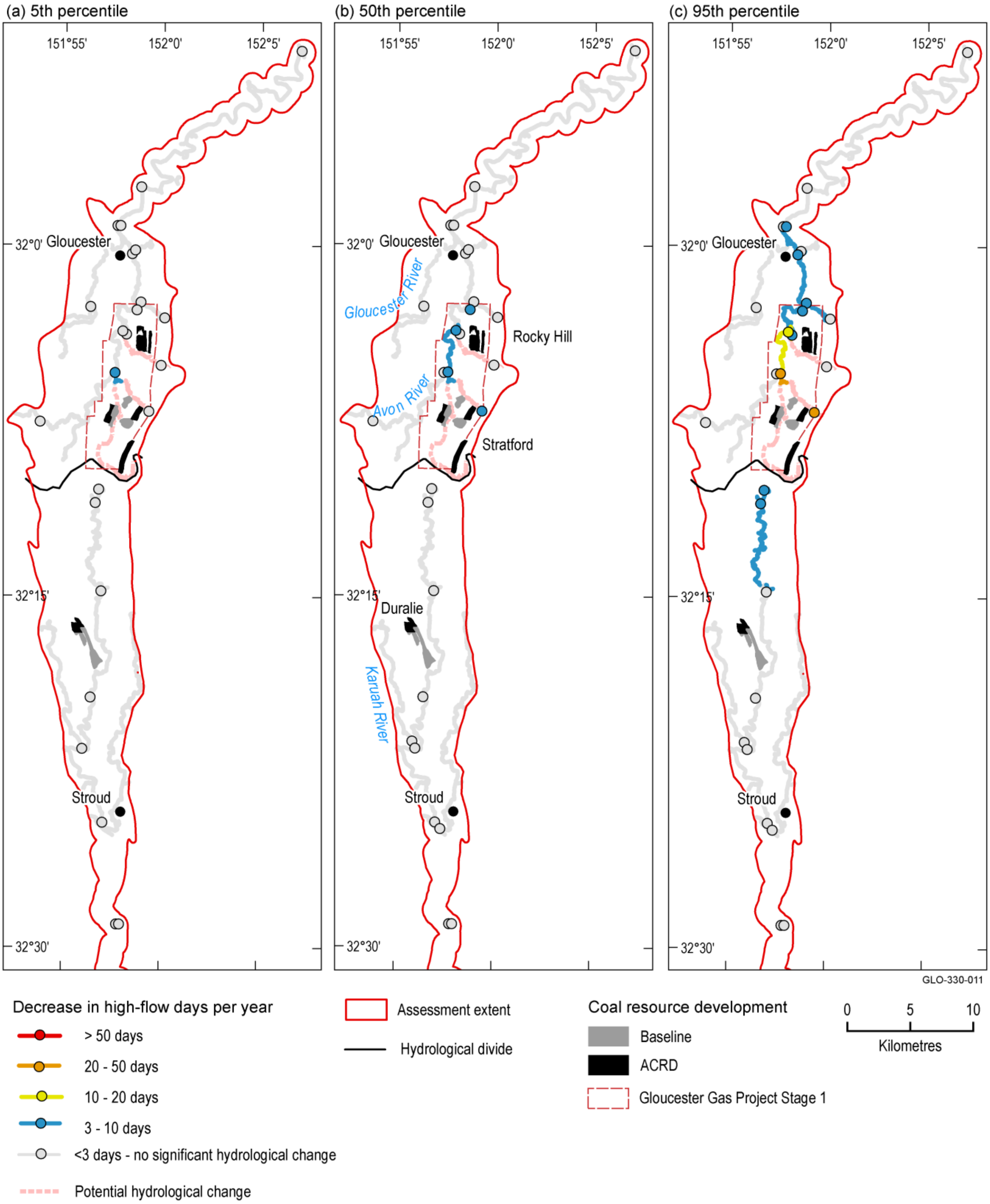

Figure 23 Decrease in the number of high-flow days (FD) due to additional coal resource development (ACRD)

The extent of the mines in the CRDP is the union of the extents in the baseline and in the ACRD.
Data: Bioregional Assessment Programme (Dataset 1)

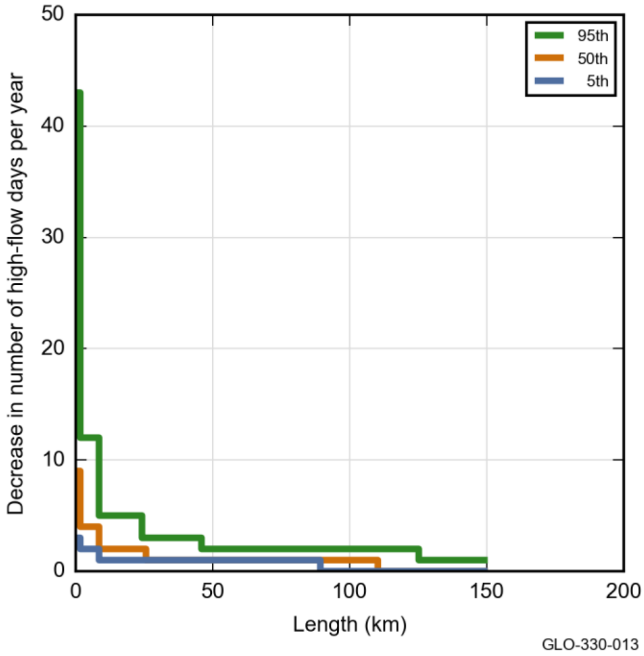

Figure 24 Cumulative exceedance plot of the decrease in the number of high-flow days due to additional coal resource development (ACRD) for 5th (blue), 50th (orange) and 95th (green) percentiles

Data: Bioregional Assessment Programme (Dataset 1)

Table 10 Stream length (km) potentially exposed to varying reductions in high-flow days due to additional coal resource development in the Gloucester and Karuah river basins

Basin	Length in zone of potential hydrological change	Length potentially impacted but not quantified			Length with reduction of ≥3 high-flow days per year			Length with reduction of ≥10 high-flow days per year			Length with reduction of ≥20 high-flow days per year		
		5th	50th	95th	5th	50th	95th	5th	50th	95th	5th	50th	95th
Gloucester River	143.6	25.2	25.2	25.2	1.7	8.5	29.7	0.0	0.0	8.5	0.0	0.0	1.7
Karuah River	98.9	5.7	5.7	5.7	0.0	0.0	16.3	0.0	0.0	0.0	0.0	0.0	0.0
Total	**242.5**	**30.9**	**30.9**	**30.9**	**1.7**	**8.5**	**46.0**	**0.0**	**0.0**	**8.5**	**0.0**	**0.0**	**1.7**

The stream length potentially exposed to reductions in high-flow days (FD) is shown for the 5th, 50th and 95th percentiles. The reduction due to additional coal resource development is obtained by subtracting the results under the baseline from the results under the coal resource development pathway (CRDP).
Data: Bioregional Assessment Programme (Dataset 1)

The comparison of maximum change in high-flow days due to the additional coal resource development and interannual variability in high-flow days under the baseline (Figure 25) indicates that at the 5th and 50th percentiles, the decrease in the number of high-flow days is either not significant, or less than the interannual variability. There is a possibility that the Avon River and tributaries near Stratford and Rocky Hill mines and the Gloucester Gas Project could experience decreases in high-flow days of up to half the range due to interannual variability. At the 95th percentile, the decrease in number of high-flow days is comparable to interannual variability at one model node downstream of the Stratford mine. This indicates a potential for localised changes in high-flow days outside the baseline range due to climate.

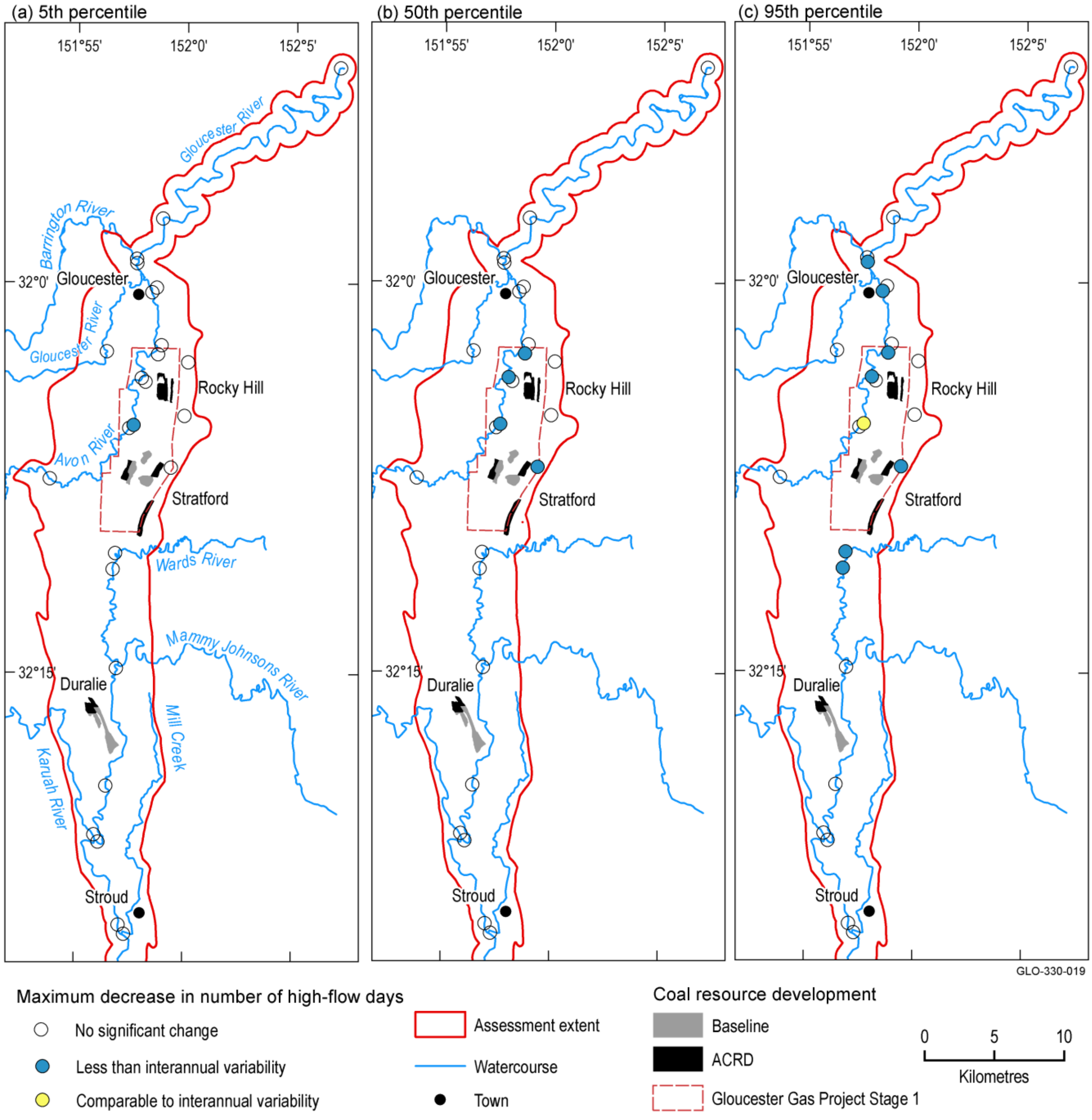

Figure 25 Ratio of decrease in the number of high-flow days due to additional coal resource development (ACRD) to the interannual variability in number of high-flow days

The extent of the mines in the CRDP is the union of the extents in the baseline and in the ACRD.
Data: Bioregional Assessment Programme (Dataset 1)

3.3.3.3 Annual flow

The decrease in annual flow due to additional coal resource development in the Gloucester subregion is shown in Figure 26. A cumulative exceedance plot of these decreases in annual flow is shown in Figure 27, while the underlying data are presented in Table 11.

Figure 26 shows that the reductions in annual flow are identical at the 5th, 50th, and 95th percentiles. This is because the reductions in annual flow are driven primarily by the area of overland flow intercepted by the open-cut mine pits, which is not included in the uncertainty analysis. There are 1.7 km of stream with a little over 5% reduction on Dog Trap Creek downstream of the Stratford mine and an additional 24 km of stream with 1% to 5% reduction further downstream, on the Avon River.

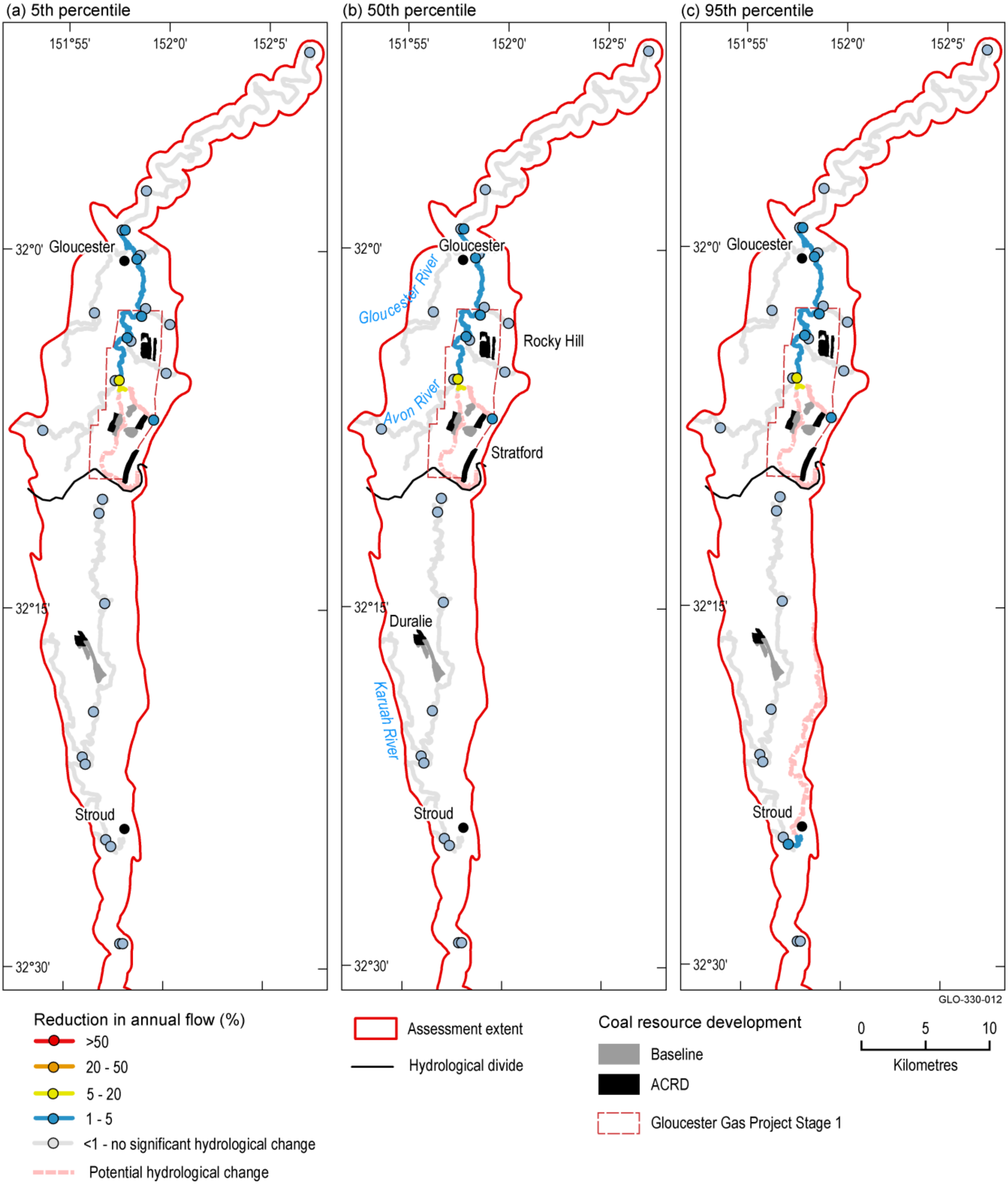

Figure 26 Decrease in annual flow (AF) due to additional coal resource development (ACRD)

The extent of the mines in the CRDP is the union of the extents in the baseline and in the ACRD.
Data: Bioregional Assessment Programme (Dataset 1)

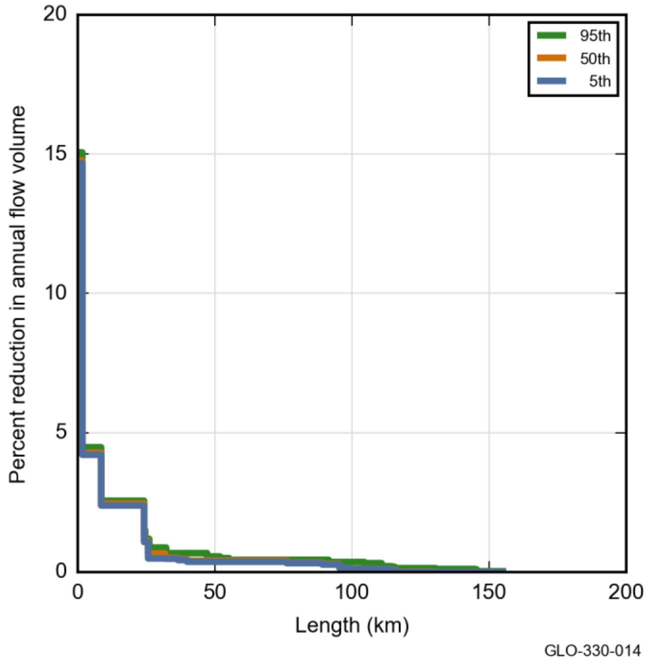

Figure 27 Cumulative exceedance plot of the decrease in annual flow due to additional coal resource development (ACRD) for 5th (blue), 50th (orange) and 95th (green) percentiles

Data: Bioregional Assessment Programme (Dataset 1)

Table 11 Stream length (km) potentially exposed to varying reductions in annual flow due to additional coal resource development in the Gloucester and Karuah river basins

Basin	Length in zone of potential hydrological change	Length potentially impacted but not quantified			Length with ≥1% reduction in annual flow			Length with ≥5% reduction in annual flow			Length with ≥20% reduction in annual flow		
		5th	50th	95th	5th	50th	95th	5th	50th	95th	5th	50th	95th
Gloucester River	143.6	19.8	19.8	19.8	25.7	36.6	51.6	1.7	1.7	1.7	0	0	0
Karuah River	98.9	0	0	25.2	0	0	3.7	0	0	0	0	0	0
Total	**242.5**	**19.8**	**19.8**	**45.0**	**25.7**	**36.6**	**55.3**	**1.7**	**1.7**	**1.7**	**0**	**0**	**0**

The extent potentially exposed to reductions in annual flow (AF) is shown for the 5th, 50th and 95th percentiles. The reduction due to additional coal resource development is obtained by subtracting the results under the baseline from the results under the coal resource development pathway (CRDP).
Data: Bioregional Assessment Programme (Dataset 1)

The maximum change in annual flow due to additional coal resource development relative to the interannual variability of annual flow under the baseline is shown for each surface water model node in Figure 28. There are six model nodes where a reduction in annual flow is observed, and this change is less than the natural variability seen under the baseline. The small changes in annual flow due to the additional coal resource development are unlikely to cause a significant change in the interannual variability of annual flow compared to that under the baseline.

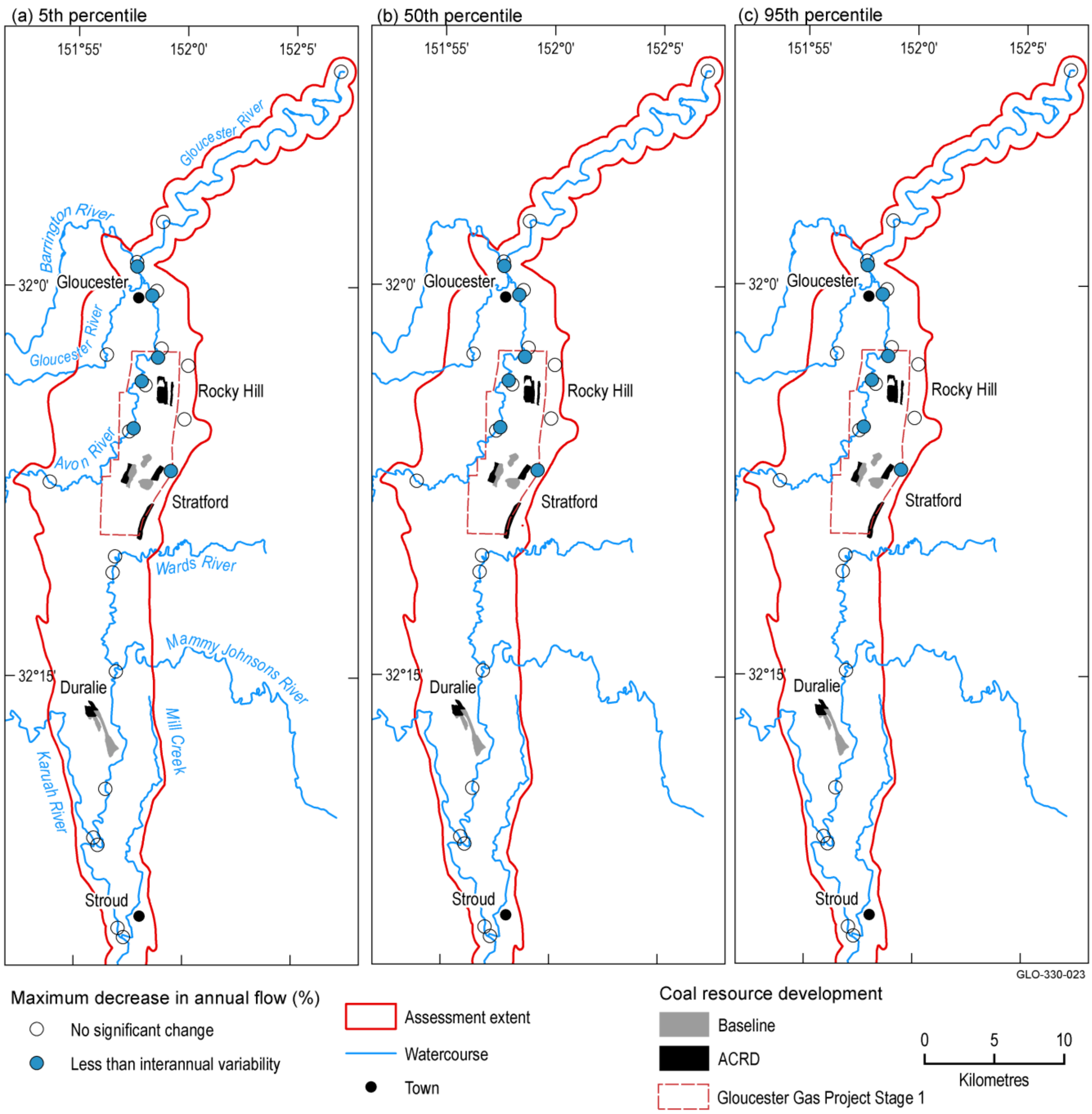

Figure 28 Ratio of change in annual flow due to additional coal resource development (ACRD) to the interannual variability in annual flow

The extent of the mines in the CRDP is the union of the extents in the baseline and in the ACRD.
Data: Bioregional Assessment Programme (Dataset 1)

3.3.4 Potential water quality changes

Regional changes in surface water and groundwater flows due to additional coal resource development could potentially lead to changes in the quality of surface water and groundwater. Although water quality changes due to the additional coal resource development were not modelled explicitly as part of this BA, the implications for water quality in the Gloucester subregion are considered in this section in light of the modelled hydrological changes due to the additional coal resource development.

Relevant factors for assessing the potential for changes in regional groundwater and surface water quality from the four additional coal resource developments in the Gloucester subregion are:

- Under the Gloucester Gas Project Stage 1 proposal, AGL intends to hydraulically fracture target coal seams to facilitate the release of coal seam gas. This fracturing process would involve the injection of a mixture of water, sand and various chemical components (such as biocides) at high pressures.
- Under the Gloucester Gas Project Stage 1 proposal, AGL does not propose to re-inject co-produced water into depressurised aquifers. This water disposal mechanism is not relevant to the coal mines.
- All four developments operate under a 'no discharge' rule, which means that they are not licensed to discharge co-produced or other operational water into the stream network.
- All four developments include the use of existing or new water storages, for storage of co-produced water and drainage from waste rock emplacements.
- All four developments propose to reuse co-produced water on site. Uses include dust suppression, coal handling and preparation, and irrigation. The Gloucester Gas Project Stage 1 proposal includes construction of an on-site water treatment plant to treat saline co-produced water to a quality suitable for use by a local irrigator, with salt and solid by-products trucked off site for disposal (AGL Energy Limited, 2014).

In the following sections the groundwater and surface water causal pathways that could potentially lead to regional impacts on water quality are identified and the risk of impact is qualitatively assessed. The extent of influence and existing regulation and management practices are used to inform the assessment of risk.

3.3.4.1 Groundwater quality

Changes in groundwater quality from coal resource development can occur as an indirect result of subsurface depressurisation and dewatering of aquifers and changes to subsurface physical pathways between aquifers, which may modify groundwater flow paths and flow rates between aquifers of different quality water. Changes in groundwater quality can also occur as a direct result of coal resource development and operational water management, such as when water is deliberately injected into an aquifer or coal seam to manage surplus water, counter the effects of groundwater depressurisation and/or facilitate the process of CSG extraction. Unless hydrologically isolated from their surroundings, the creation of coal stockpiles, rock dumps and tailings dams on coal mine sites can result in leaching of contaminants to groundwater. In all these cases, a hazard arises when the quality of the receiving water is changed such that it reduces its beneficial-use value. BAs are concerned with the risk from non-accidental changes to water quality off site, which may be cumulative where different mining operations are in proximity.

Table 12 lists potential causes of changes in groundwater quality from coal resource development in the Gloucester subregion and identifies the potential for off-site impacts. Three of the four causal pathways in Table 12 could potentially have off-site impacts. However, one of these, ‘Hydraulic fracturing’ causal pathway, is not within the scope of the BAs and is identified here simply to acknowledge the hazard. Hydraulic fracturing is often, but not always, used in CSG extraction. It involves injecting water, often containing chemicals and sand, into the coal seams to create pathways to liberate gas and could have the potential for water quality impacts off site. Although AGL put their Gloucester Gas Project on hold in February 2016, this development is included in the CRDP for the Gloucester subregion and must be considered a potential cause for water quality impacts off site. In the remainder of this section, the risk to water quality off site is considered in the context of the scale of the effect and existing regulatory controls.

Table 12 Potential causal pathways for changes in groundwater quality and potential for off-site impacts

Causal pathway	Water quality concern	Scale	Off-site impacts in Gloucester subregion
Groundwater pumping enabling resource extraction	Leakage between aquifers that diminishes the beneficial-use value due to changes in water quality	Local to regional	Potential for off-site impacts from changes in the hydraulic gradients between connected aquifers of differing water quality
Failure of well (bore) integrity	Leakage between aquifers that diminishes the beneficial-use value due to changes in water quality	Local	Unlikely. NSW code of practice for CSG well design, construction and maintenance and guidelines developed by the National Uniform Drillers Licensing Committee are assumed to manage the risk
Hydraulic fracturing	Movement of fracking chemicals from coal seam to aquifers that have a beneficial use	Local	Potentially, but not considered here. Not in scope for BAs
Leaching from stockpiles, rock dumps, tailings dams, storage dams	Movement of contaminants into aquifers that reduce their beneficial use	Local to regional	Potential for off-site impacts, but regulatory controls in place to minimise risk

BA = bioregional assessment, CSG = coal seam gas

While not specifically identified for each development, wells are necessary parts of CSG extraction, and monitoring bores and production bores are typical of coal mining developments. Well integrity can be an issue, with well failure considered an inevitable consequence of CSG extraction. NSW Department of Industry Resources and Energy (DIRE) have a code of practice for CSG well integrity (DTI, 2012), which includes mandatory standards for well design and construction to protect groundwater resources. As a condition of title to explore, extract or produce under NSW’s *Petroleum (Onshore) Act 1991*, wells must be designed, constructed, maintained and abandoned to: (i) prevent any interconnection between coal seams and aquifers; (ii) ensure isolation between different aquifers and water-bearing zones; and (iii) not introduce substances that may cause environmental harm. All chemicals to be used must be disclosed during the approvals process. Given this, off-site impacts on water quality from well leakage are considered unlikely.

Bore leakage may result in local changes in groundwater quality, but the propagation of these changes off site, and hence the potential for regional, cumulative impacts, is considered unlikely. Bore construction and maintenance must be undertaken in accordance with state regulation to minimise leakage. In NSW, a water-supply work approval is needed under NSW's *Water Management Act 2000* for a new bore. Construction of a bore must be undertaken by a licensed driller and drillers are expected to meet minimum requirements set out in guidelines developed by the National Uniform Drillers Licensing Committee (NUDLC, 2012). These guidelines detail mandatory requirements and good industry practice for all aspects of the bore life cycle – from bore design through to bore siting, drilling fluids, casing, maximising bore efficiency, sealing and bore completion. While some leakage from older bores is considered likely, these bores are not part of the potential impact from additional coal resource development and not within the scope of this BA.

The potential impacts on watertable level, water pressure and groundwater quality from environmentally relevant activities such as CSG operations and coal mines are managed through the *NSW Aquifer Interference Policy* (DPI, 2012). This policy requires that: all water taken from an aquifer is properly accounted for; minimal impact considerations on the watertable, water pressure and water quality are addressed; and remedial measures are planned for in the event that actual impacts are greater than predicted. For aquifers in the Gloucester subregion, no change in the beneficial-use category of a groundwater source further than 40 m from the activity is permitted, unless studies can demonstrate that the change in groundwater quality will not affect the long-term viability of any water sharing plan, groundwater-dependent ecosystem, culturally significant site or water supply work. An increase of more than 1% per activity of the long-term average salinity is not permitted in a highly connected water source at the nearest point to the activity. As part of their groundwater monitoring and modelling plans, mining companies must demonstrate to the satisfaction of the NSW Department of Primary Industries, that the proposed development is undertaken in accordance with the policy. Given this, the potential for significant changes in regional groundwater quality is likely to be low.

In relation to leaching of contaminants from mining-related contaminant sources, NSW DIRE, under NSW's *Mining Act 1992*, requires mines to have an approved mining operations plan. The mining operations plan provides details of how the mining operation will be carried out, including details of management of stockpiles, rock dumps and tailings dams.

3.3.4.2 Surface water quality

Changes in surface water quality from coal resource development can occur as result of disruptions to surface drainage from the removal of vegetation and disturbance of soil in construction of roads, site facilities, excavation of open-cut pits and landscaping of the site during production and rehabilitation. Bare surfaces increase the risk of erosion with potential to increase total suspended solids in waterways. The discharge of mine water into the stream network as part of operational water management is potentially hazardous, if the quality of the discharged water lowers the quality of the receiving water below its current beneficial-use level. Depressurisation and dewatering of aquifers and changes to subsurface physical pathways between aquifers can lead to a change in baseflow to streams and potentially affect the water quality of the stream. Table 13 lists potential causes of changes in surface water quality from coal resource development in the Gloucester subregion and identifies the potential for off-site impacts, having regard to the relevance of the causal pathway in the subregion and the likely scale of the effect.

Table 13 Potential causes of changes in surface water quality and potential for off-site impacts

Causal pathway	Water quality concern	Scale	Off-site impacts in Gloucester subregion
Altering surface water system	Increased TSS in waterways from soil eroded off mine site	Local	Potential for off-site impacts
Groundwater pumping enabling resource extraction	Change in baseflow to stream diminishes the beneficial-use value due to changes in water quality	Local to regional	Potential for off-site impacts

TSS = total suspended solids

Altering the surface water system is an inevitable consequence of open-cut mining operations and will therefore directly impact on streamflow. Changes in baseflow on the other hand will depend, in the case of open-cut mines, on the proximity of mining to the stream network, hydraulic conductivity of the rock around the mine and mine pumping rates, which ultimately determine the drawdown zone and changes in direction and magnitude of hydraulic gradients.

The likelihood of off-site water quality impacts from disruptions to surface drainage on the mine sites is considered unlikely. There is a long history of soil erosion management in NSW, which has its origins in the agricultural sector, but has been extended to minimise the generation and mobilisation of sediments in all developments where disturbance of the soil occurs. NSW DIRE requires mines to provide details of how the mining operation proposes to minimise soil loss at all life stages of the mine and post-mining as part of an approved mining operations plan. Environmental protection licences, issued by DIRE under NSW's *Protection of the Environment Operations Act 1997*, may also specify erosion control conditions. Furthermore, DIRE requires authorised mines to develop, implement and report on environmental monitoring programs. In annual environmental management reports, the coal mining companies must publish their monitoring data in order to demonstrate that they are meeting their environmental objectives under their licence to operate.

The likelihood of off-site deterioration in stream water quality caused by changes in baseflow following dewatering of mines and/or changes in subsurface physical flow paths will depend on the quality of the groundwater relative to the quality of the water in the stream into which it discharges. Modelling of the hydrological changes due to additional coal resource development predicts a probable reduction in baseflows to streams in the Gloucester subregion. If, as is usually the case, the salinity of the groundwater is higher than that of the stream into which it discharges, a reduction in baseflow would be expected to improve stream water quality. This is likely as reported electrical conductivity measurements in Gloucester subregion streams vary between 100 and 600 µS/cm (Section 1.1.5.2 of companion product 1.1 for the Gloucester subregion (McVicar et al., 2014)), while published electrical conductivity readings of groundwater vary from around 400 to 6000 µS/cm in alluvial aquifers and around 2400 to 9400 µS/cm in sandstone-siltstone and coal seam aquifers (Section 1.1.4.2 in McVicar et al., 2014). Streamflow and groundwater level data indicate that streams in the Avon river basin are generally gaining streams and that groundwater is exchanged between the alluvium and surrounding shallow weathered rock aquifer (Section 1.1.6.1 in McVicar et al., 2014). These data suggest that any reduction in baseflow due to the drawdown from additional coal resource development could lead to a decrease in stream salinities, but there are other factors at play and a broader analysis may be warranted.

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3.4 Impacts on and risks to landscape classes

Summary

The heterogeneous natural and human-modified ecosystems in the Gloucester subregion were classified into 20 landscape classes, which were aggregated into five landscape groups based on their likely response to hydrological changes: 'Riverine', 'Groundwater-dependent ecosystem (GDE)', 'Estuarine', 'Non-GDE' and 'Economic land use'.

The 'Native vegetation' landscape class was ruled out from potential impacts, because it is classified as a 'Non-GDE' landscape and not considered water dependent for the purposes of bioregional assessments (BAs).

The following are *very unlikely* to be impacted because they are located outside the zone of potential hydrological change:

- the 'Estuarine' landscape group
- the 'Freshwater wetland' landscape class within the 'GDE' landscape group.

Intermittent and perennial gravel/cobble streams are the most extensive riverine landscape classes in the zone of potential hydrological change, and qualitative models and receptor impact models were constructed for these landscape classes. The receptor impact models determined the potential impact of hydrological changes using these variables:

- annual mean percent canopy cover of woody riparian vegetation (perennial streams)
- mean number of larvae of the Hydropsychidae family (net-spinning caddisflies) in a 1 m^2 sample of riffle habitat (perennial streams)
- mean number of the eel-tailed catfish (*Tandanus tandanus*) in a 600 m^2 transect whose long axis lies along the mid-point of the stream (perennial streams)
- mean richness of hyporheic invertebrate taxa (intermittent streams).

Overall, no changes are detectable in any of these receptor impact variables due to additional coal resource development. This is because the modelled hydrological changes in these streams are very minor.

Approximately 1.1 km^2 of GDEs have a 5% chance of experiencing groundwater drawdown between 0.2 and 2 m. Most of the potential impact is in the 'Forested wetlands' landscape class. No GDE landscape classes are subject to greater than 2 m of potential drawdown. The water requirements of GDEs are poorly understood and there is large uncertainty as to the frequency, timing and duration of groundwater use in the Gloucester subregion. It is therefore unclear how much (if any) impact this additional drawdown is likely to have on GDEs.

3.4.1 Overview

This section describes the risks to landscape classes that are potentially impacted by hydrological changes arising in response to additional coal resource development. The focus is on landscape classes with potential ecological impacts. Impacts on economic assets are addressed in Section 3.5.

Landscape classification was used to characterise the diverse range of water-dependent assets into a smaller set of classes for further analysis. Landscape classes were organised into five landscape groups, which reflect their water-dependencies: 'Riverine', 'Groundwater-dependent ecosystem (GDE)', 'Estuarine', 'Non-GDE' and 'Economic land use' (Table 14). The basis for the landscape groups and classes is described in companion product 2.3 for the Gloucester subregion (Dawes et al., 2018). Landscapes classes that intersect the 250 km^2 zone of potential hydrological change are considered potentially impacted due to additional coal resource development and are the focus of this section. Landscape classes that do not intersect the zone or are not water dependent can be ruled out as *very unlikely* to be impacted (less than 5% chance) due to additional coal resource development (see Section 3.4.2).

About 242 km (82%) of the 296 km of river length in the Gloucester assessment extent is in the zone of potential hydrological change (Table 14). Outside this zone are 51 km of perennial streams and 3 km of intermittent streams, mainly along the Karuah River in the south of the assessment extent (Figure 29). Most (87%) of the stream length in the zone comprises intermittent and perennial gravel/cobble streams (Table 14). Potential impacts on these two landscape classes are assessed using both qualitative models and quantitative receptor impact models developed for the Gloucester subregion (see companion product 2.7 for the Gloucester subregion (Hosack et al., 2018b)), with results presented in Section 3.4.3.

There is about 3.3 km^2 of the 'Groundwater-dependent ecosystem (GDE)' landscape group in the zone of potential hydrological change (Table 14). Each of the five landscape classes in the 'GDE' landscape group is described by a qualitative model (companion product 2.7 for the Gloucester subregion (Hosack et al., 2018b)), which forms the basis for assessing the potential for impacts on the landscape class. Section 3.4.4 provides an assessment of the potential impacts on and risk to the landscape classes in the 'Groundwater-dependent ecosystem (GDE)' landscape group.

Receptor impact modelling converts the potentially abstract information about hydrological changes to quantities that stakeholders care about and can more readily understand and interpret. In particular, outcomes of the modelling will relate more closely to their ecological values and beliefs and therefore support community discussion and decision making about acceptable levels of coal resource development (companion submethodology M08 (as listed in Table 1) for receptor impact modelling (Hosack et al., 2018a)). Receptor impact models are not intended to make site-specific predictions but rather to quantify the range of possible responses of select receptor impact variables to a given change in hydrology. It is beyond the scope of a bioregional assessment (BA) to make precise predictions at exact locations.

Receptor impact variables represent biological components of the ecosystem that experts have chosen as indicators of ecosystem condition, and which are considered likely to be sensitive to changes in the hydrology of that system (see companion submethodology M08 (as listed in

Table 1) for receptor impact modelling (Hosack et al., 2018a)). Changes in hydrology are represented in the model by hydrological response variables, chosen to reflect particular water requirements of the ecosystem. The magnitude of change in the chosen receptor impact variables to changes in one or more hydrological response variables, captured through an expert elicitation process, is an indicator of the magnitude of risk to the ecosystem as a result of hydrological perturbation. For example, a prediction that the number of riffle breeding frog species is likely to decrease in a particular reach where zero-flow days are predicted to increase does not necessarily mean that there are riffle breeding frogs present and that they will be impacted; rather, it means that given the magnitude of hydrological change predicted in that reach, there is a specific risk to the habitat requirements of riffle breeding frogs, and more generally a risk to the ecosystems represented by the landscape class the riffle breeding frog inhabits. The receptor impact modelling results are provided at a landscape scale and should not be interpreted as exactly representing the local conditions of a particular site.

Table 14 Extent of each landscape class in the assessment extent and the zone of potential hydrological change, and the landscape classes that have a qualitative model and/or a receptor impact model (RIM)

The extent of each landscape class is either an area of vegetation (km^2) or length of stream network (km).

Landscape group	Landscape class	Extent in assessment extent	Extent in zone of potential hydrological change	Qualitative model	RIM
Riverine	Intermittent – gravel/cobble streams (km)	81	78	Intermittent gravel/cobble	Yes
	Intermittent – high gradient bedrock confined streams (km)	5	5	None	None
	Intermittent – lowland fine streams (km)	4	4	None	None
	Perennial – gravel/ cobble streams (km)	175	133	Perennial gravel/cobble	Yes
	Perennial – high gradient bedrock confined streams (km)	28	9	None	None
	Perennial – lowland fine streams (km)	1	0	None	None
	Perennial – transitional fine streams (km)	17	13	None	None
Groundwater-dependent ecosystem (GDE)	Dry sclerophyll forests (km^2)	1.4	0.2	Dry sclerophyll forests	None
	Forested wetlands (km^2)	5.2	1.9	Forested wetlands	None
	Freshwater wetlands (km^2)	1.1	0	None	None
	Rainforests (km^2)	2.2	1.0	Wet sclerophyll forests	None
	Wet sclerophyll forests (km^2)	0.4	0.15	Wet sclerophyll forests	None
Estuarine	Barrier river (km)	33	0	None	None
	Saline wetlands (km^2)	5.4	0	None	None
Non-GDE	Native vegetation (km^2)	139	54	None	None
Economic land use	Dryland agriculture (km^2)	277	170	None	None
	Irrigated agriculture (km^2)	4.4	4.1	None	None
	Intensive uses (km^2)	20.9	14.2	None	None
	Plantation or production forestry (km^2)	3.2	1.0	None	None
	Water (km^2)	9.4	3.4	None	None

GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 1)

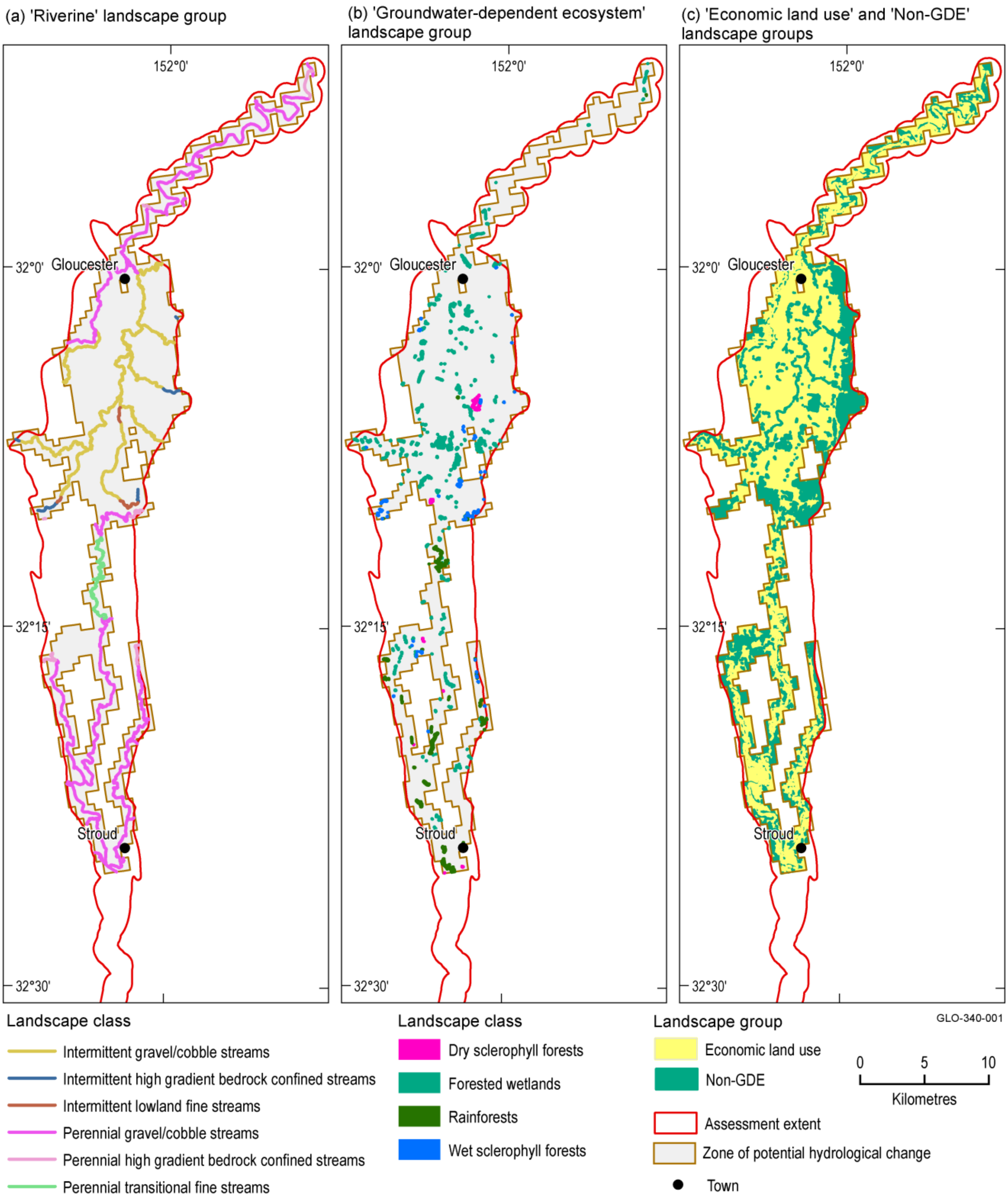

Figure 29 Landscape classes in the zone of potential hydrological change

Note that groundwater-dependent ecosystems (GDEs) are exaggerated (not to scale) for clarity.
Data: Bioregional Assessment Programme (Dataset 2, Dataset 3, Dataset 5); NSW Office of Water (Dataset 4); ABARES (Dataset 6)

3.4.2 Landscape classes that are unlikely to be impacted

The vast majority (247 km^2 or 99%) of the zone of potential hydrological change comprises landscape classes from the 'Non-GDE' and 'Economic land use' landscape groups (Table 14, Figure 29).

The 'Native vegetation' landscape class was ruled out from potential impacts, because it is classified in the 'Non-GDE' landscape group and is therefore not considered water dependent for the purposes of BAs.

The following are *very unlikely* to be impacted because they are located outside the zone of potential hydrological change:

- the 'Estuarine' landscape group
- the 'Freshwater wetland' landscape class within the 'GDE' landscape group.

While some landscape classes in the 'Economic land use' landscape group are water dependent (e.g. irrigated agriculture), impacts on economic assets are not evaluated by landscape class. Potential impacts on economic assets are considered in Section 3.5.

The perennial transitional fine streams within the Gloucester subregion are along the Wards River north of the Duralie mine site. Because hydrological impact is *very unlikely* in this area (see Figures 16 to 27 in Section 3.3), this landscape class, and the assets associated with it, are unlikely to be impacted.

3.4.3 'Riverine' landscape group

3.4.3.1 Description

Hydrological regimes for the Gloucester assessment extent are discussed in more detail in companion product 1.1 (McVicar et al., 2014) and companion product 2.1-2.2 (Frery et al., 2018) for the Gloucester subregion and only a brief summary is presented here for context. The Gloucester Basin is separated into a northern sub-basin (where regional groundwater flow is predominantly from south to north) and a southern sub-basin (where regional groundwater flow is predominantly from north to south). There is no surface water connection between the northern and southern river basins, nor is there evidence of a substantial groundwater connection between them.

Stream and aquifer salinity indicate that streams within the assessment extent are generally gaining. Thus, groundwater is an important source of baseflow in this landscape group (companion product 1.1 for the Gloucester subregion (McVicar et al., 2014)). Groundwater recharge has been variously estimated as being between 0% and 17% (steady-state conditions) and between 0% and 28% (transient conditions) of rainfall, with high values associated with alluvial aquifers (Australasian Groundwater and Environmental, 2013; Heritage Computing, 2009, 2012; Parsons Brinckerhoff, 2013). Discharge occurs from all the hydrogeological units to rivers and streams and, as evapotranspiration by deep-rooted vegetation, from the shallow watertable. Groundwater salinity increases with depth, although typically, groundwater associated with alluvial aquifers varies from fresh to brackish (electrical conductivity (EC) of 387–5810 µS/cm; companion product

1.1 for the Gloucester subregion (McVicar et al., 2014)). Companion product 2.1-2.2 for the Gloucester subregion (Frery et al., 2018) reported that groundwater depths in the alluvium ranged from very near the surface to 13.4 m below ground level. Almost no data were available outside the alluvium; however, modelled depths to watertable (Summerell and Mitchell, 2011) suggest that groundwater is no deeper than 12 to 16 m in any of the lowland areas of the assessment extent (Figure 30).

The two closely related landscape classes, ‘Perennial – gravel/cobble streams’ and ‘Intermittent – gravel/cobble streams’, dominate potentially impacted stream reaches in the ‘Riverine’ landscape group (Table 14). The ‘Perennial – gravel/cobble streams’ landscape class represents 52% of the stream network within the non-estuarine region of the assessment extent (Dawes et al., 2018). In the northern half of the assessment extent, the landscape class is mainly restricted to the Gloucester River; in the southern half of the assessment extent it also occurs along the Karuah and Mammy Johnsons rivers. The ‘Intermittent – gravel/cobble streams’ landscape class occupies 20% of the stream network within the non-estuarine region of the assessment extent, with the majority occurring in the northern half of the assessment extent (companion product 2.3 for the Gloucester subregion (Dawes et al., 2018)). The Avon River (which is a major tributary of the Gloucester River) and its tributaries dominate this landscape class. The Avon river basin area occupies approximately 73% of the northern-flowing part of the assessment extent, and descends 412 m over its 42 km course (companion product 1.1 for the Gloucester subregion (McVicar et al., 2014)).

Pools and riffles are most common in streams with mixed bed materials ranging from 2 to 256 mm in size (Knighton, 1984); hence, they are a feature of the ‘Perennial – gravel/cobble streams’ and ‘Intermittent – gravel/cobble streams’ landscape classes. The mixed substrate forms alternating pool and riffle sequences that increase the geomorphic and habitat complexity along the reach (Boulton et al., 2014). Riparian vegetation lining the banks of the landscape classes in the ‘Riverine’ landscape group provides important in-stream and terrestrial habitats and contributes to geomorphic condition by maintaining bank stability (Boulton et al., 2014). This riparian vegetation is dominated by forested wetlands, typically characterised by a eucalypt-dominant overstorey and a grassy or shrubby understorey, although actual species composition is highly variable (Keith, 2004). The Karuah River from Stroud to Karuah is relatively well vegetated, but much of the riparian zone is cleared along the Avon and Gloucester rivers (see Section 1.1.7.2 of companion product 1.1 for the Gloucester subregion (McVicar et al., 2014)) and much of the riparian zone outside of the Karuah National Park and reserves is in poor condition (Haine et al., 2012). Patches of rainforest, including the ‘Lowland Rainforest of Subtropical Australia’ threatened ecological community, are largely restricted to reaches along the Karuah River (see Section 2.3.3.1 of companion product 2.3 for the Gloucester subregion (Dawes et al., 2018)).

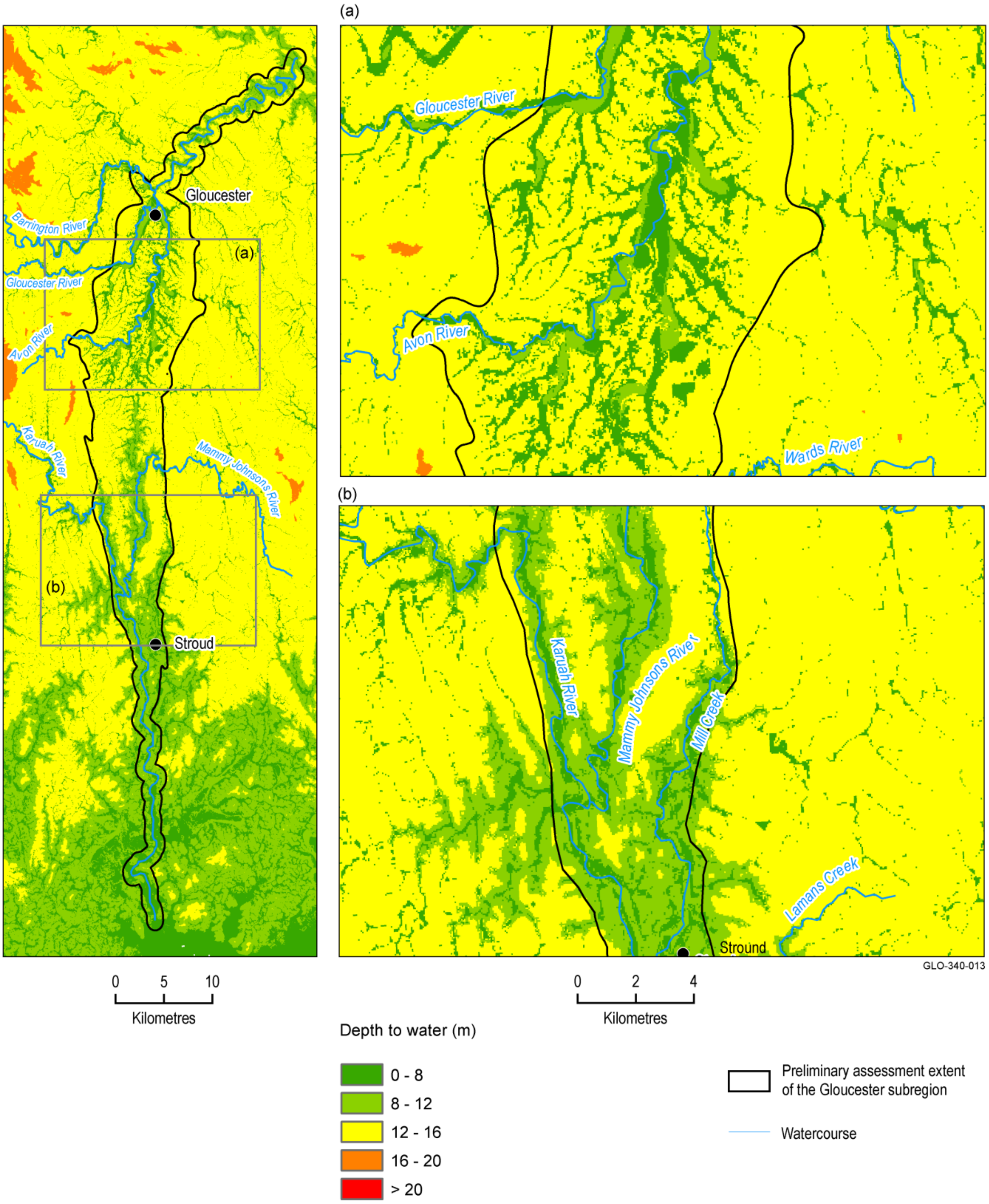

Figure 30 Modelled depth to watertable

Data: NSW Department of Primary Industries (Dataset 7)

Only 3% of the perennial streams and 2% of the intermittent streams in the zone of potential hydrological change were classed as good geomorphic condition (Figure 31). Chessman et al. (2006) observed that reaches of the Bega River in good geomorphic condition were important for maintaining native biodiversity and were biologically very different from stream reaches in moderate or poor condition. Deterioration from moderate to poor geomorphic condition resulted in less biological change than the deterioration from good to moderate. Of the intermittent streams in the zone, 51% were in moderate condition and 46% were in poor condition. Of the perennial streams in the zone, 83% were in moderate condition and 15% were in poor condition. The relatively poor geomorphic condition of the intermittent streams was reflected in riparian cover: 59% of the intermittent river reaches in the zone had some vegetation cover, while 88% of the perennial river reaches had some vegetation cover (Figure 32). Riparian vegetation (Figure 32) along both perennial and intermittent streams is dominated by ‘Forested wetlands’ and ‘Rainforest’ landscape classes.

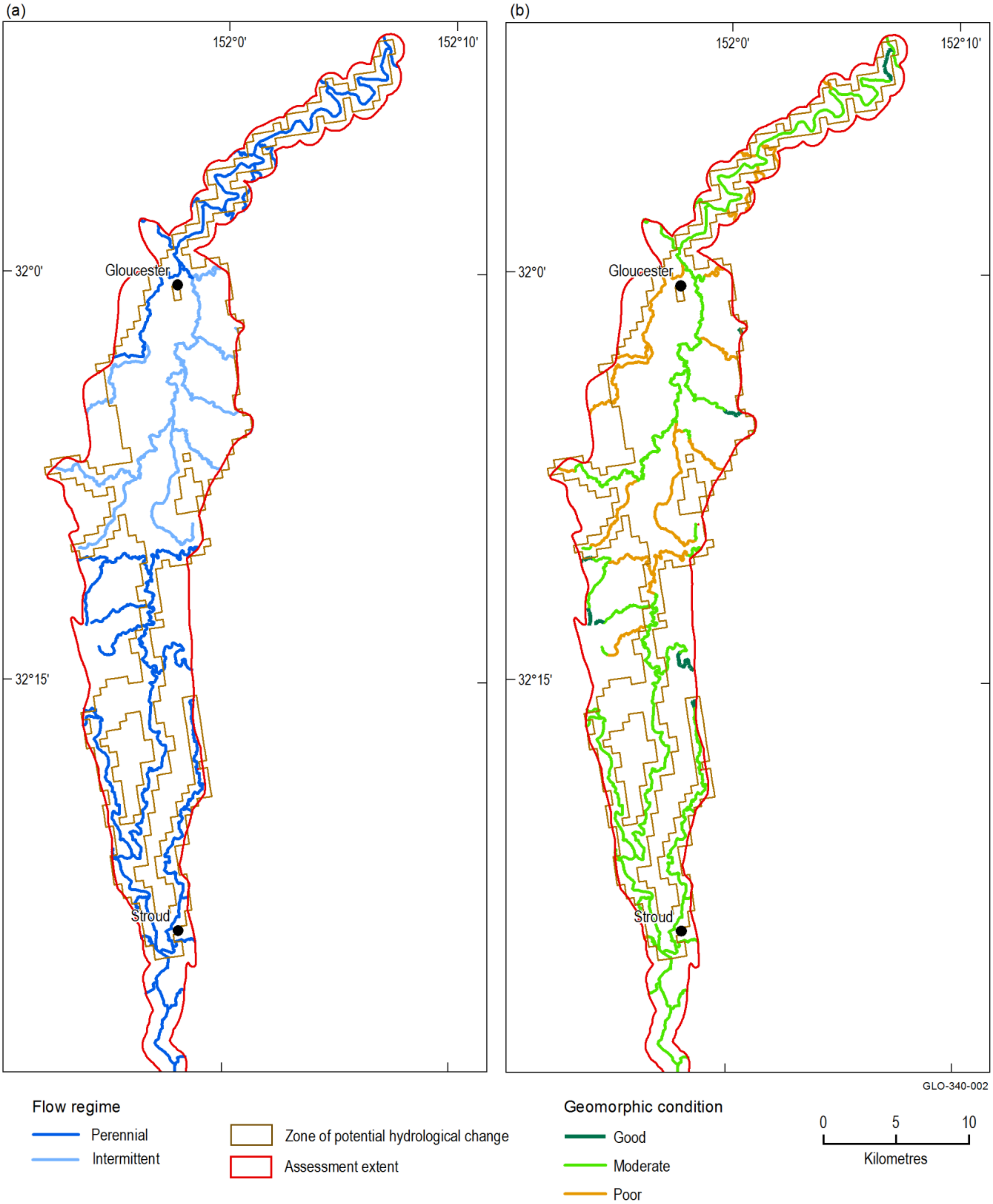

Figure 31 (a) Flow regime and (b) geomorphic condition of perennial and intermittent streams

Data: Bioregional Assessment Programme (Dataset 2, Dataset 3, Dataset 5)

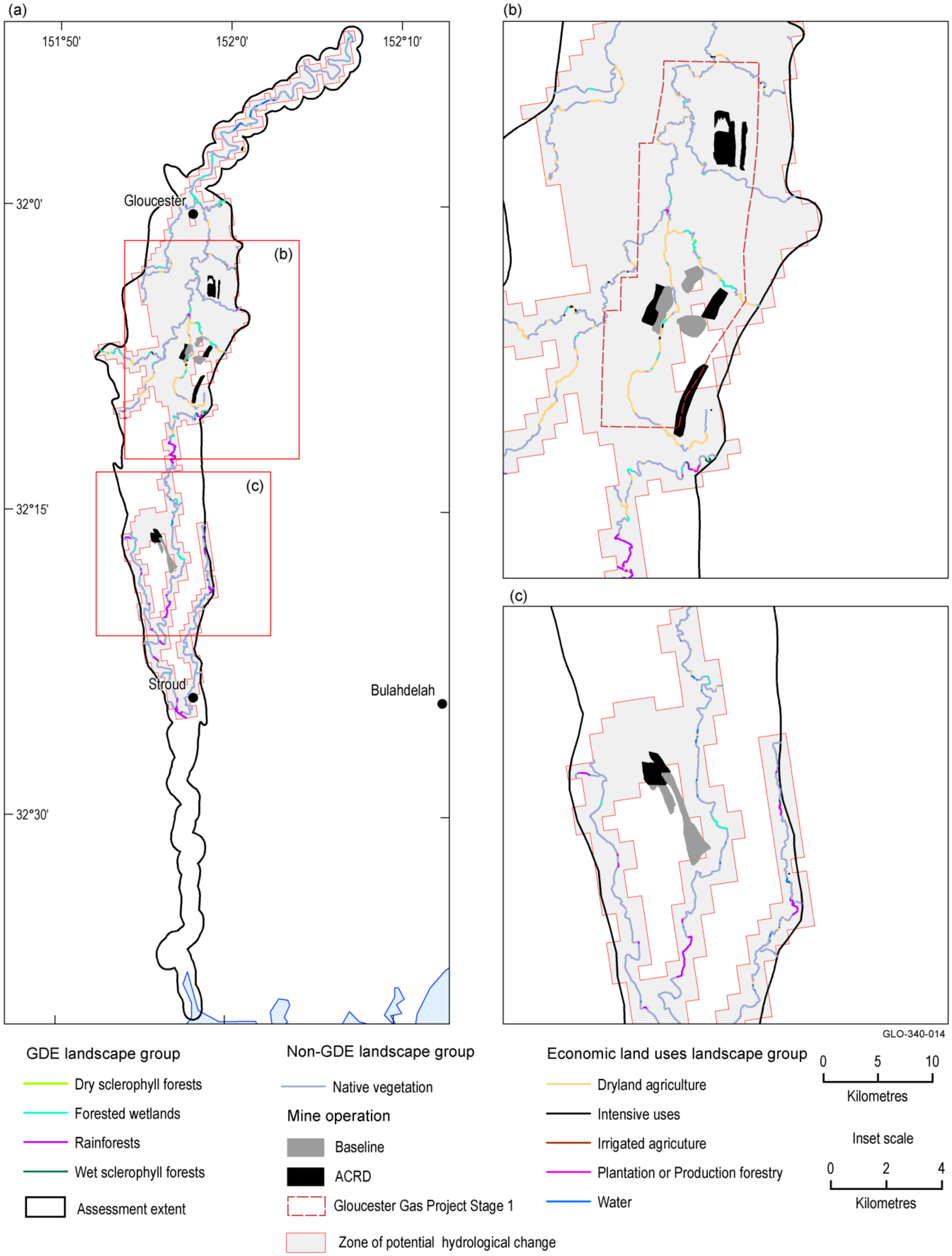

Figure 32 Keith (2004) vegetation classes associated with streams in the zone of potential hydrological change

ACRD = additional coal resource development, CSG = coal seam gas, GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 2, Dataset 3, Dataset 8, Dataset 9); NSW Office of Water (Dataset 4); ABARES (Dataset 6)

The 'Riverine' landscape group supports a range of native and introduced fish species. Native species that migrate upstream and downstream may be important indicators of longitudinal connectivity (Koehn and Crook, 2013). Examples include the diadromous (migrates between fresh and estuarine waters) Australian bass (*Macquaria novemaculeata*) and striped gudgeon (*Gobiomorphus australis*), and the potamodromous (migrates wholly within fresh waters) Cox's gudgeon (*Gobiomorphus coxii*). Changes to flow regimes or water quality may impact the life cycles of these fish by (NSW Department of Primary Industries, 2006):

- interrupting spawning or seasonal migrations
- restricting access to preferred habitat and available food resources
- reducing genetic flow between populations
- increasing susceptibility to predation and disease through accumulations of fish below barriers
- fragmenting previously continuous communities
- disrupting downstream movement of adults and impeding larval drift through the creation of still-water (lentic) environments.

Other native fish species reported from NSW DPI Fisheries monitoring (NSW Department of Primary Industries, Dataset 10) of the Gloucester, Karuah, Wards and Mammy Johnsons rivers include Australian smelt (*Retropinna semoni*), bullrout (*Notesthes robusta*), common jollytail (*Galaxias maculatus*), dwarf flat-headed gudgeon (*Philypnodon macrostomus*), empire gudgeon (*Hypseleotris compressa*), firetail gudgeon (*Hypseleotris galii*), flat-headed gudgeon (*Philypnodon grandiceps*), eel-tailed catfish (*Tandanus tandanus*), freshwater herring (*Potamalosa richmondia*), freshwater mullet (*Myxus petardi*), long-finned eel (*Anguilla reinhardtii*), sea mullet (*Mugil cephalus*), short-finned eel (*Anguilla australis*), southern blue-eye (*Pseudomugil signifer*) and yellowfin bream (*Acanthopagrus australis*). Exotic fish species have also been observed (e.g. eastern gambusia and goldfish).

Qualitative and quantitative mathematical models for the 'Intermittent – gravel/cobble streams' and 'Perennial – gravel/cobble streams' landscape classes are presented in Section 2.7.3 of companion product 2.7 for the Gloucester subregion (Hosack et al., 2018b).

3.4.3.2 Potential hydrological change

3.4.3.2.1 'Perennial – gravel/cobble streams' landscape class

The hydrological factors identified by experts in the qualitative modelling workshops (see companion product 2.7 for the Gloucester subregion (Hosack et al., 2018b) have been interpreted as a set of hydrological response variables. The groundwater hydrological factors and associated hydrological response variables for the 'Perennial – gravel/cobble streams' landscape class are the:

- maximum difference in drawdown under the baseline future or under the coal resource development pathway future relative to the reference period (1983 to 2012) (dmaxRef)
- year that the maximum decrease of groundwater occurs (tmaxRef).

The surface water hydrological factors and associated hydrological response variables for the 'Perennial gravel/cobble streams' landscape class are the:

- mean annual number of events with a peak daily flow exceeding the volume of flow that is assumed to result in 'overbench' flow (EventsR0.3)
- mean annual number of events with a peak daily flow exceeding the volume of flow that is assumed to result in 'overbank' flow (EventsR3.0)
- number of zero-flow days per year, averaged over a 30-year period (ZQD, subsequently referred to in this section as 'zero-flow days')
- ratio of total baseflow generation to total streamflow generation, averaged over a 30-year period (QBFI).

For details of these variables the reader is referred to Section 2.7.3 of companion product 2.7 for the Gloucester subregion (Hosack et al., 2018b).

Figure 33 Perennial gravel/cobble stream in the Gloucester subregion

Source: Heinz Buettikofer, CSIRO

The total length of perennial gravel/cobble streams in the zone of potential hydrological change is 133 km. Modelling results indicate that there is a 95% chance that the length of perennial gravel/cobble stream subjected to a drawdown of greater than 0.2 m due to additional coal resource development will be less than 1.8 km (Table 15). Hence, it is *very unlikely* that the length of perennial gravel/cobble streams subject to a drawdown of greater than 0.2 m will exceed

1.8 km. The median estimate is that no stream length will be subject to a drawdown of greater than 0.2 m due to additional coal resource development (Table 15). This is consistent with the remoteness of perennial gravel/cobble streams from additional coal resource development (Figure 34).

Based on the median estimates, it is likely that there will be little change in baseflow index resulting from additional coal resource development. The median estimate of stream length with no change resulting from additional coal resource development is 34.7 km in the 30-year periods preceding both 2042 (Figure 34) and 2102 (Figure 35, Table 16). A further 59.8 km of stream length is predicted to have a very small (<0.01) increase in baseflow index, based on the median estimate. The impact is unknown for 11.6 km of perennial stream for the 5th percentile and median estimates (Figure 34, Figure 35). A greater change in baseflow index was modelled for the 5th and 95th percentile estimates but the changes in baseflow index were small (<0.01). The impact is unknown for 36.6 km of perennial stream for the 95th percentile estimate (Figure 34, Figure 35). Overall, it is unlikely that any length of perennial gravel/cobble stream will be subject to a detectable change in baseflow index.

Based on the median estimates, it is likely that there will be little change in zero-flow days resulting from additional coal resource development. The median estimate of stream length with no change resulting from additional coal resource development is 94.5 km in the 30-year periods preceding both 2042 (Figure 36) and 2102 (Figure 37, Table 17). This is the entire length of perennial gravel/cobble streams in the zone of potential hydrological change (excepting the length of streams with 'potential hydrological change' east of the Duralie mine where changes cannot be ruled out). The 95th percentile estimate is that approximately 8 km of stream length (including a section of Wards River and the Avon and Gloucester rivers near their junction) will experience an increase of 0–10 zero-flow days (Table 17, Figure 37) in the two 30-year periods. The impact is unknown for 36.6 km of perennial stream for the 95th percentile estimate, including parts of Mammy Johnsons River, Mill Creek and a section of the Gloucester River. Overall, it is *very unlikely* that the length of perennial stream subject to an increase in zero-flow days will exceed 8 km and that the increase in zero-flow days will exceed 10 days.

Based on the median estimates, it is likely that there will be little change in overbench flow resulting from additional coal resource development. The median estimate of perennial gravel/cobble stream length with no change resulting from additional coal resource development is 129.1 km in the 30-year period preceding 2042 (Figure 38) and 2102 (Figure 39, Table 18). A further 7.5 km of stream length is predicted to have a small (<0.2) decrease in overbench flow in the 30-year period preceding 2042, based on the median estimate. The 95th percentile estimate is that 59.8 km of stream length will experience a decreased overbench flow of up to 0.2 (Table 18) in the two 30-year periods. There is no length of stream for which the impact is unknown for overbench flow. Hence, it is *very unlikely* that the length of perennial stream subject to a decrease in overbench flow will exceed 59.8 km and that the impact would be greater than a 0.2 reduction in the frequency of overbench flow. A reduction of 0.2 means that there would be 0.2 fewer overbench events per year (one fewer every 5 years).

Based on the median estimates, it is likely that there will be little change in overbank flow resulting from additional coal resource development. The median estimate of stream length with no change resulting from additional coal resource development is 129.1 km in the 30-year period preceding 2042 (Figure 40, Table 19) and 131.1 km in the 30-year period preceding 2102 (Figure 41, Table 19), which is virtually the entire length of stream in the zone of potential hydrological change. The 95th percentile estimate is that 49.2 km of stream length will experience a decreased overbank flow of up to 0.05 (Table 19) in the 30-year period preceding 2042, and that 16.2 km of stream length will experience a decreased overbank flow of up to 0.02 (Table 19) in the 30-year period preceding 2102. There is no length of stream for which the impact is unknown for overbank flow. Hence, it is *very unlikely* that the length of perennial gravel/cobble streams subject to a decrease in overbank flow will exceed 49.2 km and that the impact would be greater than a 0.02 reduction in the frequency of overbank flow. A reduction of 0.02 means there would be 0.02 fewer overbank events per year (one fewer every 50 years).

Overall, it is unlikely that perennial gravel/cobble streams in the Gloucester assessment extent will be significantly impacted by groundwater drawdown, change in baseflow index or increased zero-flow days as a result of additional coal resource development. There is an unquantified risk along a section of Mammy Johnsons River, to the east of Duralie mine, and local-scale information is needed to determine the actual risk here. Small decreases in the frequency of overbench and overbank flows are possible in short reaches of the perennial gravel/cobble streams.

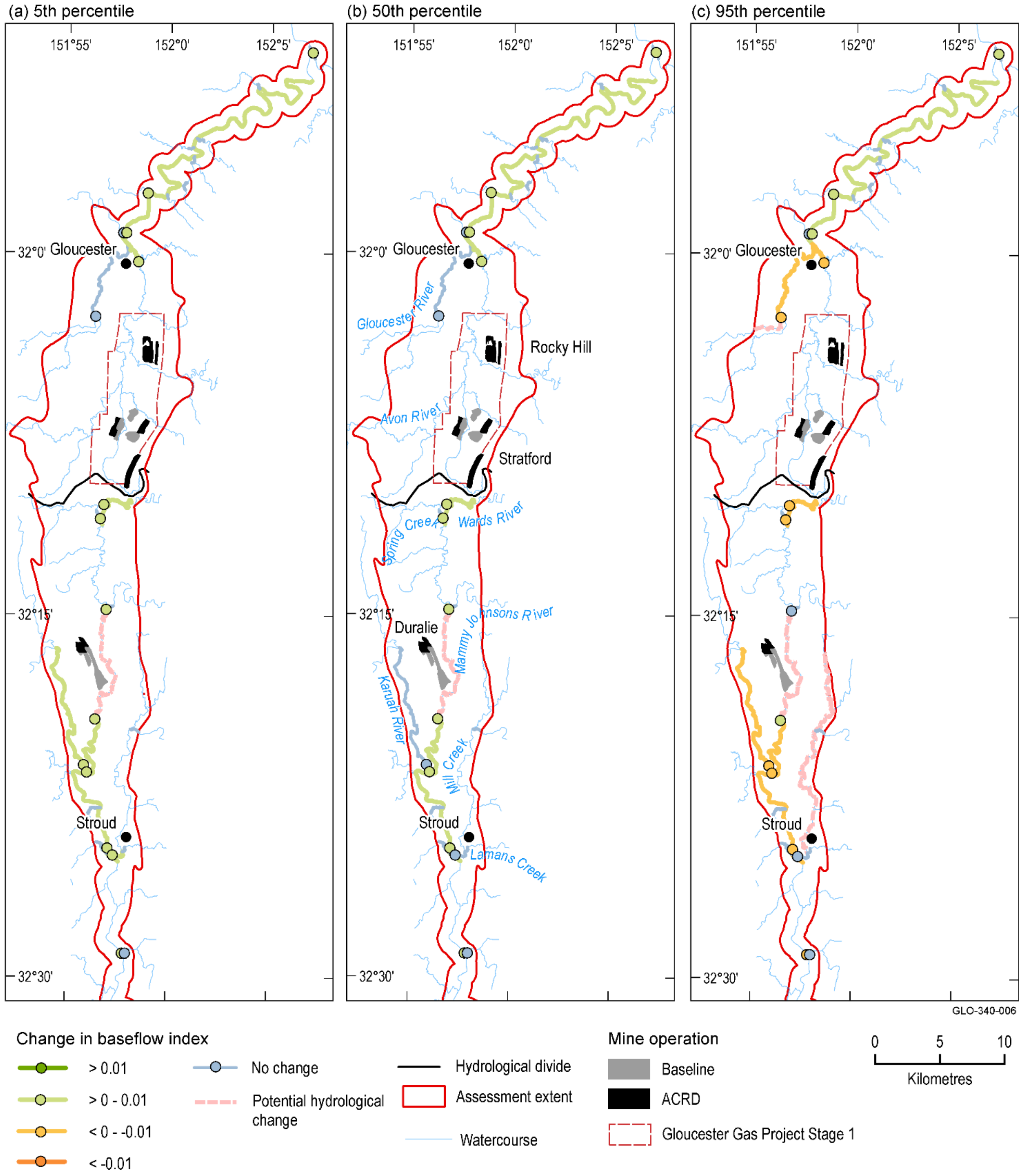

Figure 34 Modelled change in baseflow index in perennial gravel/cobble streams in 2042 in the zone of potential hydrological change

ACRD = additional coal resource development, CSG = coal seam gas

Data: Bioregional Assessment Programme (Dataset 1, Dataset 3, Dataset 8, Dataset 9)

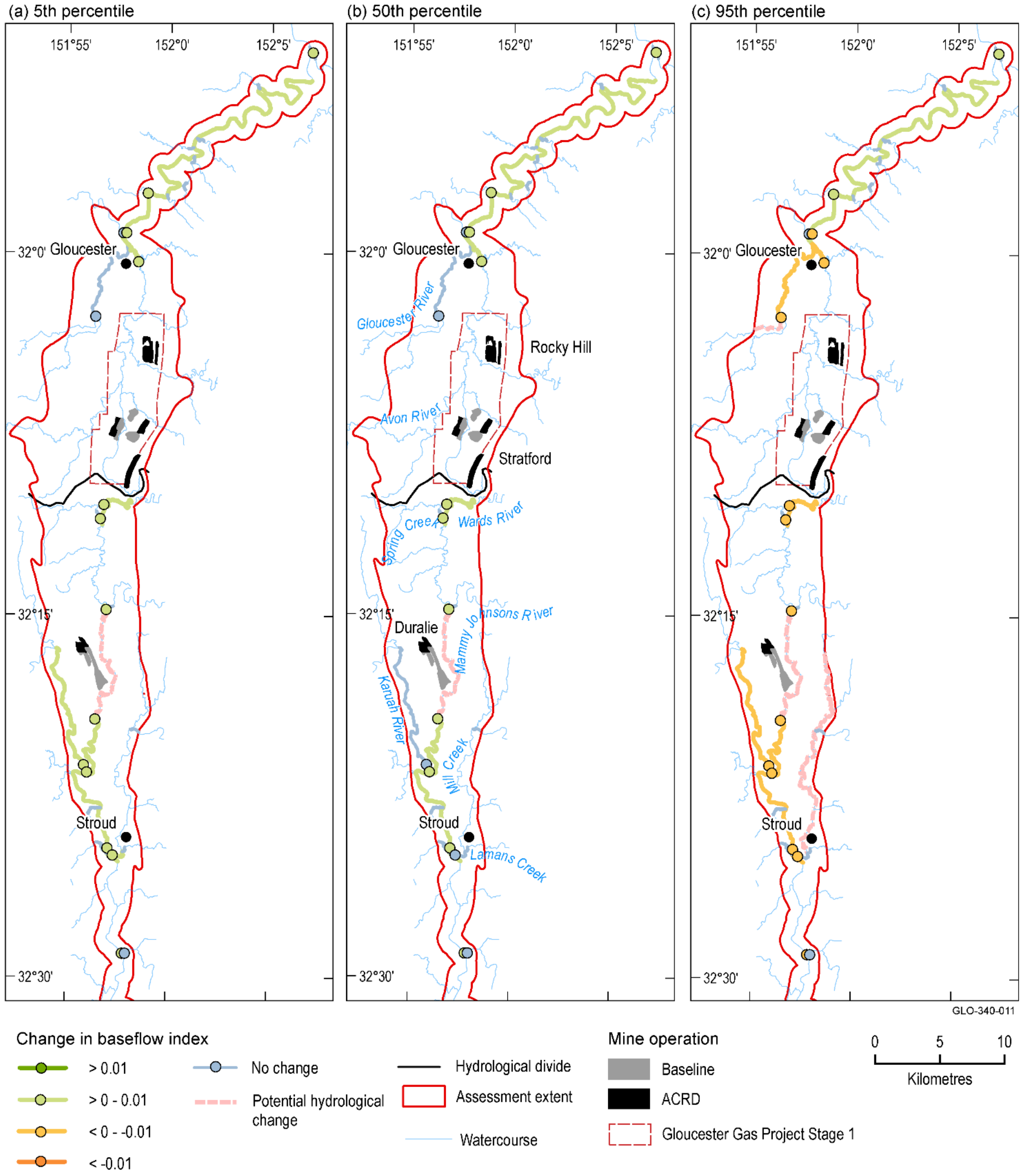

Figure 35 Modelled change in baseflow index in perennial gravel/cobble streams in 2102 in the zone of potential hydrological change

ACRD = additional coal resource development, CSG = coal seam gas

Data: Bioregional Assessment Programme (Dataset 1, Dataset 3, Dataset 8, Dataset 9)

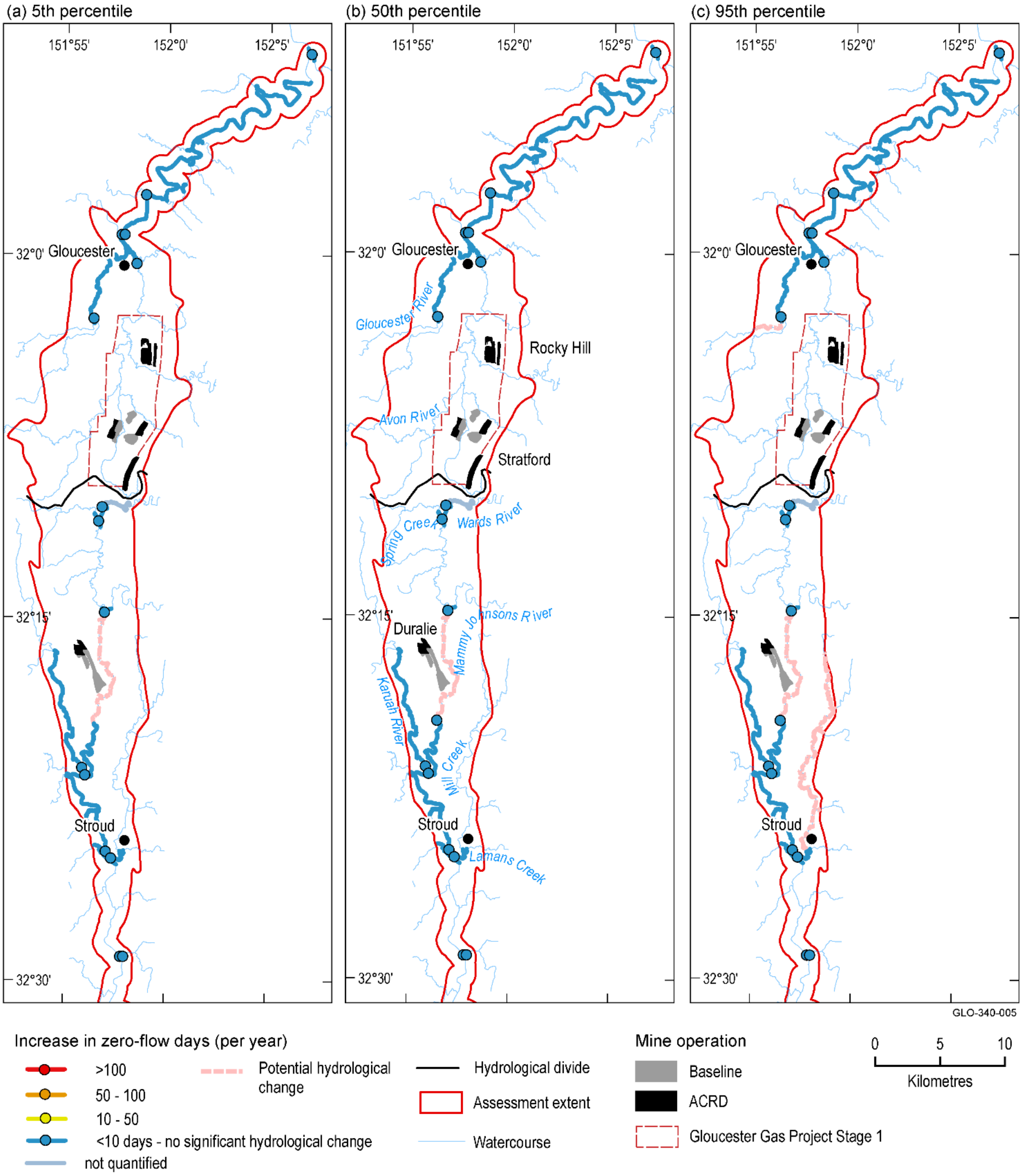

Figure 36 Modelled increase in zero-flow days in perennial gravel/cobble streams in 2042 in the zone of potential hydrological change

ACRD = additional coal resource development, CSG = coal seam gas
Data: Bioregional Assessment Programme (Dataset 1, Dataset 3, Dataset 8, Dataset 9)

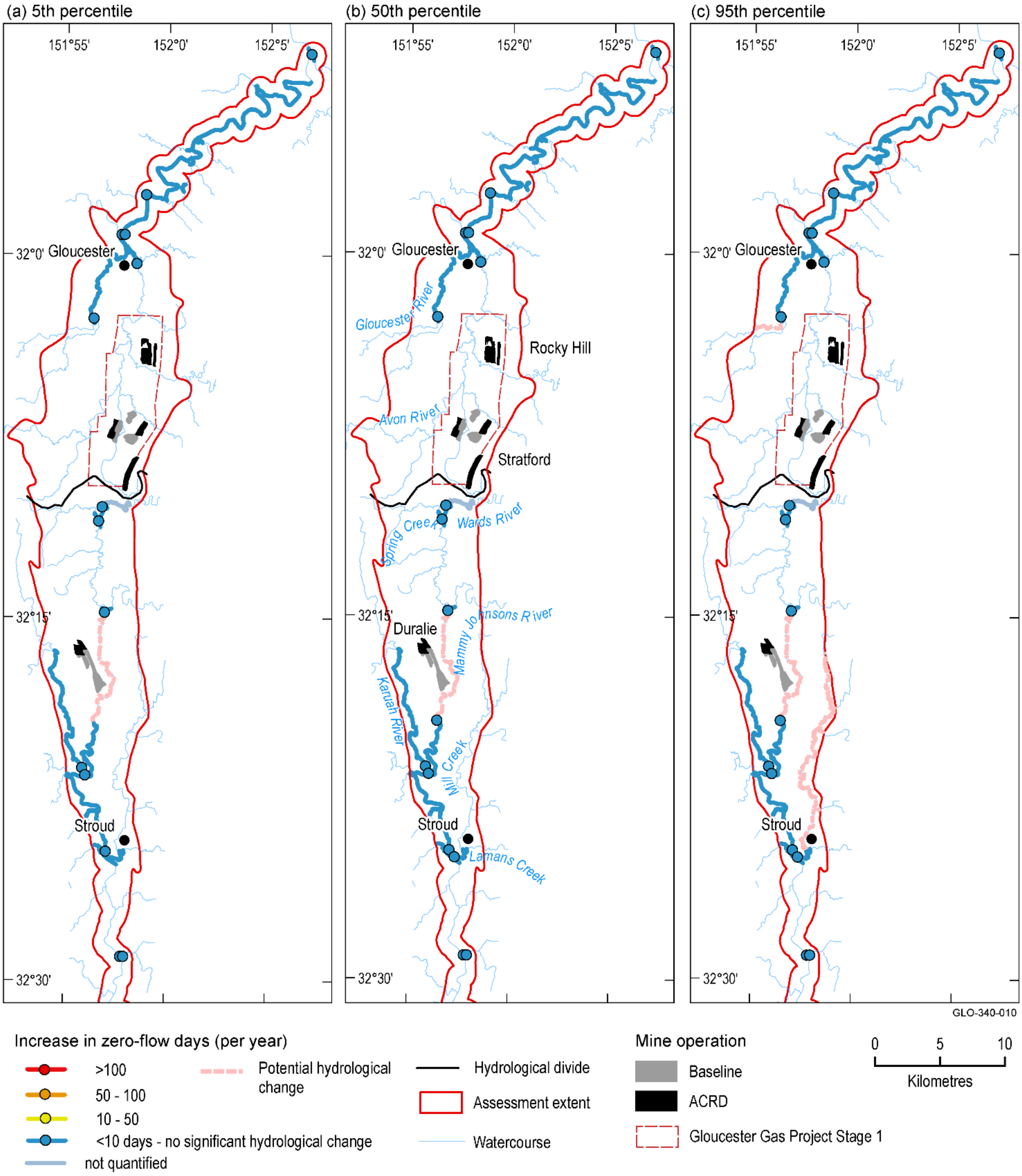

Figure 37 Modelled increase in zero-flow days in perennial gravel/cobble streams in 2102 in the zone of potential hydrological change

ACRD = additional coal resource development, CSG = coal seam gas
Data: Bioregional Assessment Programme (Dataset 1, Dataset 3, Dataset 8, Dataset 9)

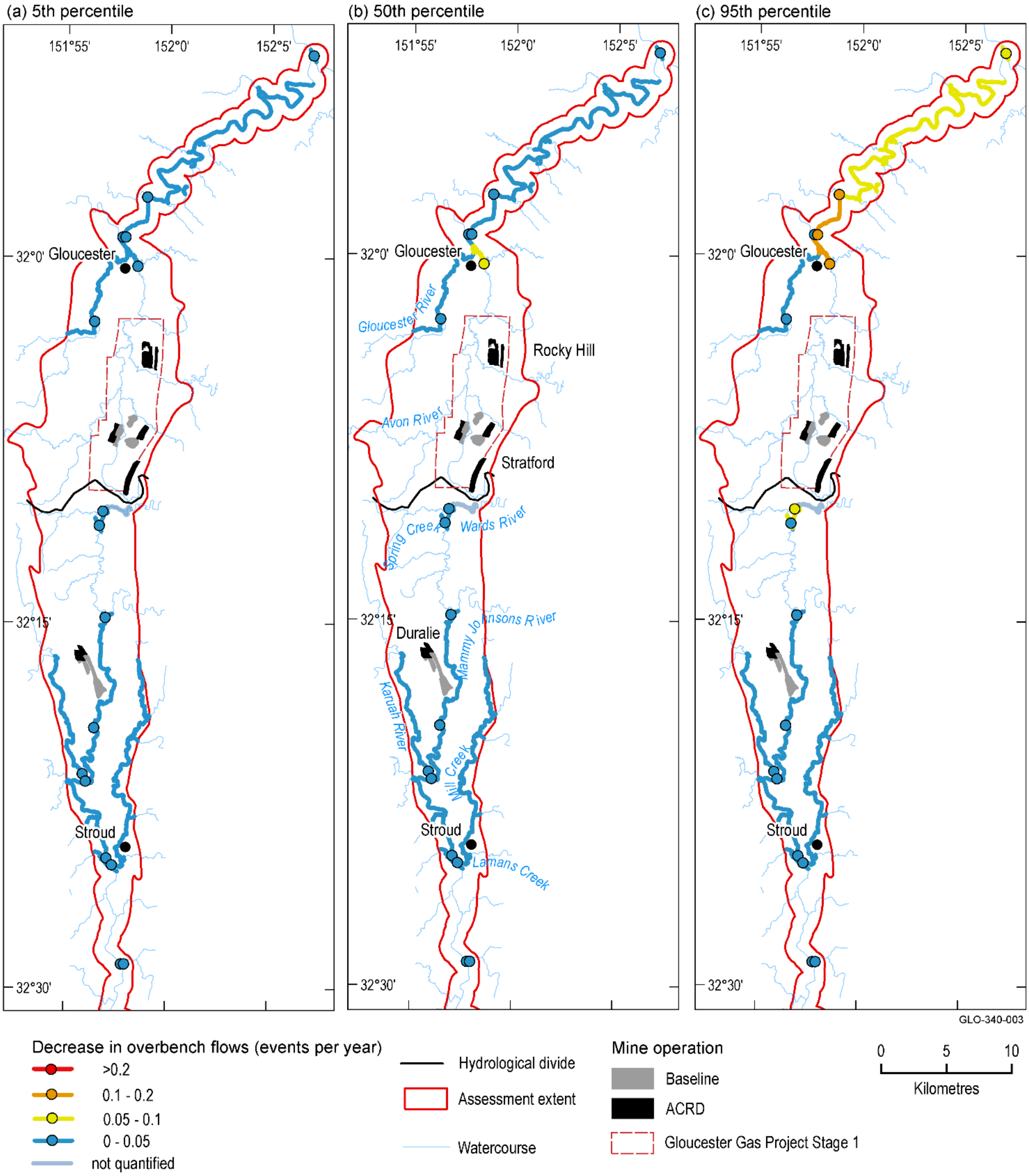

Figure 38 Modelled decrease in overbench flows in perennial gravel/cobble streams in 2042 in the zone of potential hydrological change

ACRD = additional coal resource development, CSG = coal seam gas
Data: Bioregional Assessment Programme (Dataset 1, Dataset 3, Dataset 8, Dataset 9)

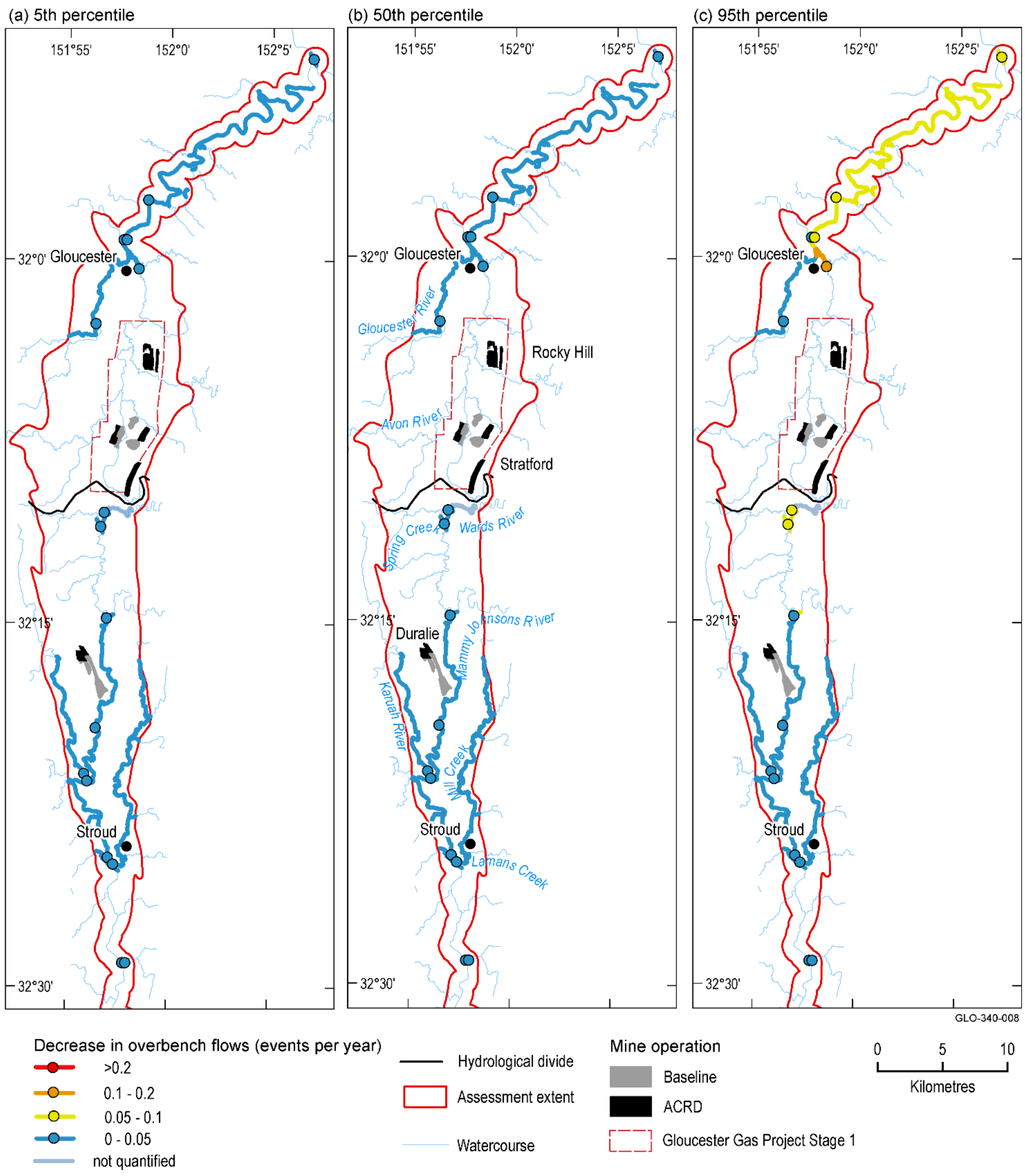

Figure 39 Modelled decrease in overbench flows in perennial gravel/cobble streams in 2102 in the zone of potential hydrological change

ACRD = additional coal resource development, CSG = coal seam gas

Data: Bioregional Assessment Programme (Dataset 1, Dataset 3, Dataset 8, Dataset 9)

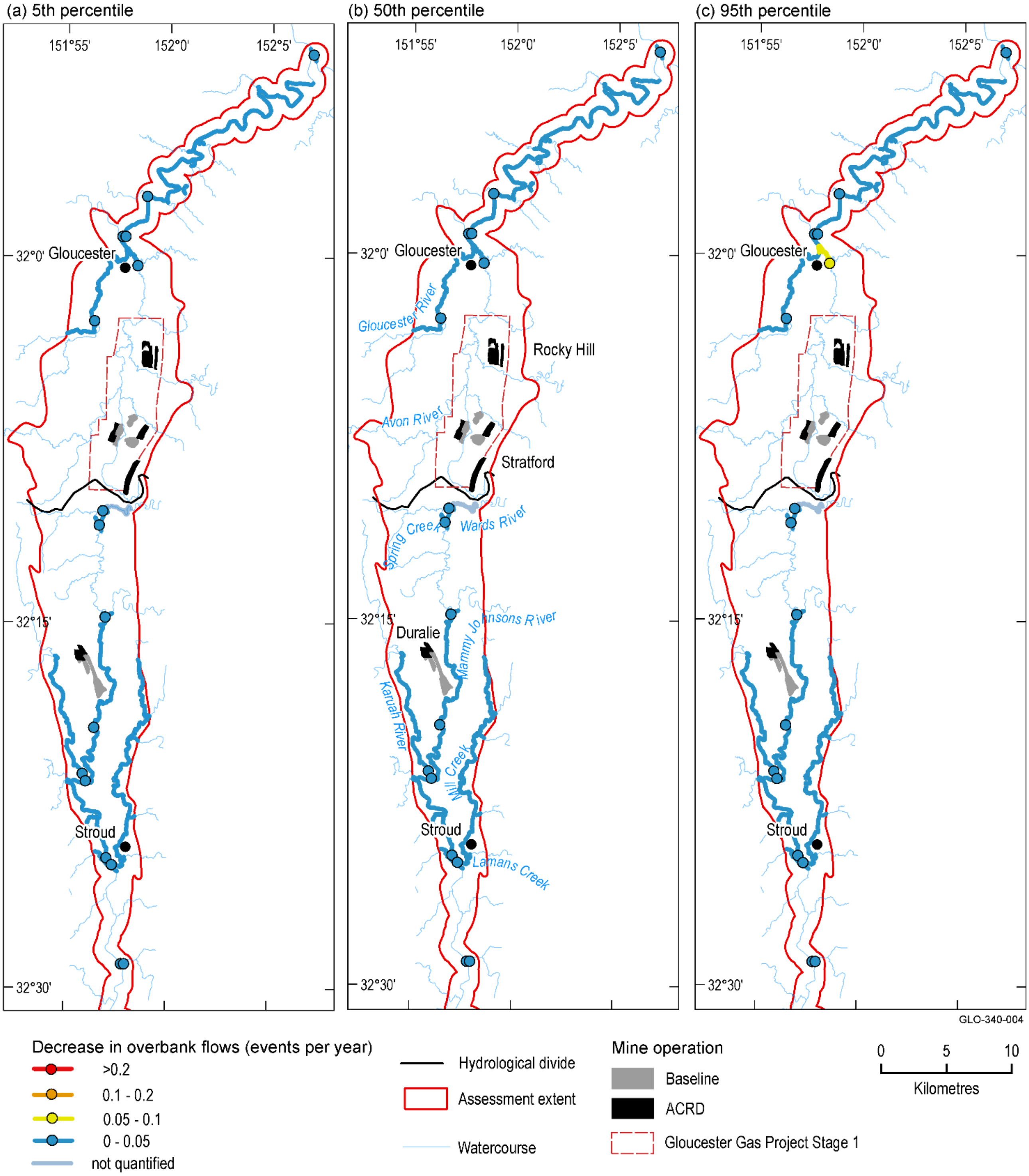

Figure 40 Modelled decrease in overbank flows in perennial gravel/cobble streams in 2042 in the zone of potential hydrological change

ACRD = additional coal resource development, CSG = coal seam gas
Data: Bioregional Assessment Programme (Dataset 1, Dataset 3, Dataset 8, Dataset 9)

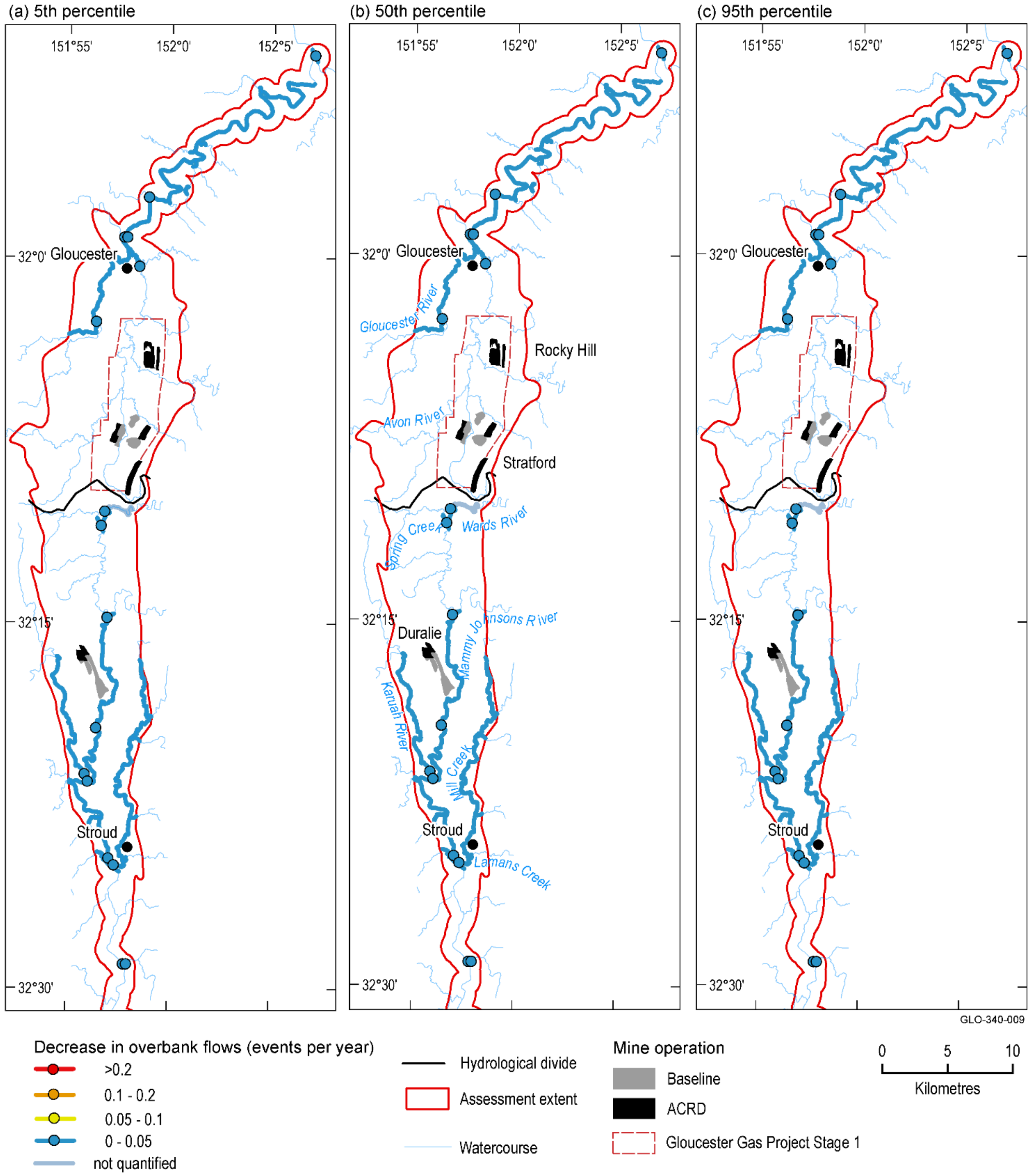

Figure 41 Modelled decrease in overbank flows in perennial gravel/cobble streams in 2102 in the zone of potential hydrological change

ACRD = additional coal resource development, CSG = coal seam gas
Data: Bioregional Assessment Programme (Dataset 1, Dataset 3, Dataset 8, Dataset 9)

Table 15 Cumulative stream length (km) of perennial – gravel/cobble streams potentially exposed to varying levels of drawdown (dmaxRef) due to additional coal resource development, in the year that the maximum decrease of groundwater occurs (tmaxRef)

Landscape class	Length in zone of potential hydrological change (km)	Length in mine pit exclusion zone (km)	Length with additional drawdown ≥0.2 m (km)			Length with additional drawdown ≥2 m (km)			Length with additional drawdown ≥5 m (km)		
			5th	50th	95th	5th	50th	95th	5th	50th	95th
Perennial – gravel/cobble streams	133	0.2	0.0	0.0	1.8	0	0	0	0	0	0

The area potentially exposed to ≥0.2, ≥2 and ≥5 m additional drawdown is shown for the 5th, 50th and 95th percentiles. Excludes areas within mine pit exclusion zones.
Data: Bioregional Assessment Programme (Dataset 1)

Table 16 Stream length (km) of perennial – gravel/cobble streams potentially exposed to varying baseflow index (QBFI) due to additional coal resource development, in the years 2042 and 2102

Year	Length with no change to QBFI (km)			Length with ≥0.01 decrease of QBFI (km)			Length with 0–0.01 decrease of QBFI (km)			Length with 0–0.01 increase of QBFI (km)			Length with ≥0.01 increase of QBFI (km)		
	5th	50th	95th	5th	50th	95th	5th	50th	95th	5th	50th	95th	5th	50th	95th
2042	14	34.7	21	0	0	0	0	0	46.3	73.5	59.8	34.2	0	0	0
2102	12	34.7	21	0	0	0	0	0	49.6	73.5	59.8	33	0	0	0

Stream length potentially exposed to no change, ≥0.01 decrease, 0–0.01 decrease, 0–0.01 increase, and ≥0.01 increase in baseflow index is shown for the 5th, 50th and 95th percentiles. Excludes stream length where the magnitude of the potential change could not be quantified.
Data: Bioregional Assessment Programme (Dataset 1)

Table 17 Cumulative stream length (km) of perennial – gravel/cobble streams potentially exposed to varying zero-flow days (ZQD) due to additional coal resource development, in the years 2042 and 2102

Year	Length with no change to ZQD (km)			Length with additional ZQD >0 days (km)			Length with additional ZQD ≥10 days (km)			Length with additional ZQD ≥50 days (km)			Length with additional ZQD ≥100 days (km)		
	5th	50th	95th	5th	50th	95th	5th	50th	95th	5th	50th	95th	5th	50th	95th
2042	94.5	94.5	86.6	0	0	7.9	0	0	0	0	0	0	0	0	0
2102	94.5	94.5	86.1	0	0	8.4	0	0	0	0	0	0	0	0	0

Stream length potentially exposed to no change, >0, ≥10, ≥50 and ≥100 days of additional zero-flow days is shown for the 5th, 50th and 95th percentiles. Excludes stream length where the magnitude of the potential change could not be quantified.
Data: Bioregional Assessment Programme (Dataset 1)

Table 18 Cumulative stream length (km) of perennial – gravel/cobble streams potentially exposed to varying overbench flow (EventsR0.3) due to additional coal resource development, in the years 2042 and 2102

Year	Length with no change to EventsR0.3 (km)			Length with >0 decrease of EventsR0.3 (km)			Length with ≥0.2 decrease of EventsR0.3 (km)			Length with ≥0.5 decrease of EventsR0.3 (km)			Length with ≥1 decrease of EventsR0.3 (km)		
	5th	50th	95th	5th	50th	95th	5th	50th	95th	5th	50th	95th	5th	50th	95th
2042	131.1	129.1	71.3	0	7.5	59.8	0	0	0	0	0	0	0	0	0
2102	131.1	129.1	71.3	0	2.0	59.8	0	0	0	0	0	0	0	0	0

Stream length potentially exposed to no change, >0, ≥0.2, ≥0.5 and ≥1 decrease in overbench flows per year is shown for the 5th, 50th and 95th percentiles. Excludes stream length where the magnitude of the potential change could not be quantified.
Data: Bioregional Assessment Programme (Dataset 1)

Table 19 Cumulative stream length (km) of perennial – gravel/cobble streams potentially exposed to varying overbank flow (EventsR3.0) due to additional coal resource development, in the years 2042 and 2102

Year	Length with no change to EventsR3.0 (km)			Length with >0 decrease of EventsR3.0 (km)			Length with ≥0.02 decrease of EventsR3.0 (km)			Length with ≥0.05 decrease of EventsR3.0 (km)			Length with ≥0.1 decrease of EventsR3.0 (km)		
	5th	50th	95th	5th	50th	95th	5th	50th	95th	5th	50th	95th	5th	50th	95th
2042	131.1	129.1	81.9	0	2.0	49.2	0	2	49.2	0	0	2.0	0	0	0
2102	131.1	131.1	114.9	0	0	16.2	0	0	16.2	0	0	0	0	0	0

Stream length potentially exposed to no change, >0, ≥0.02, ≥0.05 and ≥0.1 decrease in overbank flows per year is shown for the 5th, 50th and 95th percentiles. Excludes stream length where the magnitude of the potential change could not be quantified.
Data: Bioregional Assessment Programme (Dataset 1)

3.4.3.2.2 'Intermittent – gravel/cobble streams' landscape class

One surface water hydrological factor and associated hydrological response variable was identified for the 'Intermittent – gravel/cobble streams' landscape class, which is the mean number of days per year with zero streamflow during a 30-year period (ZQD). For details of this variable, the reader is referred to Section 2.7.3 of companion product 2.7 for the Gloucester subregion (Hosack et al., 2018b). The total length of intermittent gravel/cobble streams in the zone of potential hydrological change is 78 km. Of this, the 5th percentile and median estimates of stream length with an unknown impact resulting from additional coal resource development is 19 km and the 95th percentile estimates of stream length with an unknown impact is 29 km (Figure 42 and Figure 43). Based on the median estimates, it is likely that there will be little change in zero-flow days resulting from additional coal resource development. The median estimate of stream length with no change resulting from additional coal resource development is 52 km in the 30-year periods preceding both 2042 and 2102 (Table 20), which is almost the entire length of stream in the zone of potential hydrological change for which there is a quantifiable impact. In contrast, the 95th percentile estimate is that most of the stream length will experience an increase of up to 10 zero-flow days (Table 20), and in the 30-year period preceding 2102 it is predicted that 12 km of stream will have an increase of 10–50 zero-flow days.

Overall, modelling results suggest at least a 5% chance of increases in zero-flow days in short sections of the intermittent gravel/cobble streams as a result of additional coal resource development. Changes in zero-flow days along the intermittent gravel/cobble streams close to the Stratford and Rocky Hill mines, which were not modelled, cannot be ruled out. Local scale information is needed to determine the level of risk to instream and riparian habitats associated with these potentially impacted streams.

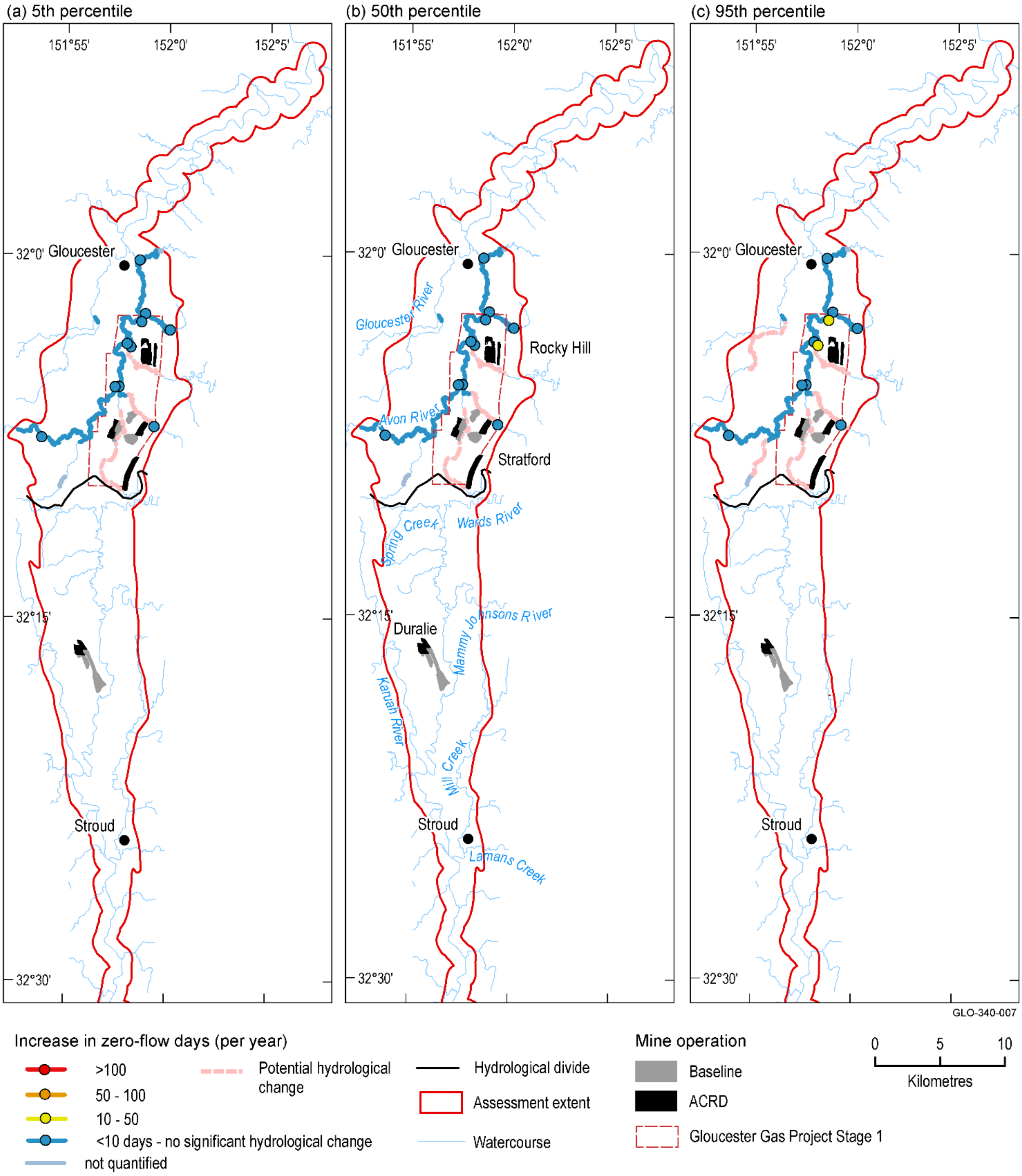

Figure 42 Modelled increase in zero-flow days in intermittent gravel/cobble streams in 2042 in the zone of potential hydrological change

ACRD = additional coal resource development, CSG = coal seam gas

Data: Bioregional Assessment Programme (Dataset 1, Dataset 3, Dataset 8, Dataset 9)

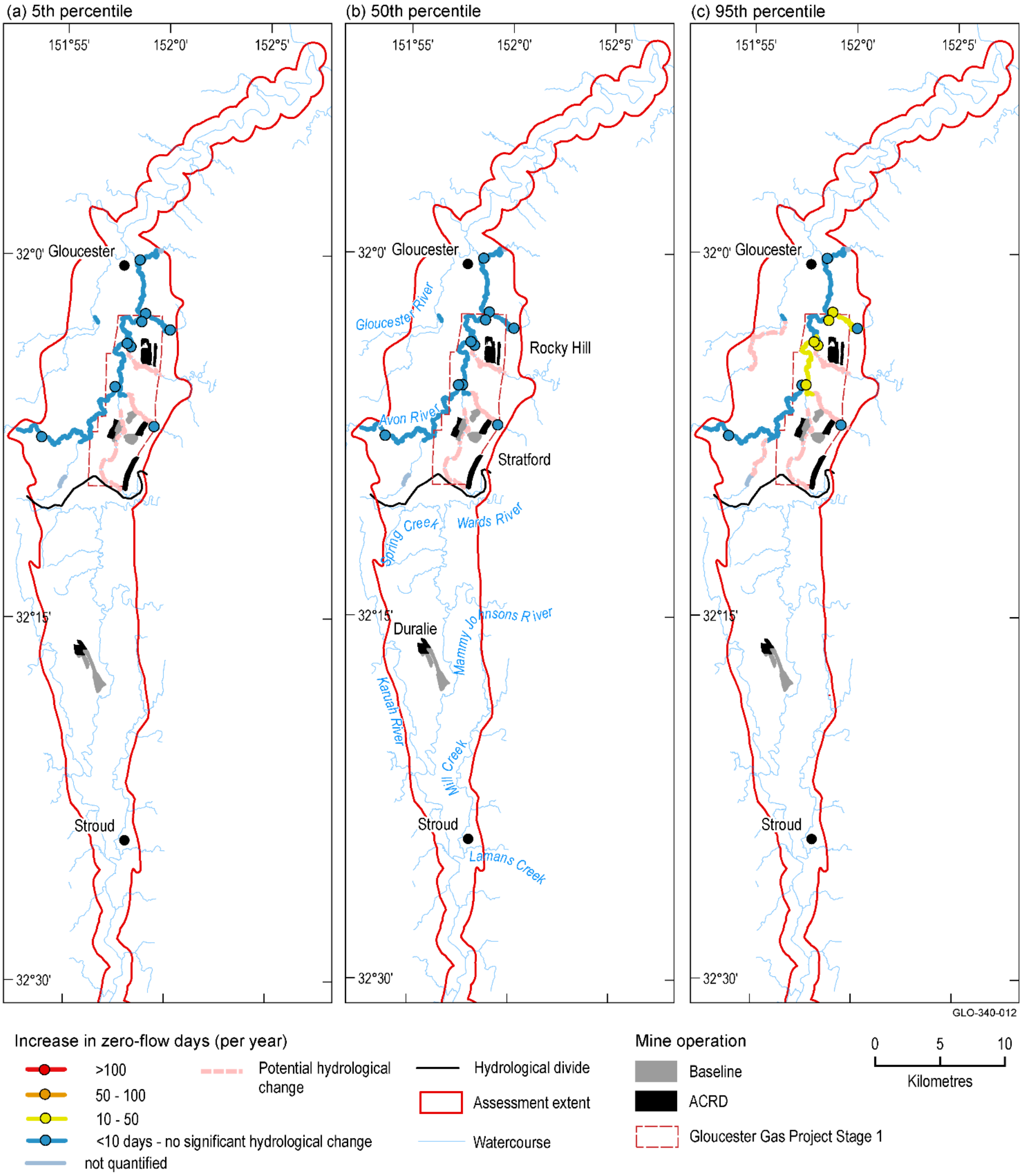

Figure 43 Modelled increase in zero-flow days in intermittent gravel/cobble streams in 2102 in the zone of potential hydrological change

ACRD = additional coal resource development, CSG = coal seam gas

Data: Bioregional Assessment Programme (Dataset 1, Dataset 3, Dataset 8, Dataset 9)

Table 20 Cumulative stream length (km) of intermittent – gravel/cobble streams potentially exposed to varying zero-flow days (ZQD) due to additional coal resource development, in the years 2042 and 2102

Year	Length with no change to ZQD (km)			Length with additional ZQD >0 days (km)			Length with additional ZQD ≥10 days (km)			Length with additional ZQD ≥50 days (km)			Length with additional ZQD ≥100 days (km)		
	5th	50th	95th	5th	50th	95th	5th	50th	95th	5th	50th	95th	5th	50th	95th
2042	53	52	9	0	1	34	0	0	1	0	0	0	0	0	0
2102	53	52	0	0	1	43	0	0	12	0	0	0	0	0	0

Stream length potentially exposed to no change, >0, ≥10, ≥50 and ≥100 days of additional zero-flow days is shown for the 5th, 50th and 95th percentiles. Excludes stream length where the magnitude of the potential change could not be quantified.
Data: Bioregional Assessment Programme (Dataset 1)

3.4.3.3 Potential ecosystem impacts

3.4.3.3.1 'Perennial – gravel/cobble streams' landscape class

The receptor impact models for perennial gravel/cobble streams identified potential relationships between the hydrological response variables described in Section 3.4.3.2 and three indicators of ecological condition:

- annual mean percent canopy cover of woody riparian vegetation (predominately *Casuarina cunninghamiana*, *Melia azedarach*, *Eucalyptus amplifolia* and *Angophora subvelutina*) in a transect 20 m wide and 100 m long covering the bottom of the stream bench to the high bank, to groundwater drawdown, and altered overbench and overbank flow
- mean number of larvae of the Hydropsychidae family (net-spinning caddisflies) in a 1 m^2 sample of riffle habitat, to changes in zero-flow days
- mean number of the eel-tailed catfish (*Tandanus tandanus*) in a 600 m^2 transect whose long axis lies along the mid-point of the stream, to changes in zero-flow days and the baseflow index.

There was great uncertainty surrounding absolute values of percent canopy cover in perennial gravel/cobble streams in the Gloucester assessment extent in both the baseline and coal resource development (CRDP) futures, and in the assessment years 2042 and 2102 (Figure 44). Estimates of percent canopy ranged from <10% to >90%. Median estimates of the percent canopy cover in the baseline and coal resource development futures ranged from approximately 40% to 50% (Figure 44).

There was no evidence that percent canopy cover would differ between the two futures for either the 5th percentile, median or 95th percentile estimates (Figure 44).

The 5th percentile and median estimates of percent canopy cover suggest that there would be little difference between the assessment years 2042 and 2102 (Figure 44). The 95th percentile estimate suggests that percent canopy cover could be approximately 5% smaller in 2102 than in 2042.

There was great uncertainty surrounding absolute numbers of Hydropsychidae larvae in 1 m^2 of perennial gravel/cobble streams in the Gloucester assessment extent in both the baseline and coal resource development futures, and in the assessment years 2042 and 2102 (Figure 45). Estimates of numbers of Hydropsychidae larvae ranged from <20 to >600 per 1 m^2. Median estimates of the number of Hydropsychidae larvae per 1 m^2 in the baseline and coal resource development futures ranged from approximately 100 to 180 (Figure 45).

There was no evidence that the number of Hydropsychidae larvae per 1 m^2 would differ between the two futures for either the 5th percentile, median or 95th percentile estimates (Figure 45).

The 5th percentile, median and 95th percentile estimates suggest that the number of Hydropsychidae larvae per 1 m^2 could be approximately 10% to 30% larger in 2102 than in 2042 (Figure 45).

There was great uncertainty surrounding absolute numbers of eel-tailed catfish per 600 m transect of perennial gravel/cobble streams in the Gloucester assessment extent in both the baseline and coal resource development futures, and in the assessment years 2042 and 2102 (Figure 46). Estimates of numbers of eel-tailed catfish ranged from <1 to >50 per 600 m transect. Median estimates of the number of eel-tailed catfish per 600 m transect in the baseline and coal resource development futures ranged from approximately 4 to 6 (Figure 46).

There was no evidence that the number of eel-tailed catfish per 600 m transect would differ between the two futures for either the 5th percentile, median or 95th percentile estimates (Figure 46).

The 5th percentile and median estimates suggest that the number of eel-tailed catfish per 600 m transect would be no different in 2102 than in 2042 (Figure 46). The 95th percentile estimate suggests that the number of eel-tailed catfish per 600 m transect could be approximately 20% smaller in 2102 than in 2042.

Overall, the modelled results suggest little detectable change to the condition of perennial gravel/cobble streams in the Gloucester subregion owing to additional coal resource development but that there is very high uncertainty surrounding estimates. This is consistent with the small modelled changes in groundwater drawdown, overbench flow, overbank flow, zero-flow days and baseflow index described in Section 3.4.3.2.1.

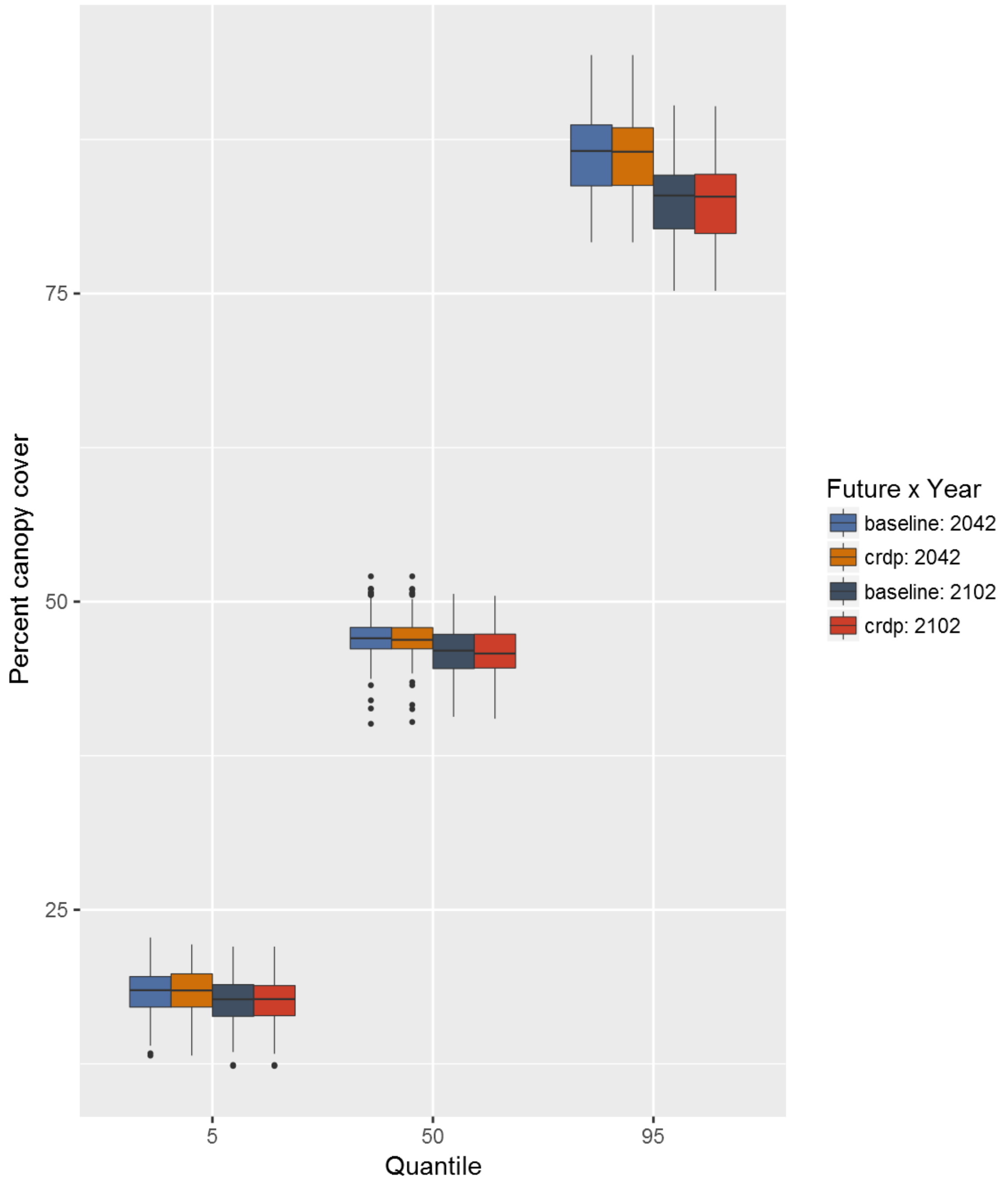

Figure 44 Boxplot summary of the distribution of 5th, 50th and 95th quantiles for modelled percent canopy cover (pcc) across the 'Perennial – gravel/cobble streams' landscape class under both baseline and coal resource development (CRDP) futures and in the assessment years 2042 and 2102

Data: Bioregional Assessment Programme (Dataset 1, Dataset 12)

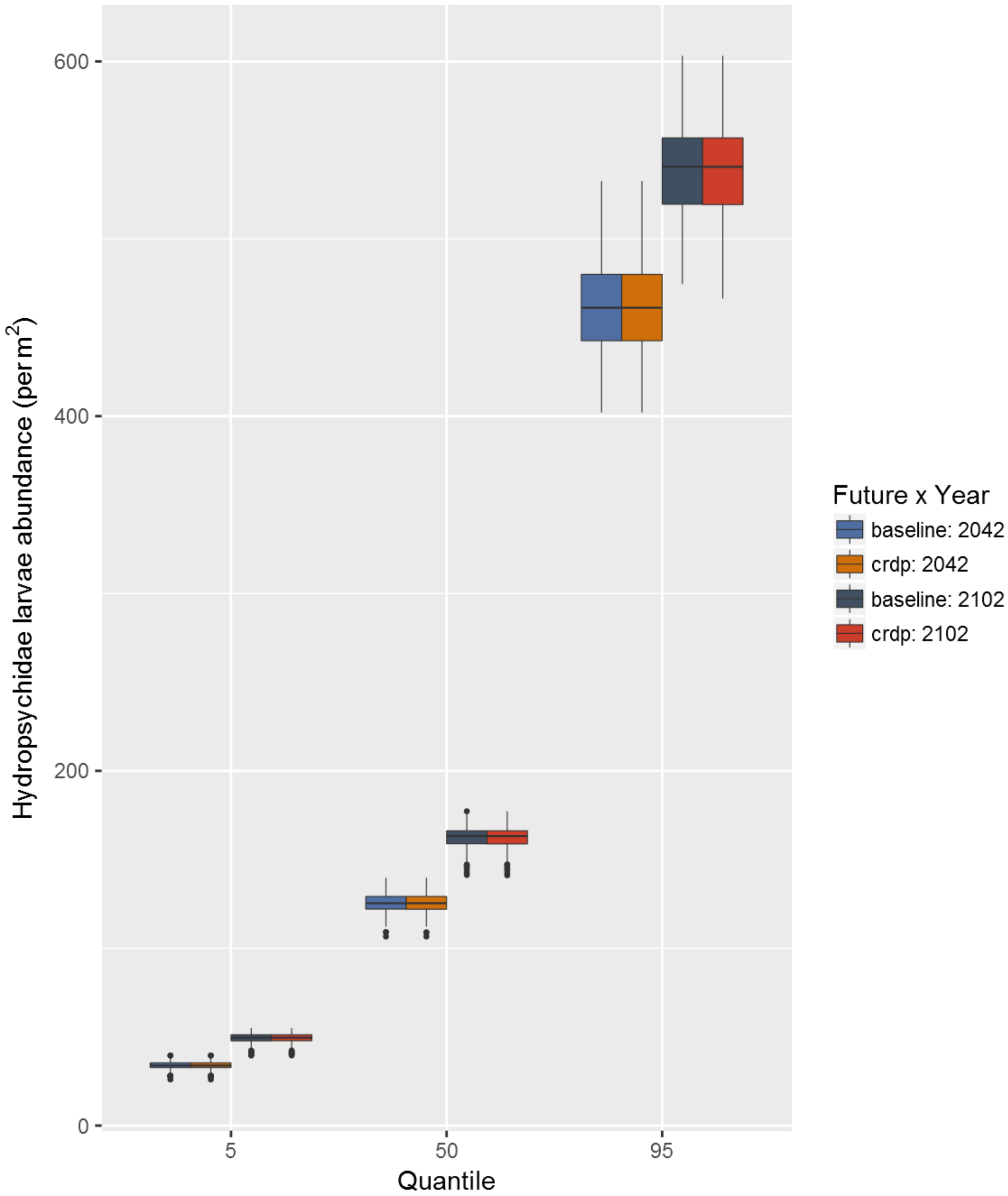

Figure 45 Boxplot summary of the distribution of 5th, 50th and 95th quantiles for modelled hydropsychidae larval abundance (hla) across the 'Perennial – gravel/cobble streams' landscape class under both baseline and coal resource development (CRDP) futures and in the assessment years 2042 and 2102

Data: Bioregional Assessment Programme (Dataset 1, Dataset 12)

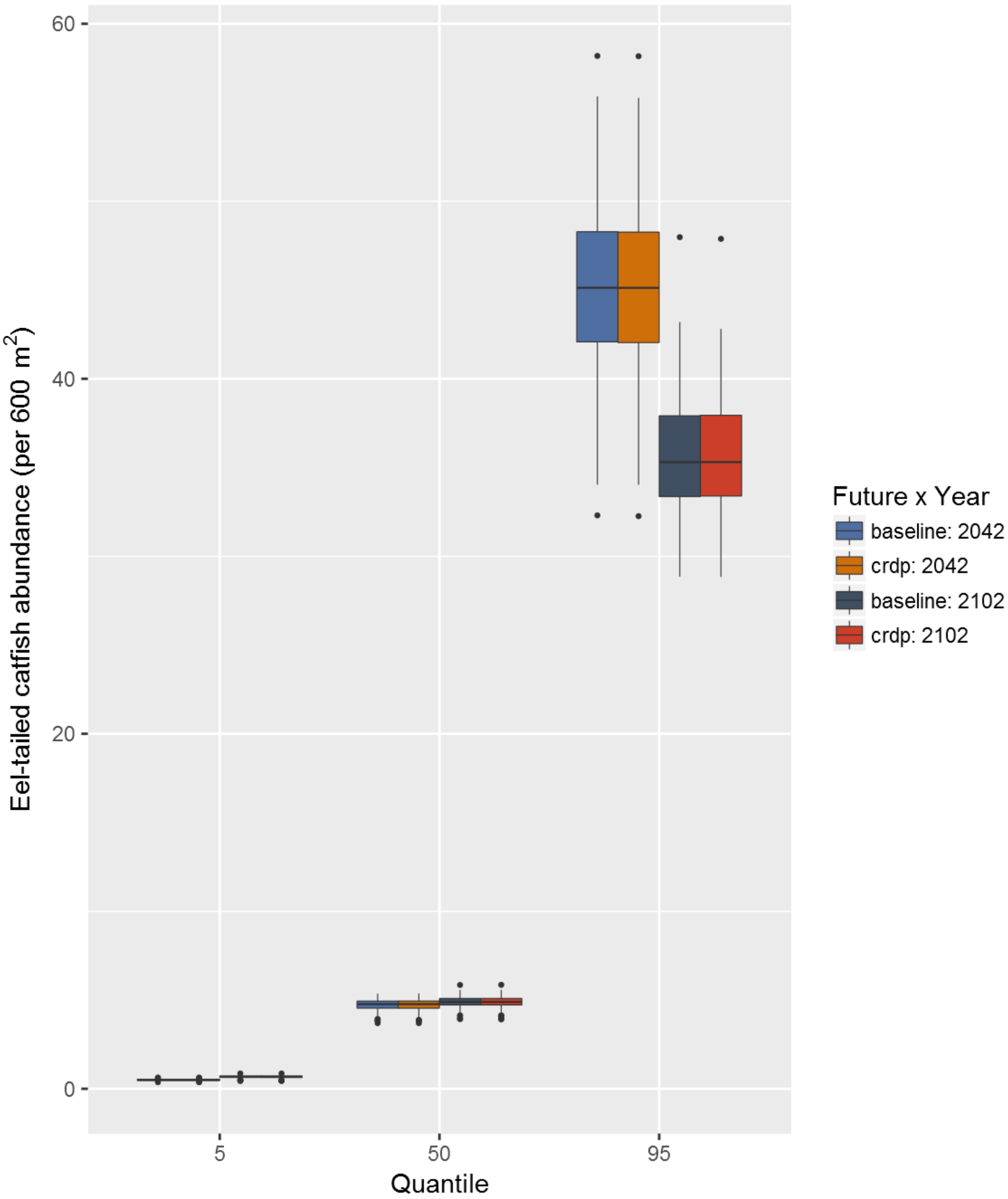

Figure 46 Boxplot summary of the distribution of 5th, 50th and 95th quantiles for modelled eel-tailed catfish abundance (eca) across the 'Perennial – gravel/cobble streams' landscape class under both baseline and coal resource development (CRDP) futures and in the assessment years 2042 and 2102

Data: Bioregional Assessment Programme (Dataset 1, Dataset 12)

3.4.3.3.2 'Intermittent – gravel/cobble streams' landscape class

The receptor impact model for intermittent gravel/cobble streams focused on the relationship of mean richness of 'hyporheic invertebrate taxa (HTR) in 6 L of water pumped from a depth of 40 cm below the streambed (riffle and gravel bars)' to changes in zero-flow days (ZQD) as an indicator of ecological condition.

There was great uncertainty surrounding absolute values of hyporheic invertebrate taxa richness in intermittent gravel/cobble streams in the Gloucester assessment extent in both the baseline and coal resource development futures, and in the assessment years 2042 and 2102 (Figure 47). Estimates of hyporheic invertebrate taxa richness ranged from <10 to >35 taxa in 6 L of water pumped from a depth of 40 cm below the streambed (riffle and gravel bars). Median estimates of hyporheic invertebrate taxa richness in the baseline and coal resource development futures ranged from approximately 13 to 15 (Figure 47).

There was no evidence that values of hyporheic invertebrate taxa richness would differ between the two futures for either the 5th percentile, median or 95th percentile estimates (Figure 47).

The median estimate suggests that hyporheic invertebrate taxa richness would be no different in 2102 than in 2042 (Figure 47). The 5th percentile estimate suggests that hyporheic invertebrate taxa richness could be approximately 30% smaller in 2102 than in 2042, while the 95th percentile estimate suggests that hyporheic invertebrate taxa richness could be approximately 35% larger in 2102 than in 2042 (Figure 47).

Overall, the modelled results suggest little detectable impact on the condition of intermittent gravel/cobble streams in the Gloucester subregion due to additional coal resource development but that there is very high uncertainty surrounding estimates. This is consistent with the small modelled changes in zero-flow days described in Section 3.4.3.2.2.

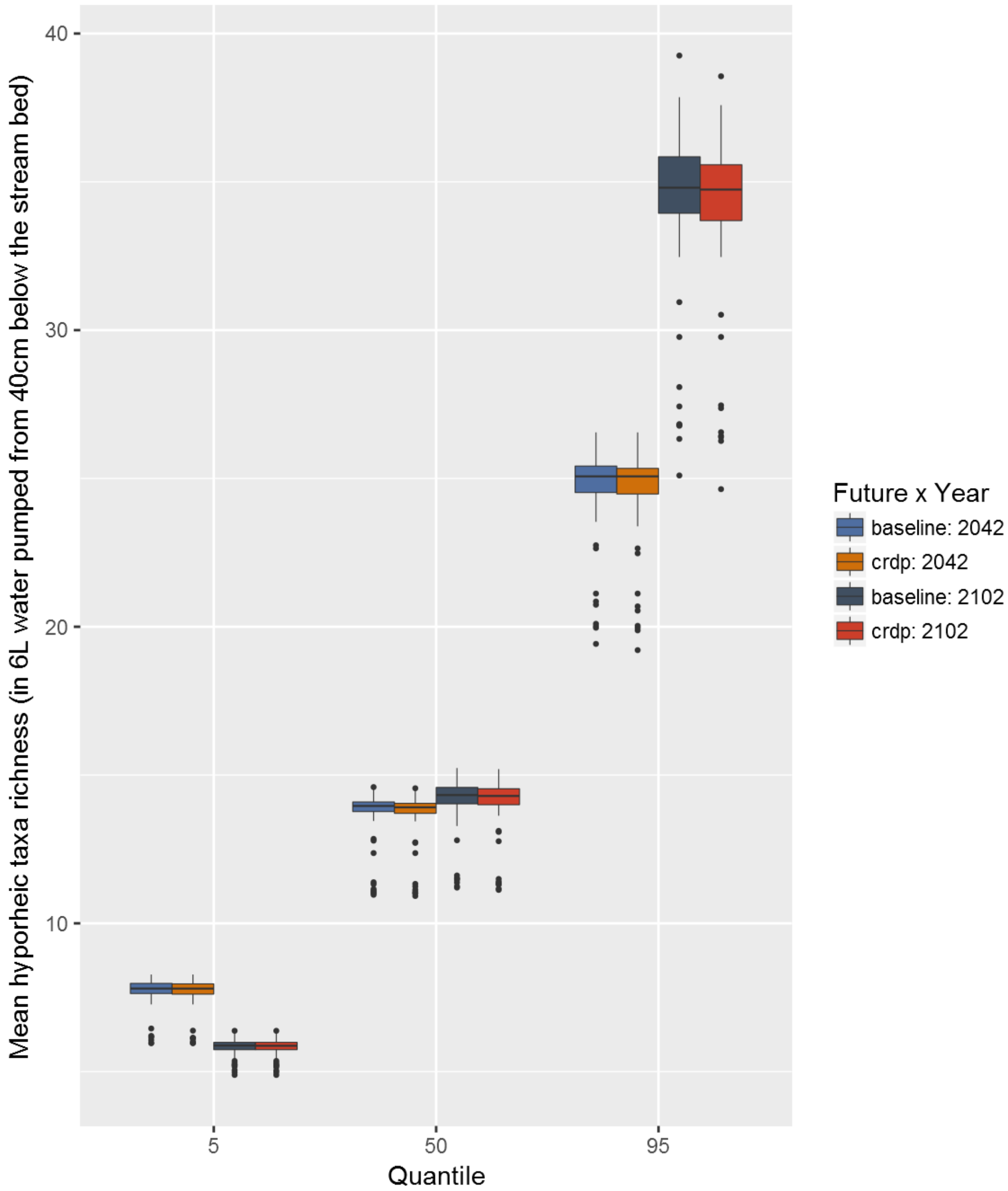

Figure 47 Boxplot summary of the distribution of 5th, 50th and 95th quantiles for modelled hyporheic taxa richness (htr) abundance (eca) across the 'Intermittent – gravel/cobble streams' landscape class under both baseline and coal resource development (CRDP) futures and in the assessment years 2042 and 2102

Data: Bioregional Assessment Programme (Dataset 1, Dataset 12)

3.4.4 'Groundwater-dependent ecosystem (GDE)' landscape group

3.4.4.1 Description

Groundwater-dependent ecosystems (GDEs) are those that rely on the surface or subsurface expression of groundwater to meet all or some of their life-cycle requirements (Eamus et al., 2006). The dependence of GDEs on groundwater varies both spatially and temporally (Eamus et al., 2006). Ecosystems may be obligate GDEs, with a continuous or entire dependence on groundwater, or facultative GDEs, with an infrequent or partial dependence on groundwater (Zencich et. al., 2002). Plants that depend solely on moisture held within the soil profile are known as vadophytes and are not groundwater dependent (Sommer and Froend, 2010). In the Gloucester subregion, as in much of Australia, there is considerable uncertainty as to the nature of groundwater dependency for much terrestrial vegetation. The hydroclimatic environment of the Gloucester subregion is subtropical. Annual rainfall ranges from about 960 to 1400 mm/year, and is highest in summer when potential evaporation is also highest (companion product 1.1 for the Gloucester subregion (McVicar et al., 2014). Nonetheless, the region is still classified as being water limited inasmuch as potential evaporation (1400 to 1700 mm/year) exceeds rainfall in most months of the year. Rainfall is also highest along the margins of the subregion because this area is associated with the higher elevation regions, whereas the deficit of rainfall, relative to potential evaporation, is greater throughout much of the lowland areas of the subregion. The Gloucester Basin underlies the Gloucester subregion and is characterised as a closed hydrogeological system. Thus, water entering the system must leave as either surface water or groundwater discharge (companion product 2.3 for the Gloucester subregion (Dawes et al., 2018)). Groundwater recharge is estimated as up to 17% of rainfall under steady-state conditions and up to 28% of rainfall under transient conditions, with high values associated with alluvial aquifers (companion product 1.1 for the Gloucester subregion (McVicar et al., 2014)). This combination of rainfall deficit and surface water and groundwater recharge creates the potential for GDEs to exist within the Gloucester subregion.

The subregion has three main hydrogeological units (companion product 1.1 for the Gloucester subregion (McVicar et al., 2014)) relevant to sustaining GDE structure and function, which provide a useful conceptual framework for examining landscape classes dependent on groundwater:

- alluvial aquifers along major creek lines
- relatively shallow weathered/fractured rock aquifers
- impermeable Alum Mountain Volcanics that underlie these hydrogeological units.

The geomorphology of the Gloucester subregion has been described in detail elsewhere (companion product 1.1 (McVicar et al., 2014); companion product 2.3 (Dawes et al., 2018) for the Gloucester subregion), and only a brief summary is presented here as context (Figure 48). The Quaternary alluvial aquifers are developed in proximity to the rivers. Soils in these alluvial deposits are dominated by Tenosols and are composed of clay layers and highly permeable sediments with high hydraulic conductivities (up to 500 m/day). The thickness of the alluvia varies from 9 to 15 m and the watertable is shallow and responsive to rainfall and flood events close to the river.

The Permian fractured rock and weathered zone is up to 150 m thick. It underlies the alluvial system and extends to the edges of the subregion. These shallow-rock hydrogeological units are composed of interbedded sandstone, silt and claystone. Generally, hydraulic conductivities of these aquifers are low with a sluggish response to rainfall. However, these hydraulic conductivities are highly variable as a result of fracturing and fault zones within the formation. Soils of the fractured rock and weathered zone tend to be dominated by Kurosols. Typically, these soils have a sharp, abrupt boundary between the upper coarser-textured ‘A horizon’ and the finer-textured ‘B horizon’, which may provide a pathway for subsurface lateral flows of water.

The outcropping Alum Mountain Volcanics formations are generally considered to be impermeable but localised fractures may provide pathways for localised groundwater flow paths (companion product 1.1 for the Gloucester subregion (McVicar et al., 2014)). These may be expressed as springs along the margins of the basin, driven by localised circulation of meteoric water.

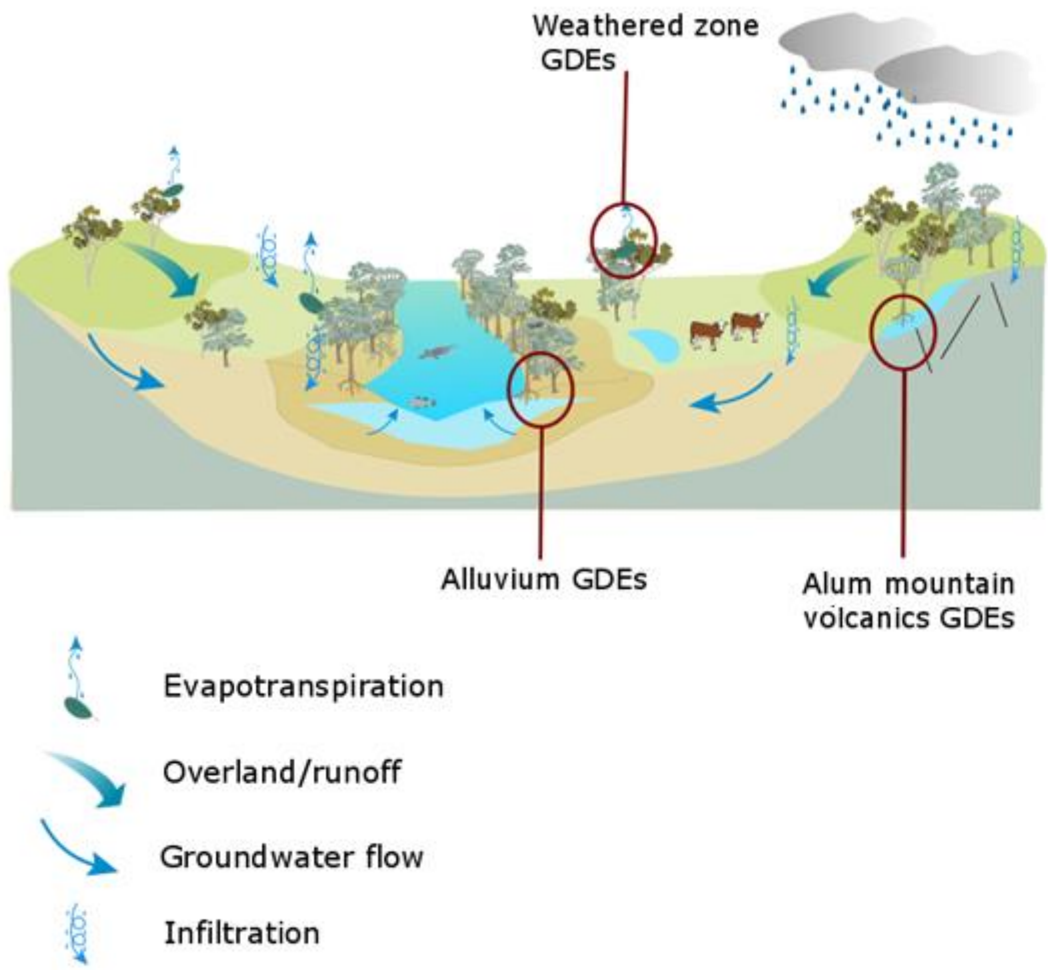

Figure 48 Conceptual model of the major groundwater processes in the Gloucester Basin

GDE = groundwater-dependent ecosystem

The water requirements of GDEs are poorly understood and there is large uncertainty as to the frequency, timing and duration of groundwater use within the Gloucester subregion. In general, transpiration of groundwater is expected to decline as the depth to groundwater increases, but there is very limited evidence to support this assumption within Australia. O'Grady et al. (2010) reviewed estimates of groundwater discharge in Australia and concluded that there is considerable variation in the relationship between transpiration of groundwater and depth to groundwater. Factors such as the rooting depth of a particular species (which is usually not known), hydroclimatic environment and groundwater salinity all impact on groundwater use by vegetation. Zolfaghar et al. (2014) examined the structure and productivity of eucalypt forest across a depth-to-watertable gradient in the upper Nepean catchment in NSW. They found that where groundwater was shallow, vegetation had significantly higher biomass and productivity than sites where groundwater was deeper than approximately 10 m. The relationships between depth to groundwater and the structural and functional attributes of the vegetation communities were highly non-linear, with steep declines in leaf area index and biomass over a range of 5 to 10 m depth to groundwater. However, it is important to note that the study was largely correlative in nature and did not quantify the groundwater requirements of the vegetation. Specific studies of GDEs within the Gloucester subregion are limited. Existing mapping of GDEs is based on a multiple-lines-of-evidence approach that incorporated existing vegetation mapping, modelled groundwater levels and remote sensing (Kuginis et al., 2012). Modelled depths to groundwater (Summerell and Mitchell, 2011) for the subregion are generally shallow (within 16 m of the ground surface). However, there is likely to be uncertainty in the mapping and this is indicated by relatively shallow groundwater modelled within the bordering Alum Mountain Volcanics.

Of the five GDE landscape classes that were identified as likely to be groundwater dependent, four were present in the zone of potential hydrological change: 'Forested wetlands', 'Wet sclerophyll forests', 'Rainforests' and 'Dry sclerophyll forests'. GDEs occur within each of the three hydrogeological units described previously but they are predominantly associated with the weathered/fractured rock zone and alluvial aquifers (Table 21). Few GDEs are present above the Alum Mountain Volcanics.

Table 21 Area of groundwater-dependent ecosystem landscape classes within each of three hydrogeological units across the assessment extent

Landscape class	Alluvium (ha)	Weathered/fractured rock zone (ha)	Alum Mountain Volcanics (ha)
Dry sclerophyll forests	0.8	19	0.1
Forested wetlands	60	138	6.9
Rainforests	80	61	3.3
Wet sclerophyll forests	0	12	5.8

The wet sclerophyll forests of NSW occur on moderately fertile soils in high rainfall areas, and are characterised by a tall, open, sclerophyllous tree canopy and a luxuriant understorey of soft-leaved, mesophyllous, shrubs, ferns and herbs. Many understorey plants are rainforest species or have close rainforest relatives. Rainforests may be embedded within a matrix of wet sclerophyll forest and the two often blend together as intermediate forms. More than 30% crown cover of emergent, non-rainforest species (including eucalypts, brushbox and turpentine) results in a classification of wet sclerophyll forest rather than rainforest (DECC, 2007). As discussed in

Section 2.7.2 of companion product 2.7 for the Gloucester subregion (Hosack et al., 2018b), a single conceptual model was developed for both the 'Wet sclerophyll forests' and 'Rainforests' landscape classes in the Gloucester subregion. The main vegetation communities are described in Table 22.

Table 22 Main vegetation communities within the 'Wet sclerophyll forests', 'Rainforests' and 'Dry sclerophyll forests' landscape classes

Vegetation community	Source
North coast wet sclerophyll forests have a subdominant stratum of mesophyllous small trees or tall shrubs up to 15 m tall and a second understorey layer of mesophyllous shrubs above a continuous ground stratum of ferns and herbs. Vines are also present on shrubs and smaller trees. They occur both in coastal ranges and foothills, and on alluvium in sheltered creek flats. They grade into both northern hinterland forests (with decreasing shelter or moisture) and subtropical rainforests (with increasing shelter, moisture or fertility). Dominant canopy species include *Eucalyptus acmenioides* (white mahogany), *E. microcorys* (tallowwood), *E. pilularis* (blackbutt), *E. saligna* (Sydney blue gum), *Lophostemon confertus* (brush box) and *Syncarpia glomulifera* (turpentine) which occur in various combinations.	NSW Office of Environment and Heritage (n.d. a)
Northern warm temperate rainforests consist of closed forest up to 30 m tall, generally lacking emergents. The canopy comprises 4–15 species but is dominated by *Acmena smithii* (lilly pilly), Ceratopetalum apetalum (coachwood) and *Doryphora sassafras* (sassafras). It occurs in sheltered gullies and slopes in the hilly-to-steep terrain of the coast and escarpment on moderately fertile soils in high rainfall areas, extending above 1000 m in elevation, on granites, rhyolites, syenites or sedimentary substrates that yield acid soils with moderate levels of nutrients. Occasional lianas and epiphytes, open shrub/sapling stratum and variable fern/herb groundcover amongst copious leaf litter. Mosses, liverworts and lichens may be conspicuous on tree trunks or the forest floor.	NSW Office of Environment and Heritage (n.d. b)
Hunter-Macleay dry sclerophyll forests are dry open eucalypt forests to 30 m tall that are associated with the major coastal river valleys along the NSW coast. They have a mixed sclerophyll and mesophyll shrub stratum, and grassy ground layer. They occur below 400 m elevation in foothills and undulating terrain in rain-shadow valleys, on well-drained loams derived from shales. Main overstorey species include *Corymbia maculata* (spotted gum), *Eucalyptus crebra* (narrow-leaved ironbark), *E. moluccana* (grey box), *E. propinqua* (grey gum), *E. siderophloia* (grey ironbark) and *Syncarpia glomulifera* (turpentine).	NSW Office of Environment and Heritage (n.d. c)

Qualitative mathematical models for the 'Dry sclerophyll forests' and 'Forested wetlands' and 'Wet sclerophyll forests' landscape classes are presented in Section 2.7.4 of companion product 2.7 for the Gloucester subregion (Hosack et al., 2018b)).

3.4.4.2 Potential hydrological change

The area of GDE landscape classes within the zone of potential hydrological change is 3.2 km^2 of which 0.4 km^2 is in the mine pit exclusion zone (Table 23). Of the remaining 2.8 km2 of GDEs, 1.2 km^2 is potentially subject to groundwater drawdown of more than 0.2 m under the baseline future based on the 95th percentile, compared to 0.6 km^2 based on the 50th percentile and 0.4 km^2 based on the 5th percentile (Table 23). The majority of the GDE area potentially subjected to groundwater drawdown under the baseline future is forested wetland. The majority of the GDE area potentially subjected to groundwater drawdown under the baseline future is subject to a drawdown of less than 2 m; 0.3 km^2 of forested wetland is potentially subject to a drawdown of 2 to 5 m under the baseline future.

Of GDEs, 1.1 km^2 is potentially subject to additional groundwater drawdown as a result of additional coal resource development based on the 95th percentile, compared to 0.5 km^2 based on the 50th percentile and 0.1 km^2 based on the 5th percentile (Table 24). The majority of the GDE area potentially subjected to additional groundwater drawdown is in the 'Forested wetlands' landscape class. No rainforest GDE is potentially subject to additional groundwater drawdown. All of the GDE area potentially subjected to additional groundwater drawdown is subject to a drawdown of less than 2 m.

3.4.4.3 Potential ecosystem impacts

Based on the modelling of the 95th percentile presented in Table 23 and Table 24, it was concluded that approximately an additional 1.1 km^2 of GDEs would be subjected to a groundwater drawdown of greater than 0.2 m but less than 2 m, and that most of the impact would be in the 'Forested wetlands' landscape class. As noted in Section 3.4.4.1, the water requirements of GDEs are poorly understood and there is large uncertainty as to the frequency, timing and duration of groundwater use within the Gloucester subregion. In general, transpiration of groundwater is expected to decline as the depth to groundwater increases, but the relationships between depth to groundwater and the structural and functional attributes of the vegetation communities are highly non-linear, with steep declines in leaf area index and biomass over a range of 5 to 10 m depth to groundwater.

Hence, for the 'GDE' landscape group in the Gloucester subregion, qualitative mathematical models of the 'Forested wetlands', 'Wet sclerophyll forest' and 'Dry sclerophyll forest' landscape classes were developed to make qualitative predictions about the impact of coal resource development on GDEs (see Sections 2.7.4.2, 2.7.4.3 and 2.7.4.4 of companion product 2.7 for the Gloucester subregion (Hosack et al., 2018b) for details of the models). GDE vegetation may form habitat for several threatened plant species included in the Gloucester subregion asset register (see companion product 1.3 for the Gloucester subregion (McVicar et al., 2015); Bioregional Assessment Programme, 2017; Bioregional Assessment Programme, Dataset 11), including the Charmhaven apple (*Angophora inopina*), white-flowered wax plant (*Cynanchum elegans*), leafless tongue orchid (*Cryptostylis hunteriana*), slaty redgum (*Eucalyptus glaucina*) and trailing woodruff (*Asperula asthenes*). In addition, GDE vegetation can form habitat for a range of vertebrate and invertebrate fauna. Examples of vertebrate fauna from the Gloucester subregion asset register listed under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) that might use GDE vegetation, either for habitat or feeding, include the grey-headed flying-fox (*Pteropus poliocephalus*), red goshawk (*Erythrotriorchis radiatus*), regent honeyeater (*Anthochaera phrygia*), swift parrot (*Lathamus discolor*), giant barred frog (*Mixophyes iteratus*), stuttering frog (*Mixophyes balbus*), Hastings River mouse (*Pseudomys oralis*) and the koala (*Phascolarctos cinereus*). Riparian vegetation, in particular, provides migration corridors for aquatic and terrestrial fauna and habitat for a range of threatened species, such as the spot-tailed quoll (*Dasyurus maculatus* ssp. *maculatus*).

Table 23 Area (km²) of groundwater-dependent ecosystem (GDE) landscape classes potentially exposed to varying levels of baseline drawdown in the zone of potential hydrological change

Landscape class	Area in zone of potential hydrological change (km²)	Area in mine pit exclusion zone (km²)	Area with baseline drawdown ≥0.2 m (km²)			Area with baseline drawdown ≥2 m (km²)			Area with baseline drawdown ≥5 m (km²)		
			5th	50th	95th	5th	50th	95th	5th	50th	95th
Dry sclerophyll forests	0.2	0.0	0.0	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Forested wetlands	2.0	0.4	0.3	0.4	0.8	0.0	0.0	0.3	0.0	0.0	0.0
Rainforests	0.9	0.0	0.0	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Wet sclerophyll forests	0.2	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Total	**3.2**	**0.4**	**0.4**	**0.6**	**1.2**	**0.0**	**0.0**	**0.3**	**0.0**	**0.0**	**0.0**

The area potentially exposed to ≥0.2, ≥2 and ≥5 m baseline drawdown is shown for the 5th, 50th and 95th percentiles. Baseline drawdown is the maximum difference in drawdown (*dmax*) under the baseline relative to no coal resource development. Areas within mine pit exclusion zones are excluded from further analysis.
Due to rounding, some totals may not correspond with the sum of the separate numbers.
Data: Bioregional Assessment Programme (Dataset 1)

Table 24 Area (km²) of groundwater-dependent ecosystem (GDE) landscape classes potentially exposed to varying levels of drawdown due to additional coal resource development

Landscape class	Area in zone of potential hydrological change (km²)	Area in mine pit exclusion zone (km²)	Area with additional drawdown ≥0.2 m (km²)			Area with additional drawdown ≥2 m (km²)			Area with additional drawdown ≥5 m (km²)		
			5th	50th	95th	5th	50th	5th	50th	95th	95th
Dry sclerophyll forests	0.2	0.0	0.1	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Forested wetlands	2.0	0.4	0.0	0.3	0.8	0.0	0.0	0.0	0.0	0.0	0.0
Rainforests	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wet sclerophyll forests	0.2	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Total	**3.2**	0.4	0.1	0.5	1.1	0.0	0.0	0.0	0.0	0.0	0.0

The area potentially exposed to ≥0.2, ≥2 and ≥5 m baseline drawdown is shown for the 5th, 50th and 95th percentiles. Additional drawdown is the maximum difference in drawdown (*dmax*) due to additional coal resource development relative to the baseline. Areas within mine pit exclusion zones are excluded from further analysis.
Data: Bioregional Assessment Programme (Dataset 1)

The models (summarised in Table 25) predicted decreases in all vegetation-related variables, including overstorey and understorey (ground layer) cover, and recruitment. Forest habitats and nectar production were also expected to be negatively impacted, while fragmentation was predicted to increase. This was predicted to have negative impacts on populations of arboreal mammals, including koalas but not flying foxes, as well as nocturnal raptors and aggressive native honeyeaters. The impact of hydrological changes on flying foxes, regent honeyeaters, swift parrots and diurnal raptors was uncertain. Although the conclusions from this modelling are qualitative, and therefore highly uncertain, it is reasonable to assume that any ecosystem impacts will be greatest where the groundwater drawdown is greatest in the immediate vicinity of resource development. The impacts on assets associated with these landscape classes are further assessed in Section 3.5.2.

Table 25 Predicted response of the signed digraph variables in the 'GDE' landscape group to cumulative changes in hydrological response variables

Signed digraph variable		Forested wetlands	Wet sclerophyll forest	Wet sclerophyll forest	Dry sclerophyll forest	Dry sclerophyll forest	Summary of all models
Full name	Short form	C1	C1 model 1	C1 model 2	C1 model 1	C1 model 2	
Diurnal raptor	DR	?	?	?	?	?	?
Nocturnal raptor	NR	–	–	–	–	–	–
Aggressive native honeyeaters	ANHE	–	–	–	–	–	–
Swift parrot	SP	?	?	?	?	?	?
Regent honeyeater	RHE	?	?	?	?	?	?
Grey-headed flying fox	GHFF	?	?	?	?	?	?
Forest habitats	FH	–	–	–	–	–	–
Forest fragmentation	FF	+	+	+	+	+	+
Flowers and nectar	FN	–	–	–	–	–	–
Precipitation	Ppt	0	0	0	0	0	0
Koala	Koa	–	–	–	–	–	–
Arboreal mammals	AM	–	–	–	–	–	–
Recruitment	Rec	–	–	–	–	–	–
Micro-climate	MC		–	–	–	–	–
Overstorey (vegetation)	FWOS, WSOS, DSOS	–	–	–	–	–	–
Ground layer vegetation	HWV, WSGL, DSGL	–	–	–	–	0	–
Mid-storey vegetation	WSMS, DSMS	na	–	–	–	0	–
Wetland community	WC	–	na	na	na	na	–

Predictions with a low probability (less than 0.80) of sign determinacy are denoted by a question mark. Zero denotes completely determined predictions of no change. na = not applicable

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3.5 Impacts on and risks to water-dependent assets

Summary

Ecological water-dependent assets

The potential for impacts on ecological assets associated with riverine landscape classes is assessed as *very unlikely* (less than 5% chance), although there is large uncertainty surrounding the receptor impact modelling on which this assessment is based. There is some potential for impacts on ecological assets associated with groundwater-dependent ecosystem (GDE) landscape classes, although median estimates of areas impacted are less than 100 ha. Assets with extensive areas (e.g. habitat (potential species distribution) of the regent honeyeater) are more likely to be identified as potentially impacted because there is greater likelihood they will intersect an area of hydrological change exceeding given thresholds. However the magnitude of the impact, if any, is uncertain; it will depend on local-scale factors, including whether or not the species associated with the asset is actually present in the 'at risk' area and the sensitivity of the species to the modelled hydrological changes. Qualitative modelling predicted negative impacts of groundwater drawdown on potential koala habitat and the median estimate of potential koala habitat associated with GDEs experiencing groundwater drawdown >0.2 m is 61.6 ha. It is *very unlikely* that significant areas of a threatened ecological community are impacted.

Economic water-dependent assets

The rule-out process identified five unregulated and alluvial water sources and two groundwater sources that are potentially impacted by hydrological changes due to additional coal resource development. Of 339 bores and surface water extraction points in the zone, 304 are potentially impacted due to additional coal resource development (35 are accessing deeper, fractured rock aquifers where impacts were not assessed). As changes in hydrology are not considered to result in an economic impact at monitoring sites, 58 monitoring bores can be ruled out as unlikely to be impacted. Thus, there is a potential for economic impacts due to additional coal resource development at 246 bores and surface water extraction points in the zone of potential hydrological change. This number includes points where the purpose of the bore is unknown.

The 95th percentile change in water availability due to additional coal resource development, assessed by change in mean annual flows, is less than 1.6 GL/year in both the Upper Gloucester River and Avon River water sources, well within the interannual variability due to climate, and corresponding to 1% and 2% changes relative to the baseline. The analysis of change in cease-to-pump days showed no significant change in any water source: for the Karuah River water source, where the potential changes were predicted to be greatest, a reduction of more than 3 days is *very unlikely*. Five bores are identified as at risk of greater

than 2 m of drawdown, the minimal impact considerations threshold for Gloucester subregion aquifers under the *NSW Aquifer Interference Policy*; four are monitoring bores and the fifth is licensed to AGL, therefore economic impacts are considered unlikely.

Sociocultural water-dependent assets

Of the 19 sociocultural assets identified as water-dependent, the Washpool in the Karuah River, north of the town site of Washpool, is the only one in the zone of potential hydrological change. However, due to the very small hydrological changes at this location, the Washpool is unlikely to be impacted by additional coal resource development.

3.5.1 Overview

This section describes the potential impacts on, and risks to, ecological, economic and sociocultural water-dependent assets from potential hydrological changes due to additional coal resource development. These were assessed using:

- **overlay analysis**, whereby asset polygons (or lines or points) are intersected with a nominated zone of potential hydrological change to identify whether the asset is potentially subject to that hydrological change
- **qualitative mathematical models** derived from expert elicitation
- **quantitative mathematical models** (receptor impact models) derived from expert elicitation and based on the qualitative mathematical models.

Details of the compilation of the Gloucester water-dependent asset register (Bioregional Assessment Programme, 2017) are reported in companion product 1.3 for the Gloucester subregion (McVicar et al., 2015). The spatial layers representing the mapped extents or potential extents of the Gloucester subregion water-dependent assets, which are used in the overlay analysis, are contained within the Gloucester subregion water-dependent assets database (Bioregional Assessment Programme, Dataset 1).

As described in companion product 2.7 for the Gloucester subregion (Hosack et al., 2018), receptor impact models were developed for two landscape classes in the ‘Riverine’ landscape group: ‘Perennial – gravel/cobble streams’ and ‘Intermittent – gravel/cobble streams’. Qualitative models were developed for the groundwater-dependent ecosystem (GDE) landscape classes. Overlay analysis can identify assets that are unlikely to be impacted by surface water or groundwater changes, based on the lack of intersection with the zone of potential hydrological change. The zone of potential hydrological change is defined in Section 3.3.

The impact and risk analysis uses different estimates of hydrological change (5th, 50th (median) and 95th percentiles) to give an indication of the likelihood of hydrological changes to different types of water-dependent assets present in the zone of potential hydrological change. The principal focus of the analysis is the median (50th percentile estimate). However, the 5th percentile is shown in order to rule out potential impacts as being *very unlikely* while the 95th percentile can be used to show where hydrological changes (although not necessarily ecological impacts) are *very likely*.

The analysis of impacts and risks considers each group of water-dependent assets separately – ecological, economic and sociocultural. Each subgroup of ecological assets is described separately – 'Surface water feature', 'Groundwater feature (subsurface)' and 'Vegetation'. To improve clarity, assets in the 'Vegetation' subgroup are further divided into two classes: 'Groundwater-dependent ecosystem' and 'Habitat (potential species distribution)'. Economic assets are separated into two classes: 'Groundwater management zone or area (surface area)' and 'Surface water management zone or area (surface area)'. Potential hydrological changes to all non-petroleum and gas bores in the zone of potential hydrological change are also considered. The intersection of sociocultural assets with the zone of potential hydrological change is then described, and potential for impact assessed.

The impact and risk analysis uses a combination of summary tables, maps of modelled hydrological change within assets, plots of cumulative asset extent and degree of modelled hydrological change, and narrative. The spatial extent and number of water-dependent assets means that not all assets can be mapped and assessed in this product. Potential impacts to individual assets can be visually explored at www.bioregionalassessments.gov.au/explorer/GLO/assets. Finally, this section describes impacts on and risks to assets due to potential hydrological changes for only that part of the coal resource development pathway (CRDP) that was able to be modelled. Section 3.6 of this product provides commentary for that part of the CRDP that was not modelled (Gloucester Gas Project Stage 2 and beyond).

3.5.2 Ecological assets

3.5.2.1 Description

Of the 116 ecological assets in the Gloucester assessment extent, there are 17 'Surface water feature' subgroup assets, 3 'Groundwater feature (subsurface)' subgroup assets and 32 'Vegetation' subgroup assets that are both water-dependent and in the zone of potential hydrological change (Table 26). The 'Surface water feature' subgroup includes catchments and the Karuah River estuary (which is not in the zone of potential hydrological change), and all assets are present in the database as polygons. The 'Groundwater feature (subsurface)' subgroup includes two alluvial aquifers and the New England Fold Belt, all of which are present in the database as polygons. The 'Vegetation' subgroup assets include the habitat (potential species distribution) of 14 EPBC Act-listed threatened ecological species and 1 threatened ecological community as polygons, 10-point assets of known platypus occurrence and 7 point assets at fish biodiversity hotspot monitoring locations.

Table 26 Classification of ecological assets in the assessment extent and zone of potential hydrological change

Group	Subgroup	Asset class	Total assets	Water-dependent assets	Water-dependent assets in the zone
Ecological	Surface water feature	River or stream reach, tributary, anabranch or bend	24	24	17
		Wetland, wetland complex or swamp	1	1	0
Ecological	Groundwater feature (subsurface)	Aquifer, geological feature, alluvium or stratum	3	3	3
Ecological	Vegetation	Groundwater-dependent ecosystems	45	0[a]	0
		Habitat (potential species distribution)	43	39	32
Total			**116**	**67**	**52**

[a]As reported in companion product 1.3 for the Gloucester subregion (McVicar et al., 2015), there was sufficient uncertainty about the groundwater dependence of GDE assets derived from the *National atlas of groundwater dependent ecosystems* (Bureau of Meteorology, 2012) to not analyse these further.
Data: Bioregional Assessment Programme (Dataset 1, Dataset 2)

3.5.2.2 ‘Surface water feature’ subgroup

All assets within this subgroup were classified as being in the ‘River or stream reach, tributary, anabranch or bend’ asset class; hence, the potential impacts on these assets are represented by impacts on the ‘Riverine’ landscape group. They consist of 17 Geofabric catchment polygons (Figure 49). The two numerically modelled landscape classes ‘Intermittent – gravel/cobble streams’ and ‘Perennial – gravel/cobble streams’ dominate the river length within this subgroup (Table 27). Based on the modelled hydrological and ecological impacts (Section 3.4.3.2 and Section 3.4.3.3), no discernible impact is expected on these assets although there is large uncertainty surrounding the ecological impacts on the riverine landscape classes.

Table 27 Length (km) of streams in landscape classes in the 'Riverine' landscape group within each asset in the 'Surface water feature' subgroup

Asset name	Intermittent – gravel/ cobble streams (km)	Intermittent – high gradient bedrock confined streams (km)	Intermittent – lowland fine streams (km)	Perennial – gravel/ cobble streams (km)	Perennial – high gradient bedrock confined streams (km)	Perennial – transitional fine streams (km)	Total (km)
Catchment_237	2.5	0.3	0	0	0	0	2.8
Catchment_244	0	0	0	4.8	0	0	4.8
Catchment_245	0	0	0	11.5	0	0	11.5
Catchment_246	0	0	0	24.3	1.6	0	25.9
Catchment_247	0	0	0	11.8	2.0	0	13.7
Catchment_250	0	0	0	2.2	0.2	12.7	15.1
Catchment_251	0	0.1	0	5.7	1.9	0	7.7
Catchment_252	35.4	2.9	4.1	0	0.1	0	42.6
Catchment_253	11.2	1.4	0	0	0	0	12.6
Catchment_254	7.8	0	0	3.3	0	0	11.1
Catchment_255	19.9	0.2	0	0	0	0	20.1
Catchment_256	0	0	0	0.6	0	0	0.6
Catchment_329	0	0	0	36.5	2.5	0	39.0
Catchment_330	1.1	0	0	12.0	0	0	13.1
Catchment_344	0	0	0	0	0.4	0	0.4
Catchment_347	0	0	0	19.5	0	0	19.5
Catchment_464	0	0	0	1.1	0.3	0	1.4
Total	**77.9**	**4.9**	**4.1**	**133.0**	**9.0**	**12.7**	**241.7**

Due to rounding, some totals may not correspond with the sum of the separate numbers.
Data: Bioregional Assessment Programme (Dataset 1, Dataset 2)

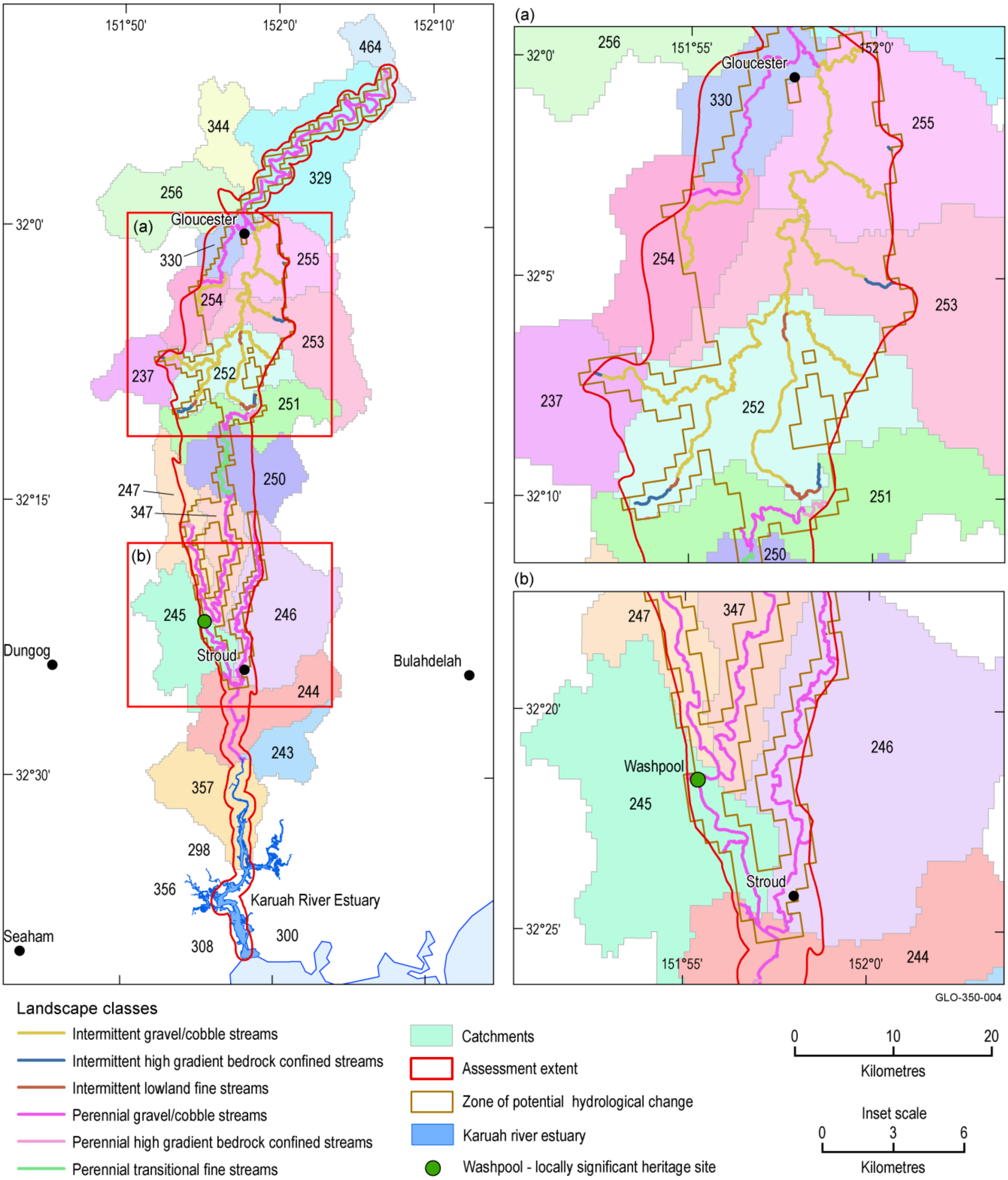

Figure 49 Surface water assets associated with landscape classes of the 'Riverine' landscape group in the zone of potential hydrological change

The Washpool (a sociocultural asset) is also shown.
Data: Bioregional Assessment Programme (Dataset 2, Dataset 3, Dataset 4)

3.5.2.3 'Groundwater feature (subsurface)' subgroup

Assets within this subgroup are the Karuah Alluvium, Manning Alluvium and New England Fold Belt. No ecological landscape classes or models were developed to represent these assets. The reader is referred to Section 3.5.3 for a discussion of impacts on groundwater.

3.5.2.4 'Vegetation' subgroup

The 'Vegetation' subgroup assets include the habitat (potential species distribution) of 14 EPBC Act-listed threatened ecological species and 1 threatened ecological community as polygons (Table 28), and 10 point assets of known platypus occurrence and 7 point assets at fish biodiversity hotspot monitoring locations. 'Vegetation' subgroup assets within the 'Groundwater-dependent ecosystem' asset class are represented by the 'GDE' landscape group and are discussed in Section 3.4. All other assets in this subgroup were classified as 'Habitat (potential species distribution)' assets.

Note that the terms 'habitat' and 'potential species distribution' are synonymous in relation to assets and that the potential species distributions or habitats do not necessarily imply that either the species or its habitat is present with the modelled distribution (see Section 2.3.3.1.3 of companion product 2.3 for the Gloucester subregion (Dawes et al., 2018)). The Department of the Environment and Energy Environmental Resources Information Network (ERIN) uses maximum entropy (MAXENT) modelling to define the geographic extent of potential species distributions based largely on physical parameters and past observations of the presence and absence of a species (Elith et al., 2011). The habitat itself, in the form of suitable vegetation types or ecosystems, is not necessarily present within the modelled potential species distribution. Furthermore, where suitable habitat does exist within the modelled potential species distribution, the species may not be known or predicted to occur based on NSW Office of Environment and Heritage species presence data and modelling (BioNet database; CSIRO, Dataset 5). As a result, not all species associated with 'Habitat (potential species distribution)' assets derived from ERIN are known or predicted to occur within the Gloucester assessment extent based on the BioNet database (Table 29), although this does not exclude the possibility that they may occur and have merely not been sighted. For example, the Australasian bittern, eastern bristlebird, red goshawk and Hastings River mouse are not known to occur within the Karuah-Manning subregion of the Hunter-Central Rivers Catchment Management Area, within which the Gloucester assessment extent lies.

Furthermore, not all 'Habitat (potential species distribution)' assets are known to be associated with all GDE landscape classes (Table 29). For example, Guthrie's grevillea is known to be associated with the 'Wet sclerophyll forests' landscape class but not with any of the other GDE landscape classes. Others, such as the grey-headed flying fox and spot-tailed quoll are associated with all the GDE landscape classes in the zone of potential hydrological change. The Australasian bittern is only known to be associated with landscape classes that lie outside the zone of potential hydrological change ('Freshwater wetlands' and 'Saline wetlands'). The known associations of 'Habitat (potential species distribution)' assets with GDE landscape classes (Table 29), and the known or predicted occurrence of species associated with 'Habitat (potential species distribution)' assets within the assessment extent (Table 29), are based on information obtained from the NSW Office of Environment and Heritage BioNet database (CSIRO, Dataset 5).

In the zone of potential hydrological change, the overwhelming majority of the polygon assets lay within landscape classes of the 'Non-GDE' and 'Economic land use' landscape groups. The area of assets classified as 'Habitat (potential species distribution)' assets within the 'GDE' landscape group ranged from as little as 6 ha for the 'Lowland Subtropical Rainforest' threatened ecological community to 407 ha for the grey-headed flying fox, koala, spot-tailed quoll, stuttering frog and regent honeyeater. Selected 'Habitat (potential species distribution)' assets are mapped in relation to the zone of potential hydrological change and GDE landscape classes in Figure 50 (plants and threatened ecological communities), Figure 51 (birds), Figure 52 (mammals) and Figure 53 (frogs, platypus and fish).

Table 28 Area (ha) of 'Groundwater-dependent ecosystem (GDE)', 'Non-GDE' and 'Economic land use' landscape groups within each habitat (potential species distribution) asset polygon, in the zone of potential hydrological change (zone)

An asterisk indicates species that are not known or predicted to be present within the Gloucester assessment extent.

Asset name	GDE (ha)	Non-GDE (ha)	Economic land use (ha)	Total in zone (ha)
Guthrie's grevillea (*Grevillea guthrieana*)	35	231	384	651
Leafless tongue-orchid (*Cryptostylis hunteriana*)	78	449	915	1,443
White-flowered wax plant (*Cynanchum elegans*)	23	347	1,084	1,455
Lowland Subtropical Rainforest (TEC)	6	65	39	111
Australasian bittern (*Botaurus poiciloptilus*)*	304	2,810	12,113	15,227
Eastern bristlebird (*Dasyornis brachypterus*)*	328	4,933	16,783	22,044
Red goshawk (*Erythrotriorchis radiatus*)*	398	5,854	19,740	25,993
Regent honeyeater (*Anthochaera phrygia*)	407	6,133	20,243	26,783
Swift parrot (*Lathamus discolor*)	135	1,138	2,470	3,744
Giant barred frog (*Mixophyes iteratus*)	15	272	576	864
Stuttering frog (*Mixophyes balbus*)	407	6,134	20,244	26,784
Grey-headed flying fox (*Pteropus poliocephalus*)	407	6,134	20,244	26,784
Hastings River mouse (*Pseudomys oralis*)*	404	6,118	20,199	26,721
Koala (*Phascolarctos cinereus*)	407	6,134	20,244	26,784
Spot-tailed quoll (*Dasyurus maculatus* ssp. *maculatus*)	407	6,134	20,244	26,784

TEC = threatened ecological community

Data: Bioregional Assessment Programme (Dataset 2)

Table 29 Area (ha) of landscape classes in the 'Groundwater-dependent ecosystem (GDE)' landscape group for each habitat (potential species distribution) asset, in the zone of potential hydrological change

An asterisk indicates species that are not known or predicted to be present within the Gloucester assessment extent. Bolded text indicates that the asset is known or predicted to be associated with that landscape class.

Asset name	Dry sclerophyll forests (ha)	Wet sclerophyll forests (ha)	Forested wetlands (ha)	Rainforests (ha)	Total associated landscape class (ha)	Total GDE landscape class (ha)
Guthrie's grevillea (*Grevillea guthrieana*)	0.6	**0**	0	34.2	0	35
Leafless tongue-orchid (*Cryptostylis hunteriana*)	**1.6**	**0**	**0**	76.9	2	78
White-flowered wax plant (*Cynanchum elegans*)	**0**	**4.3**	18.6	**0.1**	4	23
Lowland Subtropical Rainforest (TEC)	0	**0.0**	0.1	**6.3**	6	6
Australasian bittern (*Botaurus poiciloptilus*)*	20.2	6.7	135.5	141.8	0	304
Eastern bristlebird (*Dasyornis brachypterus*)*	14.9	**7.1**	**175.1**	**131.3**	313	328
Red goshawk (*Erythrotriorchis radiatus*)*	**19.6**	**22.0**	**204.1**	**152.5**	398	398
Regent honeyeater (*Anthochaera phrygia*)	**20.2**	**22.3**	**207.9**	156.4	251	407
Swift parrot (*Lathamus discolor*)	**18.0**	**4.3**	**84.7**	28.5	106	135
Giant barred frog (*Mixophyes iteratus*)	**0**	**0.5**	**3.7**	**11.2**	15	15
Stuttering frog (*Mixophyes balbus*)	**20.2**	**22.3**	207.9	**156.4**	199	407
Grey-headed flying fox (*Pteropus poliocephalus*)	**20.2**	**22.3**	**207.9**	**156.4**	407	407
Hastings River mouse (*Pseudomys oralis*)*	**19.9**	**22.3**	207.9	154.4	42	404
Koala (*Phascolarctos cinereus*)	**20.2**	**22.3**	**207.9**	156.4	251	407
Spot-tailed quoll (*Dasyurus maculatus* ssp. *maculatus*)	**20.2**	**22.3**	**207.9**	**156.4**	407	407

Data: Bioregional Assessment Programme (Dataset 2)

The assets associated with frog species were judged to be closely associated with two of the riverine landscape classes based on descriptions of their habitat and ecology (NSW Office of Environment and Heritage, 2016a, 2016b). The stuttering frog breeds in streams during summer after heavy rain. Its eggs are laid on rock shelves or shallow riffles in small, flowing streams. As the tadpoles grow they move to deep permanent pools and take approximately 12 months to metamorphose. Hence, the stuttering frog may be associated with the 'Intermittent – gravel/cobble streams' and 'Intermittent – high gradient-bedrock confined-streams' riverine landscape classes. There are 78 ha of the former class in the zone of potential hydrological change and the asset polygon for the stuttering frog, and 5 ha of the latter class. The giant barred frog is found along freshwater streams with permanent or semi-permanent water, generally (but not always) at lower elevation. Hence, the giant barred frog may occur in the 'Perennial – gravel/cobble streams', 'Perennial – high-gradient bedrock-confined streams' and 'Perennial – transitional fine-streams' riverine landscape classes. There are 25 km of the 'Perennial – gravel/cobble streams' landscape class in the zone of potential hydrological change and the asset polygon for the stuttering frog, and 2 km of the 'Perennial – high-gradient bedrock-confined streams' landscape class. The 'Perennial – transitional fine-streams' landscape class is not present in either the zone of potential hydrological change or the asset polygon for the giant barred frog. Based on modelled impacts of additional coal resource development on riverine landscape classes (Section 3.4.3.2 and Section 3.4.3.3), the habitat (potential species distribution) of the frog species are not expected to be impacted through their association with riverine landscape classes.

The platypus asset was judged to be associated with the 'Perennial – gravel/cobble streams', 'Perennial – high-gradient bedrock-confined streams' and 'Perennial – transitional fine-streams' landscape classes based on its known habitat and ecology (Grant, 1995). However, areas of potential platypus distribution were not provided owing to the point nature of the spatial data (Figure 53). Most known platypus locations are in the southern half of the Gloucester subregion. 'Fish biodiversity hotspot' monitoring sites are proxies for all fish species in the river systems and are assumed to be associated with all riverine landscape classes. Based on modelled impacts due to additional coal resource development on riverine landscape classes (Section 3.4.3.2 and Section 3.4.3.3), the platypus and fish species are not expected to be impacted through their association with riverine landscape classes.

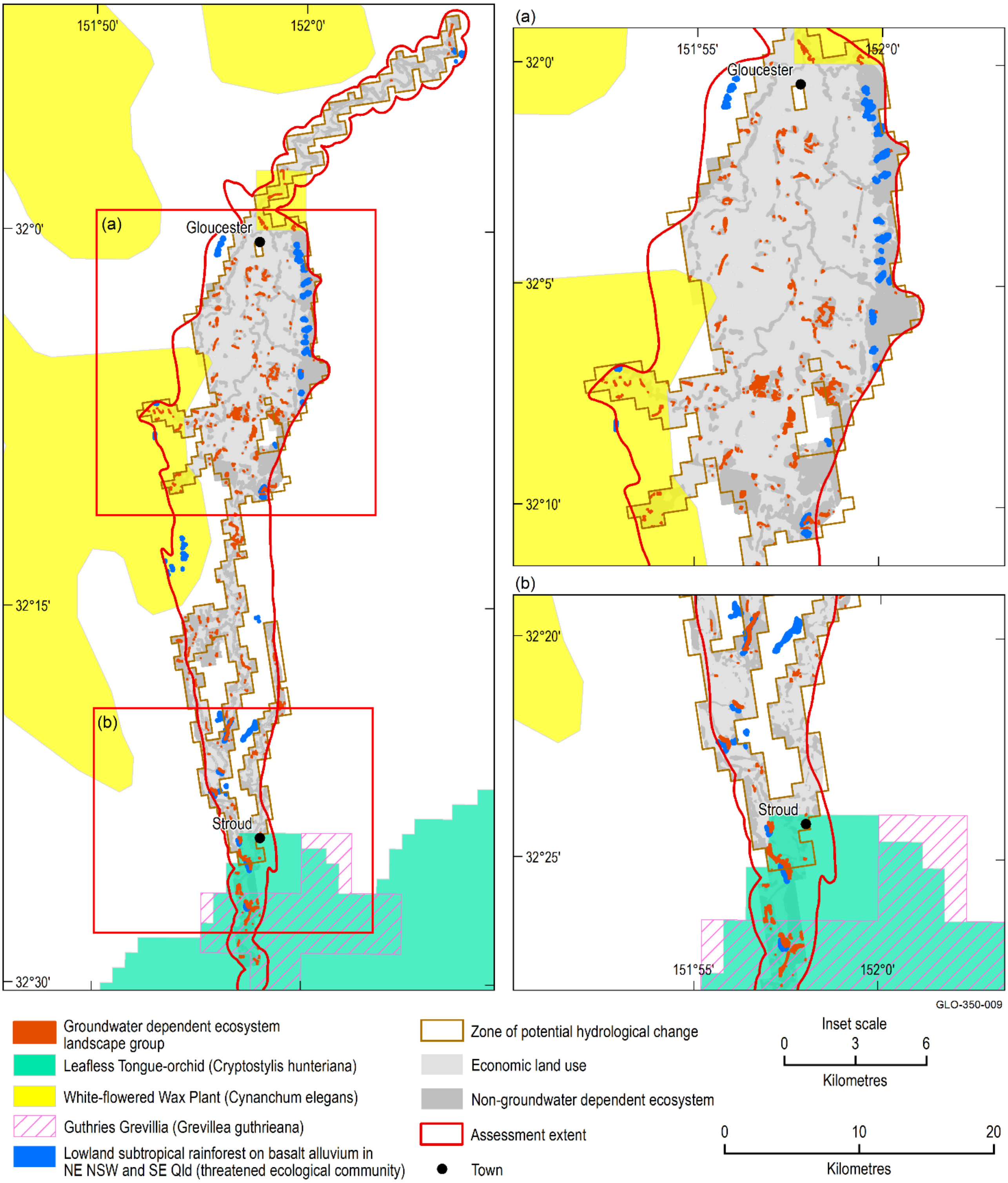

Figure 50 Habitat (potential species distribution) of the leafless tongue-orchid, white-flowered wax plant, Guthries grevillea and 'Lowland Subtropical Rainforest' threatened ecological community in relation to the 'Groundwater-dependent ecosystem (GDE)' landscape group and the zone of potential hydrological change

Data: Bioregional Assessment Programme (Dataset 2, Dataset 3, Dataset 4)

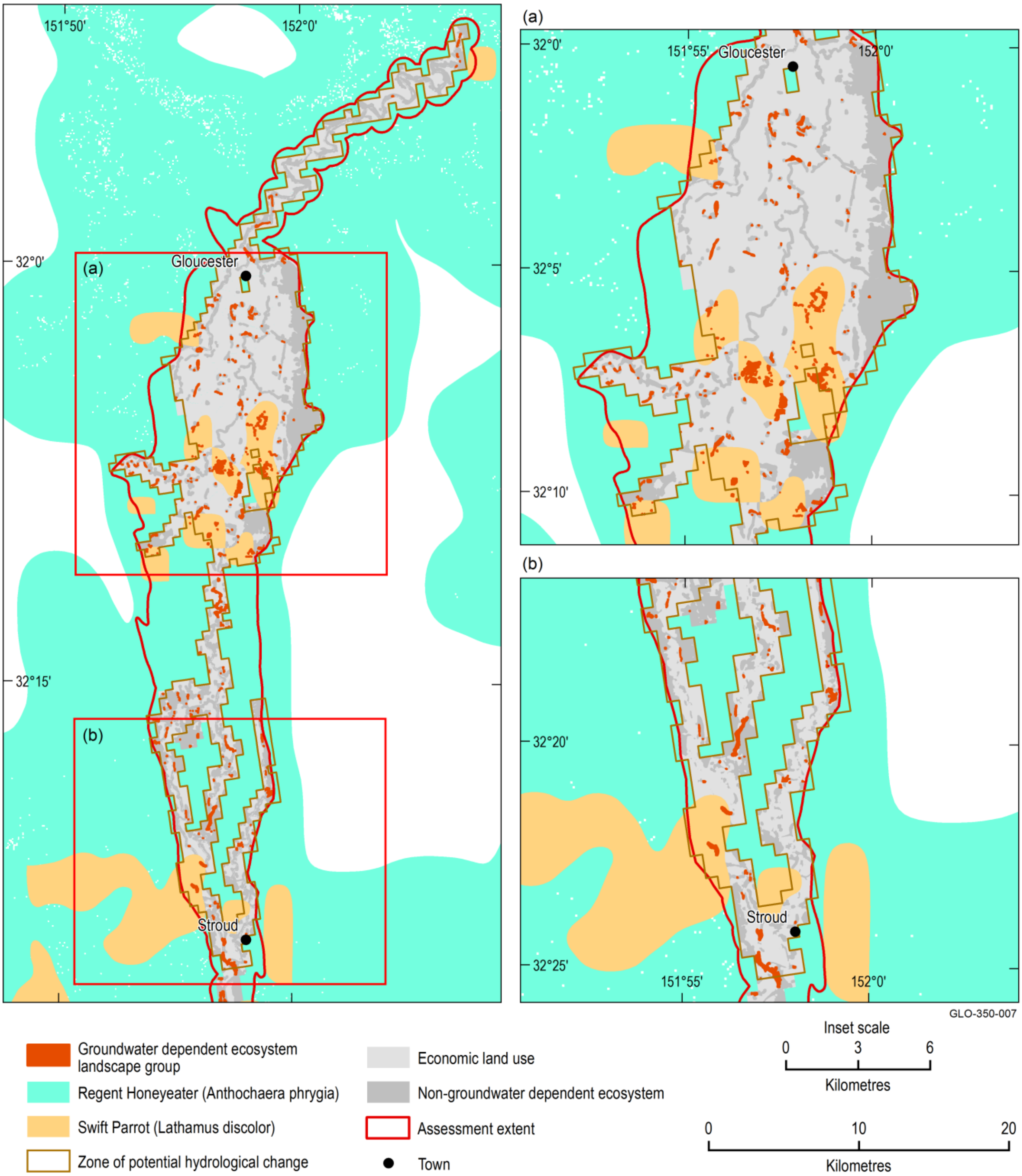

Figure 51 Habitat (potential species distribution) of the regent honeyeater and the swift parrot in relation to the 'Groundwater-dependent ecosystem (GDE)' landscape group and the zone of potential hydrological change

Data: Bioregional Assessment Programme (Dataset 2, Dataset 3, Dataset 4)

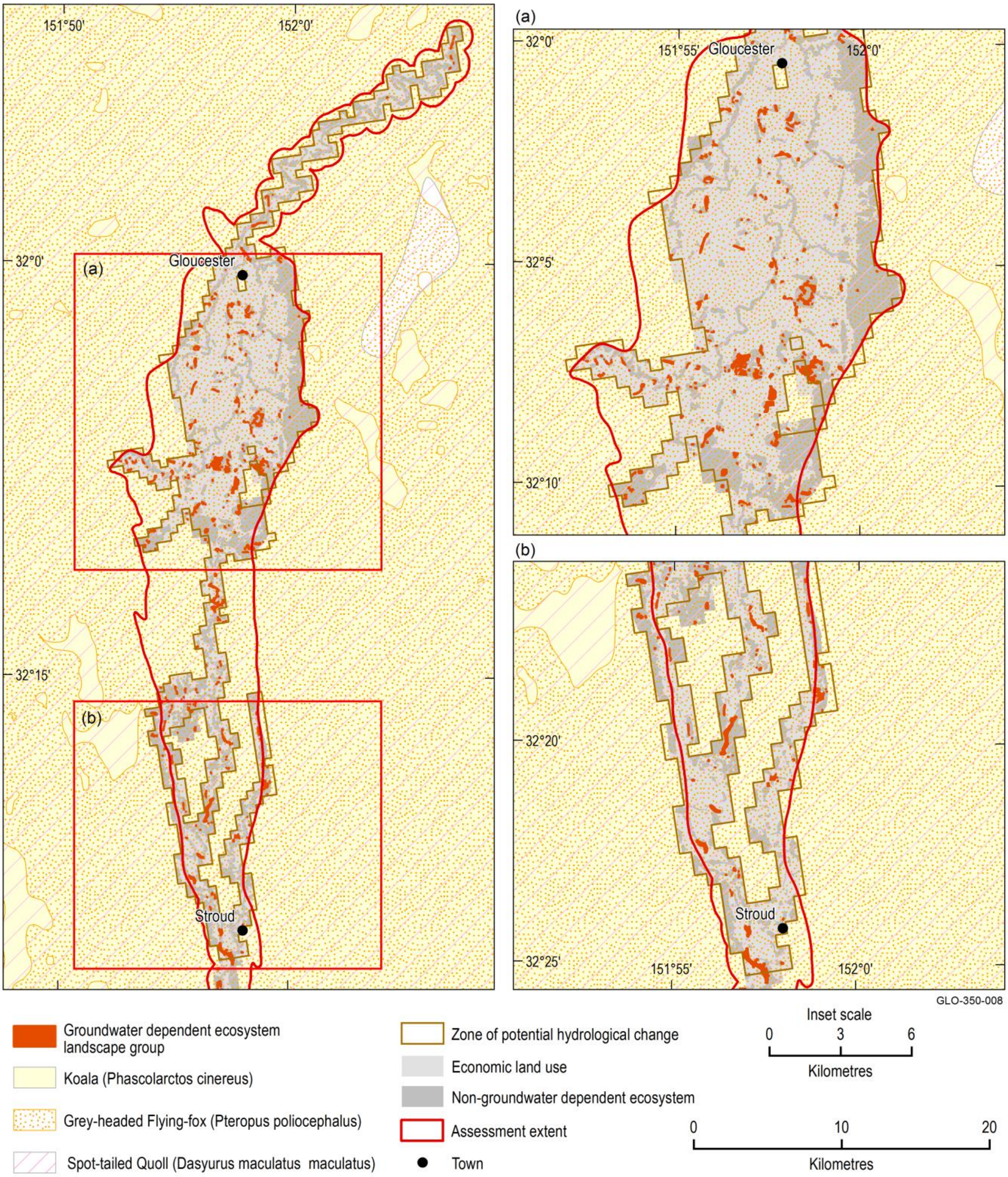

Figure 52 Habitat (potential species distribution) of the koala, grey-headed flying fox and the spotted-tailed quoll in relation to the 'Groundwater-dependent ecosystem (GDE)' landscape group and the zone of potential hydrological change

Data: Bioregional Assessment Programme (Dataset 2, Dataset 3, Dataset 4)

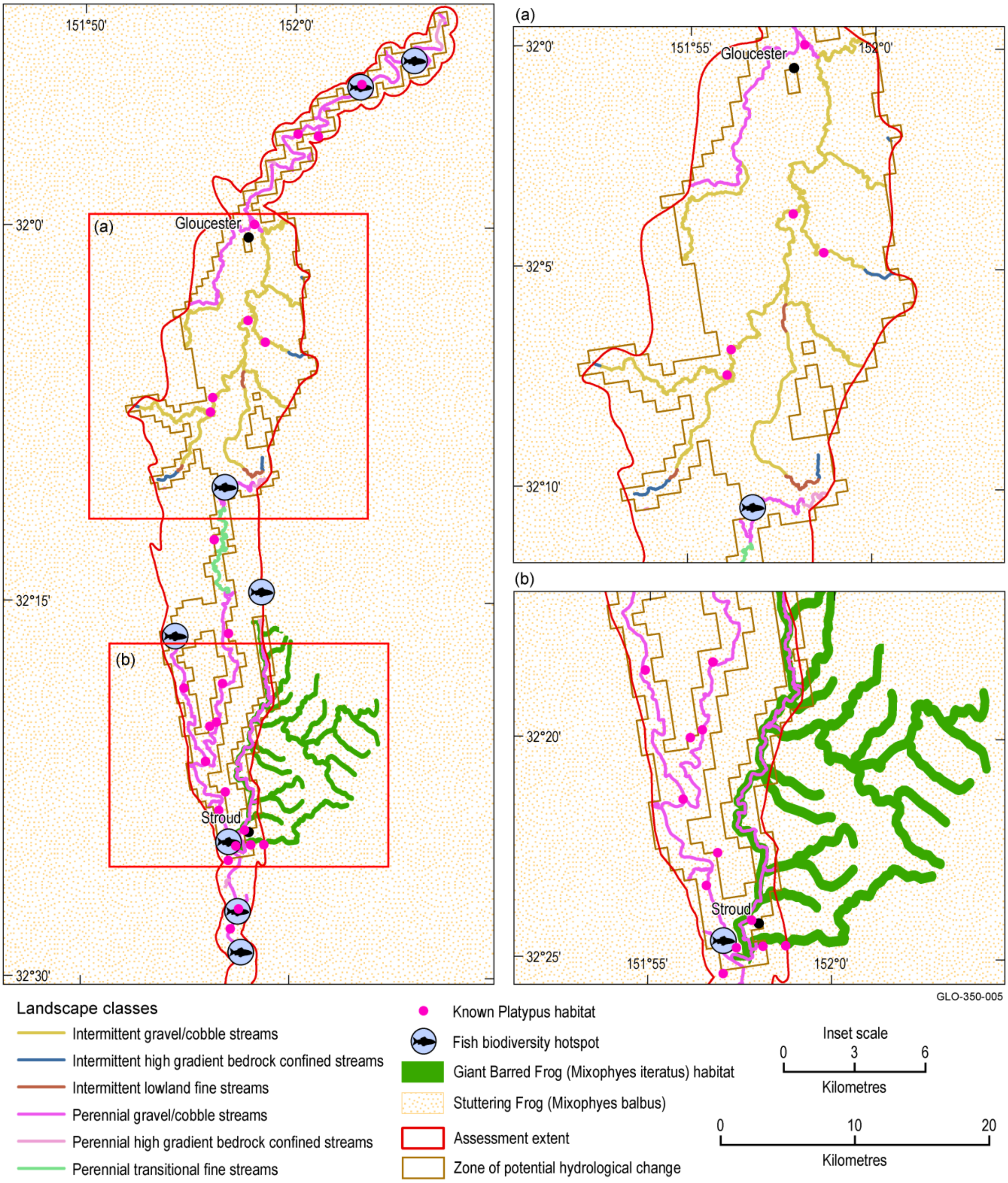

Figure 53 Habitat (potential species distribution) of the giant barred and stuttering frogs, known platypus habitat, and fish biodiversity monitoring sites in relation to the 'Riverine' landscape group and the zone of potential hydrological change

Data: Bioregional Assessment Programme (Dataset 2, Dataset 3, Dataset 4)

The total area of habitat (potential species distribution) assets potentially impacted due to additional coal resource development based on the median estimate ranges from zero for the giant barred frog to over 70 ha for the regent honeyeater (Table 30). Generally, assets that have a wide modelled distribution, such as those associated with arboreal species, are more likely to be identified as potentially impacted; while assets with restricted modelled distributions are less likely to intersect areas identified as at risk of potentially large hydrological change. No GDEs associated with habitat (potential species distributions) are expected to experience more than a 1 m groundwater drawdown and most of the area is expected to experience a less than 0.5 m groundwater drawdown. 0.2 ha of the threatened ecological community, lowland subtropical rainforest, may experience more than a 1 m groundwater drawdown based on its association with the ‘Rainforests’ landscape class.

Based on the 5th and 95th percentile estimates of groundwater drawdown beneath the GDE landscape classes due to additional coal resource development, the total area of habitat (potential species distribution) assets potentially impacted ranged from zero for the giant barred frog (Table 30) to 186.2 ha for the regent honeyeater (Table 30). Based on the 5th percentile estimate, the impact is expected to be small with nearly all groundwater drawdown less than 0.2 m (Table 30). Based on the 95th percentile estimate, the impact is expected to be larger with several tens of hectares subjected to groundwater drawdown greater than 1 and 2 m (Table 30). It is *very unlikely* that any groundwater drawdown would exceed 5 m (Table 30). Based on the 95th percentile estimate less than 5 ha of threatened ecological community is expected to be subjected to groundwater drawdown.

The qualitative models (Section 3.4.4.3) predicted negative impacts of groundwater drawdown on populations of arboreal mammals, including koalas but not flying foxes, as well as nocturnal raptors and aggressive native honeyeaters. The impact of hydrological changes on flying foxes, regent honeyeaters, swift parrots and diurnal raptors is uncertain. Hence, the species in this group for which the hydrological impacts are largest (grey-headed flying fox, red goshawk, regent honeyeater, spot-tailed quoll) are also associated with some of the assets for which the potential impact of the hydrological changes is most uncertain. The qualitative model predicted negative impacts on koalas of groundwater drawdown and, in the 95th percentile case, 109 ha of habitat (potential species distribution) of the koala could potentially be impacted by groundwater drawdown, although only 55 ha of this is likely to experience greater than 0.5 m of drawdown. In the 50th percentile case, approximately 13 ha of habitat (potential species distribution) of the koala could potentially be impacted by groundwater drawdown greater than 0.5 m.

Table 30 Cumulative area (ha), in the zone of potential hydrological change, of all GDE landscape classes with which each potential species distribution asset is associated, and the degree to which they experience groundwater drawdown based on the 5th, 50th and 95th percentile modelling outputs

An asterisk indicates species that are not known or predicted to be present within the Gloucester assessment extent.

Asset name	Area with additional drawdown >0.2 m (ha)			Area with additional drawdown >0.5 m (ha)			Area with additional drawdown >1.0 m (ha)			Area with additional drawdown >2.0 m (ha)			Area with additional drawdown >5.0 m (ha)		
	5th	50th	95th	5th	50th	95th	5th	50th	95th	5th	50th	95th	5th	50th	95th
Eastern bristlebird (*Dasyornis brachypterus*)*	2.7	34.7	72.1	0.0	2.6	44.6	0.0	0.1	9.2	0.0	0.0	1.8	0.0	0.0	0.0
Giant barred frog (*Mixophyes iteratus*)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grey-headed flying fox (*Pteropus poliocephalus*)	10.7	49.9	125.7	0.1	14.0	61.3	0.0	3.1	20.9	0.0	0.0	12.6	0.0	0.0	0.0
Hastings River mouse (*Pseudomys oralis*)*	7.7	11.6	26.1	0.1	11.0	12.1	0.0	3.0	11.1	0.0	0.0	10.5	0.0	0.0	0.0
Koala (*Phascolarctos cinereus*)	9.7	45.6	109.1	0.1	12.9	55.2	0.0	3.1	19.4	0.0	0.0	11.6	0.0	0.0	0.0
Lowland Subtropical Rainforest (TEC)	0.0	0.2	4.6	0.0	0.2	0.4	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Red goshawk (*Erythrotriorchis radiatus*)*	8.7	33.3	110.4	0.1	12.9	54.1	0.0	3.1	18.5	0.0	0.0	11.6	0.0	0.0	0.0
Regent honeyeater (*Anthochaera phrygia*)	19.0	70.2	186.2	0.1	33.1	79.9	0.0	6.1	39.6	0.0	0.0	29.3	0.0	0.0	0.0
Spot-tailed quoll (*Dasyurus maculatus* ssp. *maculatus*)	9.7	45.6	112.3	0.1	12.9	55.4	0.0	3.1	18.5	0.0	0.0	11.6	0.0	0.0	0.0
Stuttering frog (*Mixophyes balbus*)	7.7	13.6	30.4	0.1	12.9	13.3	0.0	3.0	11.3	0.0	0.0	10.5	0.0	0.0	0.0
Swift parrot (*Lathamus discolor*)	8.5	37.2	62.3	0.0	11.8	38.3	0.0	3.0	13.7	0.0	0.0	11.4	0.0	0.0	0.0

Data: Bioregional Assessment Programme (Dataset 2)

3.5.3 Economic assets

3.5.3.1 Assets in the zone of potential hydrological change

The water-dependent asset register for the Gloucester subregion (Bioregional Assessment Programme, Dataset 1) has 22 economic water-dependent assets, comprising 464 elements (Table 31). Economic elements include water source areas and monitoring bores, water access licences and basic water rights, represented spatially by groundwater production bores and surface water extraction points. The 'unknown' groundwater elements reflect the fact that the source data (NSW Office of Water, Dataset 6) did not specify the purpose for which the bore was used. The assets represent groupings of elements by water source and the purpose for which the right to water has been obtained.

In NSW, water resources in river and groundwater systems are managed through water sharing plans. These are subordinate legislation under NSW's *Water Management Act 2000*. At the time that the asset register was compiled, the water sharing plans relevant to the Gloucester subregion were the *Water Sharing Plan for the Karuah River Water Source* and the *Water Sharing Plan for the Lower North Coast Unregulated and Alluvial Water Sources*. In July 2016, NSW Department of Primary Industries Water merged the Karuah River plan into the *Water Sharing Plan for the Lower North Coast Unregulated and Alluvial Water Sources.* At the same time, the *Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources* commenced, which covers the entire Gloucester subregion. This water sharing plan was in draft form when the assets register was compiled, but is considered in the following assessment of impacts on economic assets. Each water sharing plan specifies the water sources to which it applies. There are differences between the groundwater sources specified under the *Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources* and the groundwater management units used to group elements into assets in the water-dependent assets register for the Gloucester subregion (see companion product 1.3 (McVicar et al., 2015)).

Within the Gloucester subregion zone of potential hydrological change, there are 22 economic assets, comprising 370 elements (Table 31). Thus, all surface water and groundwater economic assets in the water-dependent asset register are potentially impacted due to additional coal resource development, although not all of the elements comprising the assets are. The final column in Table 31 identifies groundwater and surface water elements in the mine pit exclusion zone. There are 35 groundwater bores in the mine pit exclusion zone. While these 35 bores are clearly within the zone of potential hydrological change and hence potentially impacted due to additional coal resource development, the modelled estimates of drawdown in the vicinity of open-cut pits are highly uncertain. In the Gloucester subregion, it is assumed that there are no significant deep, high yielding aquifers, which would necessitate consideration of different drawdown zones at depth, thus economic assets that are outside the zone, as defined in Section 3.3.1, are considered very unlikely to be impacted due to additional coal resource development.

Figure 54 identifies (i) the groundwater sources and bores and (ii) the surface water sources and extraction points that intersect the zone of potential hydrological change, and hence are potentially impacted due to additional coal resource development. Table 32 lists the potentially impacted groundwater and surface water sources and the number of water rights holders (both access licence and basic rights), monitoring bores and 'unknown' bores by water source in the zone of potential hydrological change. Of the 370 elements in the zone of potential hydrological change (Table 31), 339 relate to bores (159) and surface water extraction points (180). There are no bores or extraction points within the Lower Manning River water source in the zone of potential hydrological change. Figure 54b shows that the intersection of this water source with the zone of potential hydrological change is marginal, and probably an artefact of the assessment unit scale, and hence can be ruled out as potentially impacted due to additional coal resource development. Thus, seven groundwater and surface water sources are potentially impacted due to additional coal resource development.

Table 31 Economic assets and elements in the Gloucester assessment extent, zone of potential hydrological change and mine pit exclusion zone

Asset subgroup	Asset class	Number in assessment extent		Number in zone of potential hydrological change		Number in mine pit exclusion zone
		Assets	Elements	Assets	Elements	Elements
Groundwater management zone or area (surface area)	A groundwater feature used for water supply	0	0	0	0	0
	Water supply and monitoring infrastructure	3	66	3	58	18
	Water access right	3	22	3	17	2
	Basic water right (stock and domestic)	3	22	3	15	0
	Unknown[a]	0	85	0	69	15
	Subtotal	**9**	**195**	**9**	**159**	**35**
Surface water management zone or area (surface area)	A surface water feature used for water supply	0	0	0	0	0
	Water supply and monitoring infrastructure	0	0	0	0	0
	Water access right	5	206	5	174	0
	Basic water right (stock and domestic)	8	63	8	37	0
	Subtotal	**13**	**269**	**13**	**211**	**0**
Total		**22**	**464**	**22**	**370**	**35**

[a]Unknown elements are bores for which the purpose was not specified in the source data.
Data: Bioregional Assessment Programme (Dataset 1, Dataset 7)

Most of the bores in the zone of potential hydrological change in the Gloucester Basin groundwater source are classed as 'unknown' purpose or monitoring bores. The Avon River, Upper Gloucester River, Karuah River and Lower Manning River water sources, which include the water in the unregulated rivers and their associated alluvial aquifers, have the greatest number of water users.

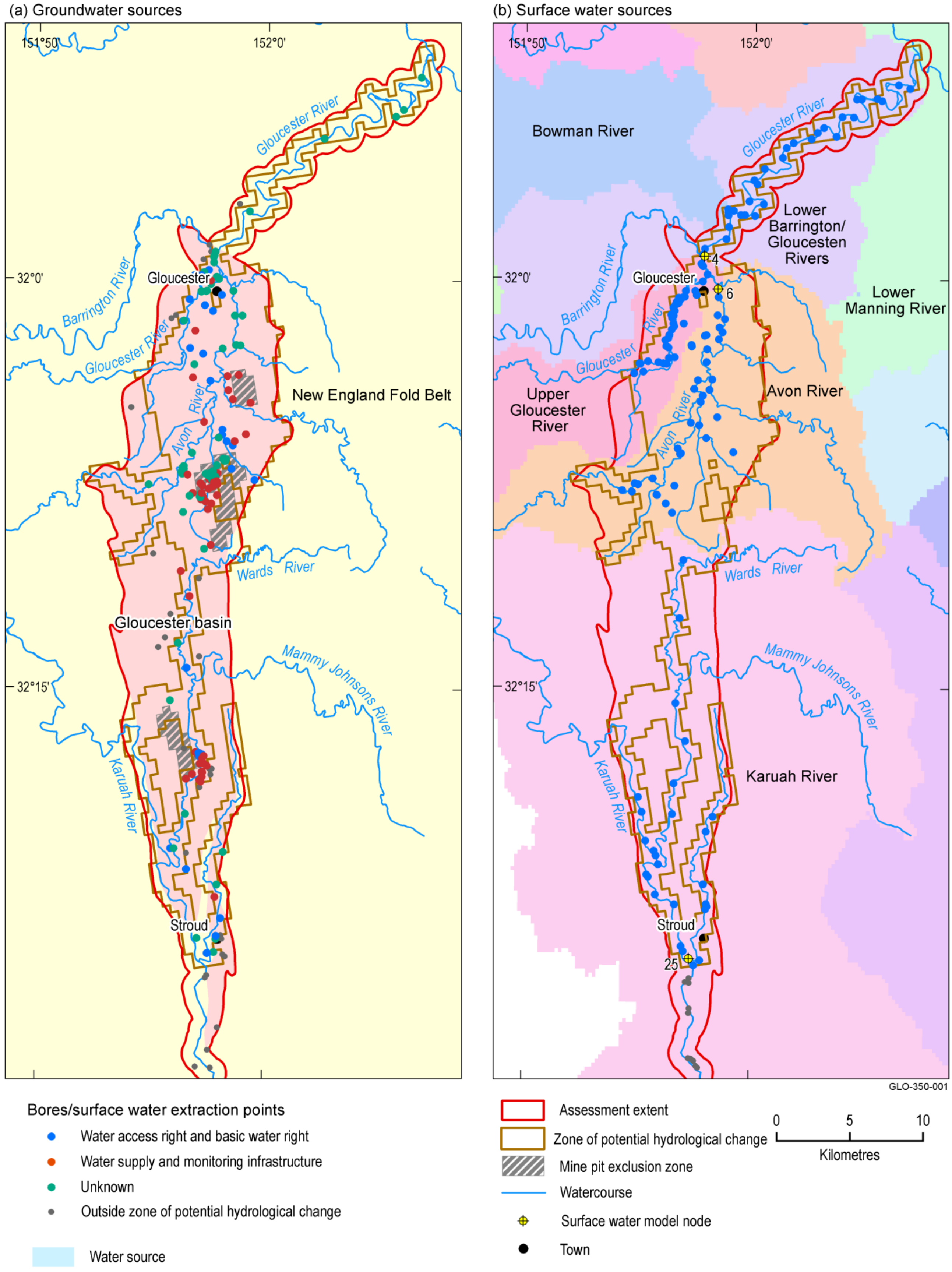

Figure 54 Water source areas, bores and surface water extraction points in the zone of potential hydrological change for (a) groundwater and (b) surface water

Data: Bioregional Assessment Programme (Dataset 1, Dataset 4)

Table 32 Water source areas and associated extraction and monitoring points in the zone of potential hydrological change

Water sharing plan	Water source area	Total	Water access licence	Basic water rights	Infrastructure (monitoring)	Unknown
Lower North Coast Unregulated and Alluvial Water Sources 2009	Avon River	82	57	6	11	8
	Bowman River	1	1	0	0	0
	Karuah River	45	30	1	11	3
	Lower Barrington / Gloucester River	37	33	0	0	4
	Upper Gloucester River	68	53	3	2	10
	Lower Manning River[a]	0	0	0	0	0
North Coast Fractured and Porous Rock Groundwater Sources 2016	Gloucester Basin	101	17	11	34	39
	New England Fold Belt	5	0	0	0	5
Total		**339**[b]	**191**	**21**	**58**	**69**

[a]Intersection of Lower Manning River water source with zone of potential hydrological change is negligible and this water source is unlikely to be impacted by additional coal resource development.
[b]Of the 370 elements in the zone of potential hydrological change (Table 31), 339 relate to water access rights and monitoring infrastructure.
Data: Bioregional Assessment Programme (Dataset 7)

The 159 groundwater bores identified in Table 31 as being in the zone of potential hydrological change include 49 bores that are in the groundwater zone of potential hydrological change and 110 bores solely in the surface water zone of potential hydrological change. Of the latter 110 bores, only those extracting from an alluvial aquifer could potentially be impacted. This relates to the high connectivity of alluvial aquifers to water in the streams and means alluvial bores could be impacted by changes in baseflow due to additional coal resource development, even though they are outside the area of drawdown used to define the groundwater zone of potential hydrological change (Section 3.3.1.1). In NSW, these highly connected water sources are managed conjunctively. In the Gloucester subregion, alluvium thickness has been reported as averaging about 9 m in the Duralie Coal Mine area (Heritage Computing, 2009) and up to 15 m in the Avon river basin (Parsons Brinckerhoff, 2015). Thus, bores in the surface water zone of potential hydrological change with a drill depth exceeding 15 m can be ruled out as *very unlikely* to be impacted due to additional coal resource development.

Figure 55 shows the bores with depths greater than or less than 15 m, as well as bores for which depth information was not available, and this is summarised in Table 33 along with bore purpose. There are 35 bores that can be ruled out as unlikely to be impacted (they are not in the drawdown area and not in the alluvium) and another 35 that are potentially impacted (they are in the alluvium but could be affected by baseflow). The 40 bores with no drill depth information cannot be ruled out. This means there is a total of 75 potentially impacted bores in the surface water zone of potential hydrological change.

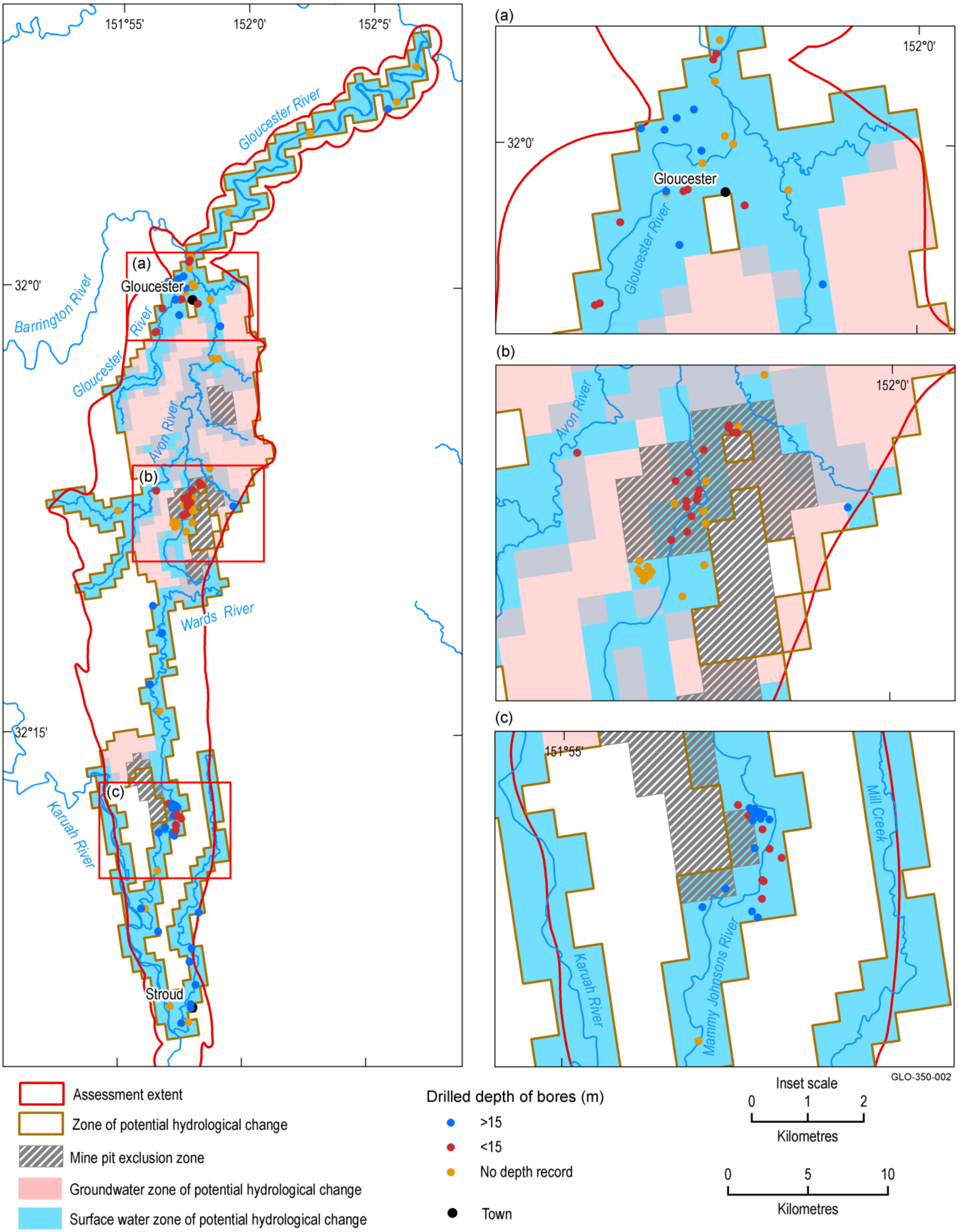

Figure 55 Groundwater bores in surface water zone of potential hydrological change by depth class

Data: Bioregional Assessment Programme (Dataset 1, Dataset 4, Dataset 7)

Table 33 Drill depths and purpose of potentially impacted bores solely in surface water zone of potential hydrological change (surface water zone)

Bores solely in surface water zone	Number with depth >15 m			Number with depth <15 m			Number with no depth		
	Mon	Prod	Unk	Mon	Prod	Unk	Mon	Prod	Unk
110	11	17	7	14	3	18	14	2	24

Mon = monitoring, Prod = production (water access licence and basic water rights), Unk = unknown purpose
Data: Bioregional Assessment Programme (Dataset 7)

In summary, five surface water sources and two groundwater sources are potentially impacted by hydrological changes due to additional coal resource development. Figure 56 summarises the rule-out process for the 339 bores and surface water extraction points in the zone. There are 304 which are potentially impacted due to additional coal resource development (35 bores are accessing deeper, fractured rock where impacts were not assessed). However, changes in hydrology are not considered to result in an economic impact at monitoring sites, so 58 monitoring bores can be ruled out as unlikely to be impacted. Thus, there is a potential for economic impacts due to additional coal resource development at 246 bores and surface water extraction points in the zone of potential hydrological change. This number includes points where the purpose of the bore is unknown.

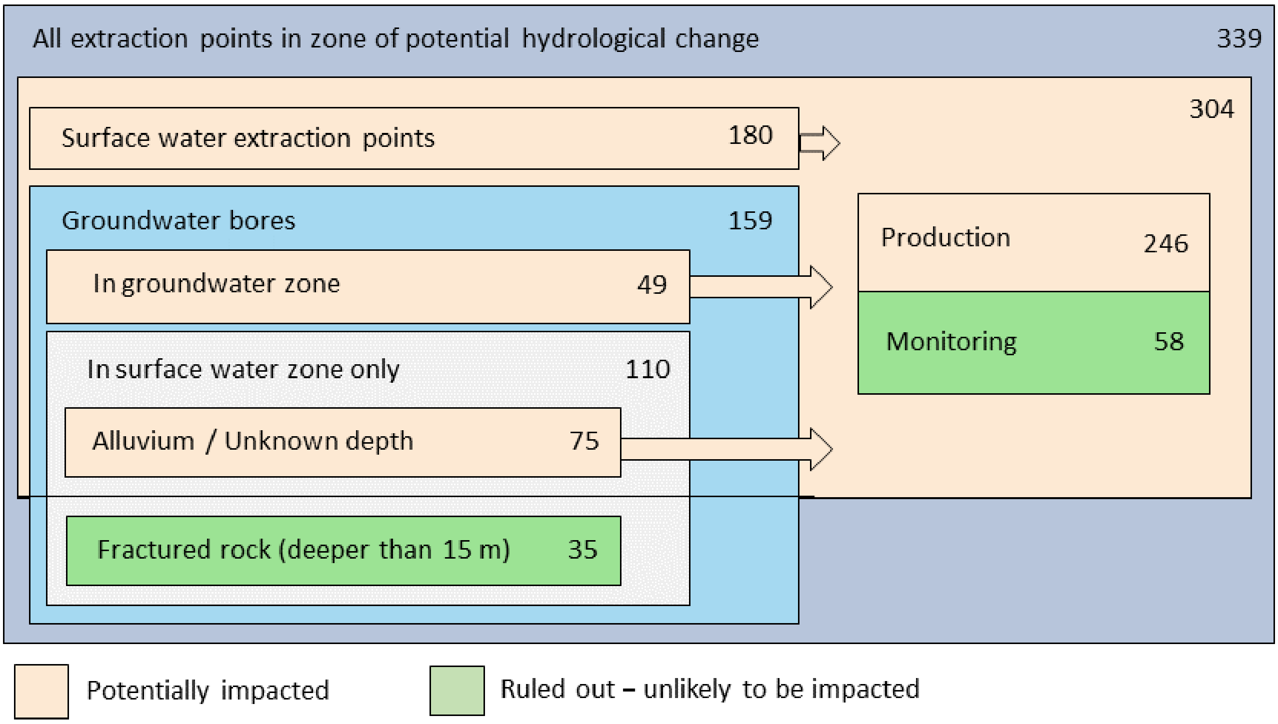

Figure 56 Rule-out process for extraction points within the Gloucester zone of potential hydrological change

Data: Bioregional Assessment Programme (Dataset 1, Dataset 7)

To determine whether the predicted hydrological changes due to additional coal resource development are likely to impact water rights holders, an assessment is made of changes in water availability and reliability of flows in the potentially impacted unregulated and alluvial water source areas. Groundwater production bores, located in areas where modelled drawdowns exceed minimal impact consideration thresholds, are identified as at risk of an economic impact. These three indicators of impact are considered in the following sections.

3.5.3.2 Potential impacts on surface water assets

To assess the potential impacts due to additional coal resource development on water availability in water sources of the Gloucester subregion, the change in mean annual flow at the most downstream model node in each water source is used. It is calculated as the difference in mean annual flow in each 30-year block between the CRDP and baseline and provides an indication of the potential change in water availability. Results are presented in Table 34 for the most downstream model node of the three water sources in the Lower North Coast Unregulated and Alluvial Water Sources plan area where the surface water modelling indicated a change in annual flow (AF) exceeding the chosen threshold. The average annual water availability under the baseline over the simulated 90-year period is included to show the variability in water availability, predominantly due to climate variability as well as to put the changes into context. In absolute terms, the biggest reductions in annual flows occur in the Upper Gloucester River (~0.86%) and Avon River (~1.83%) water sources (95th percentile of ~1.58 GL/year) between 2013 and 2042. Changes to water availability in the Karuah River water source are negligible (<0.11%), with the largest potential decrease in mean annual flow of 0.05 GL/year (95th percentile) occurring between 2073 and 2102.

Table 34 Change in water availability due to additional coal resource development (ACRD)

Average annual flow for 2013–2102 under the baseline is provided to show variability due to climate.

Water source[a]	Node	Baseline variability (GL/y)			Reduction due to ACRD (GL/y)								
		2013–2102			2013–2042			2043–2072			2073–2102		
		5th	50th	95th	5th	50th	95th	5th	50th	95th	5th	50th	95th
Upper Gloucester River	4	133	158	182	1.04	1.26	1.57	0.67	0.79	0.92	0.67	0.79	0.92
Avon River	6	59	71	86	1.04	1.26	1.58	0.67	0.80	0.93	0.67	0.80	0.93
Karuah River	25	31	38	44	0	0	0	0	0	0	0	0	0.05

[a]Water sources included are those where the surface water modelling showed a change in the annual flow (AF) hydrological response variable at the specified node exceeding the given threshold (see companion product 2.6.1 for the Gloucester subregion (Zhang et al., 2018)).
The change in water availability is shown for the 5th, 50th and 95th percentile estimates.
Data: Bioregional Assessment Programme (Dataset 8)

To ensure that sufficient water is retained in unregulated rivers to meet environmental requirements, NSW water sharing plans often specify rules governing extractions. These cease-to pump rules specify the river level/flow rate below which extractions from an alluvial water source, including the stream, are not permitted. In some water sources, these rules still attach to an individual licence holder's licence conditions, but the general trend is towards defining extraction rules by water source within water sharing plans. Cease-to-pump rules are defined with regard to all current water licence entitlements accessing either surface water or groundwater (in highly connected alluvial aquifers) – that is, rules assume full development rather than actual take.

Table 35 summarises the cease-to-pump rules for water sources in the zone of potential hydrological change where surface water modelling results also showed a change in the low-flow days (LFD) hydrological response variable exceeding the given threshold, defined in companion submethodology M06 (as listed in Table 1) for surface water modelling (Viney, 2016). The Karuah River water source is divided into two management zones, the Karuah estuarine management zone and Karuah upriver management zone, and different cease-to-pump rules apply in each management zone. Modelling results indicate that the Karuah estuarine management zone is not in the zone of potential hydrological change.

Table 35 Access rules for cease-to-pump for water sources in the surface water zone of potential hydrological change where there is a change in low-flow days due to additional coal resource development

Water source / Management zone	Access rule for cease-to-pump
Avon River	No visible inflow to, or outflow from, the pumping pool
Karuah River / estuarine	No visible inflow to, or outflow or lower than its full capacity, from natural pools
Karuah River / upriver	Flows are equal to or less than 3.5 ML/day at the reference point, Booral (Gauge Station Number 209003)
Upper Gloucester River	No visible inflow to, or outflow from, the pumping pool and flow at the Gloucester River gauge is equal to or less than 1 ML/day flow

The cease-to-pump rules indicate that differences in the number of zero-flow or low-flow days between the CRDP and baseline can be used to quantify the impact on pumping days due to additional coal resource development. Table 36 summarises the change in the number of cease-to-pump days due to additional coal resource development at model nodes (shown in Figure 54b) where there was a change in LFD exceeding the given threshold. Where cease-to-pump is triggered by ‘no visible flow’, the difference in the mean annual number of zero-flow days between the CRDP and baseline for each 30-year period is used to quantify the impact. Where cease-to-pump is based on the flow rate falling below a specified flow rate at a reference location, then the change is assessed using that flow threshold – that is, calculated as the difference in the mean annual number of days when flow is below the cease-to-pump flow rate threshold between the CRDP and baseline for each 30-year period. Due to technical issues in modelling zero flows, the change in the number of days of flows below 1 ML/day at model node 6 (shown in Figure 54b) has been used for the Avon River water source to assess the potential impact on cease-to-pump days in this water source. Table 36 includes the average number of cease-to-pump days under baseline over the analysis period (2013 to 2102), which provides an indication of the variability in cease-to-pump days as a result of climate variability.

Under the baseline for the 2013 to 2102 period, the surface water modelling results indicate there is 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/year and 35 days/year, respectively. For the Avon River water source, there is a 5% chance of 80 or more days of flows below 1 ML/day, which is not the cease-to-pump threshold, but an indicator of the low-flow regime for the 90-year climate sequence modelled. In at least 50% of years in both water sources, there are unlikely to be any cease-to-pump days in the Karuah River or Upper Gloucester River water sources, but the Avon River can expect some low-flow days, although not necessarily cease-to-pump days. The impact on cease-to-pump days due to additional coal resource development in the Karuah River and Upper Gloucester River water sources is insignificant, with even the 95th percentile change being less than one day. In the Avon River, there is a 95% chance that the increase in days with flow <1 ML/day will be fewer than three in all three 30-year periods.

Table 36 Increase in cease-to-pump days due to additional coal resource development (ACRD) in water sources in the zone of potential hydrological change

Water source / Management Zone[a]	Node	Flow threshold (ML/day)	Baseline variability			Increase due to ACRD (days/year)								
			2013–2102			2013–2042			2043–2072			2073–2102		
			5th	50th	95th	5th	50th	95th	5th	50th	95th	5th	50th	95th
Avon River	6	1	0	16	80	0	0.08	1.25	0	0.1	2.45	0	0.1	2.77
Karuah River / upriver	28	3.5	0	0	50	0	0	0.03	0	0	0.03	0	0	0.03
Upper Gloucester River	4	1	0	0	35	0	0	0.08	0	0	0.13	0	0	0.13

[a]Water sources included are those where the surface water modelling showed a change in the low-flow days (LFD) hydrological response variable exceeding the given threshold at the specified node (see companion product 2.6.1 for the Gloucester subregion (Zhang et al., 2018)).
The increase in cease-to-pump days is shown for the 5th, 50th and 95th percentile estimates.
Data: Bioregional Assessment Programme (Dataset 8)

3.5.3.3 Potential impacts on groundwater assets

Environmental provisions relating to extractions from aquifers are intended to protect the long-term storage component of the aquifer. Extractions are based on reserving a proportion of recharge for the environment. Cease-to-pump rules are used to restrict pumping when levels drop below some specified level or water quality is deteriorating. The *NSW Aquifer Interference Policy* (NSW Department of Primary Industries, 2012), which was introduced in September 2012, is intended to protect groundwater resources from activities that potentially interfere with them. It requires that all water extracted from an aquifer must be accounted for, that the activity must address minimal impact considerations and planning must make provision for situations where actual impacts are greater than predicted.

Minimal impact thresholds are specified for highly productive and less productive groundwater sources and different aquifer types (alluvial, coastal sands, porous rock and fractured rock), but can generally be defined as <10% cumulative variation in watertable level, 40 m from any high-priority GDE or culturally significant site, with a maximum decline of 2 m at any water supply work. Make good provisions could apply, unless it can be demonstrated to the Minister's satisfaction that the interference will not prevent the long-term viability of the GDE or culturally significant site, or impact a licensed water holder's access to their entitlement. For groundwater quality, minimal impacts are defined as no lowering of the beneficial-use category of the groundwater source beyond 40 m from the activity and a <1% increase in groundwater salinity in a highly connected surface water source at the nearest point to the activity.

As previously stated, there are 49 groundwater bores in the groundwater zone of potential hydrologic change. Of these, five have at least a 5% chance of experiencing a drawdown greater than 2 m due to additional coal resource development (Table 37). Three of these, including one production bore, are in the mine pit exclusion zone and might be, or have been, removed in the process of mine pit excavation. One is a monitoring bore and groundwater drawdown of any magnitude is unlikely to result in an economic impact. One is a production bore, where an economic impact might result if the licence holder's access to groundwater under their entitlement is affected. This bore is owned by AGL and therefore not likely to result in an impact that would require AGL to compensate another party (Figure 57). However, if the additional coal resource development at Rocky Hill is the cause of drawdown, then Rocky Hill might be required to compensate AGL or other affected license holder. The relative contributions to drawdown from each development were not modelled.

Using the 50% percentile to define the 'more at risk' bores, there are no bores outside the mine pit exclusion zone identified as more at risk. Figure 57 provides a graphical summary of the number of bores in the zone and those where regional scale modelled drawdowns exceed the minimal impact consideration threshold based on 95th and 50th percentile results. The locations of these bores are shown in Figure 58.

Table 37 Number of bores where maximum drawdown due to additional coal resource development (ACRD) is predicted to be greater than 2 m

Water source	Groundwater bearing unit	Mine pit exclusion zone	Change due to ACRD (number of bores)					
			Production[a]			Monitoring[b]		
			5th	50th	95th	5th	50th	95th
Gloucester Basin	Fractured rock	1	0	0	1	0	0	1
New England Fold Belt Coast	Fractured rock	0	0	0	0	0	0	0
Avon River	Alluvium	2	0	0	0	0	0	0
Karuah River	Alluvium	0	0	0	0	0	0	0
Upper Gloucester River	Alluvium	0	0	0	0	0	0	0
Lower Barrington/Gloucester River	Alluvium	0	0	0	0	0	0	0
Total		**3**	**0**	**0**	**1**	**0**	**0**	**1**

[a]Production bores are associated with a water access licence or basic water right.
[b]Monitoring bores are part of the 'Water supply and monitoring infrastructure' asset class.
The number of bores where maximum drawdown due to ACRD is predicted to be greater than 2 m is shown for the 5th, 50th and 95th percentile estimates.
ACRD = additional coal resource development
Data: Bioregional Assessment Programme (Dataset 7)

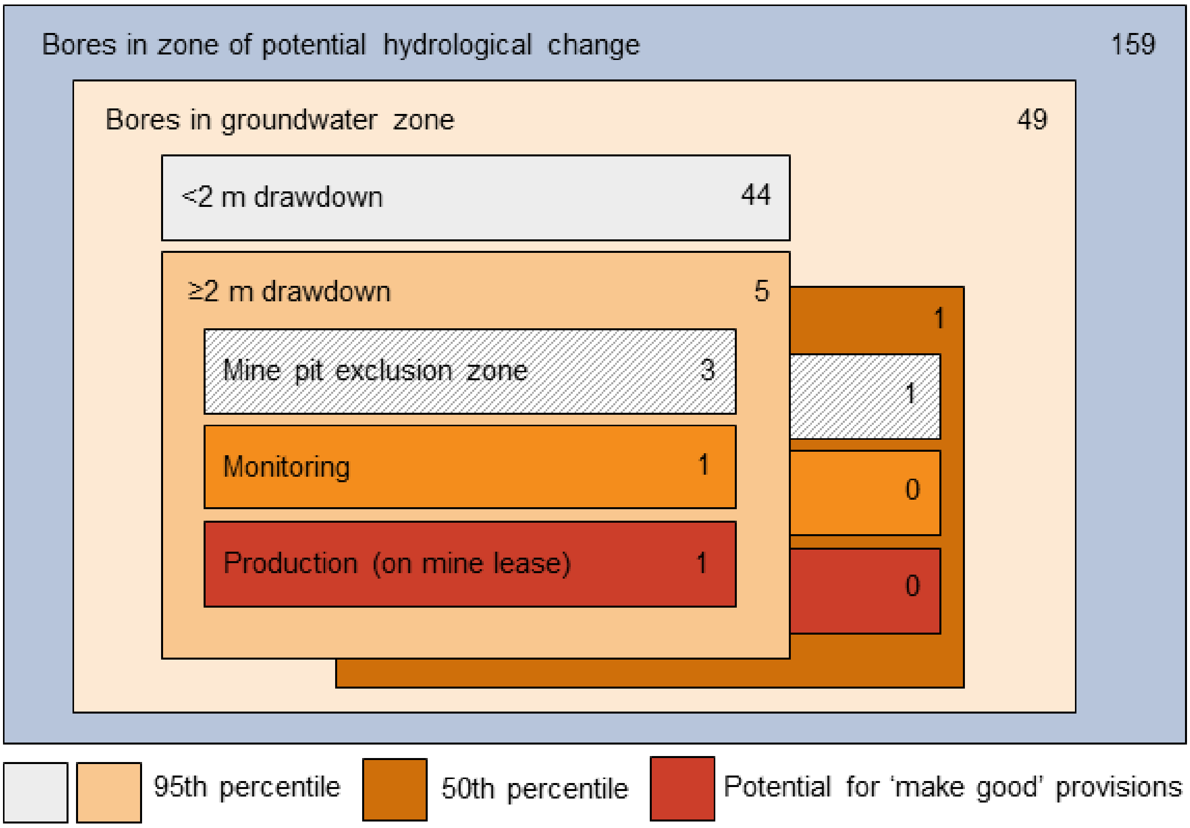

Figure 57 Summary of number of bores in the zone of potential hydrological change (95th percentile), and those with at least 5% and 50% chances that the minimal impact threshold due to additional coal resource development is exceeded

Data: Bioregional Assessment Programme (Dataset 7)

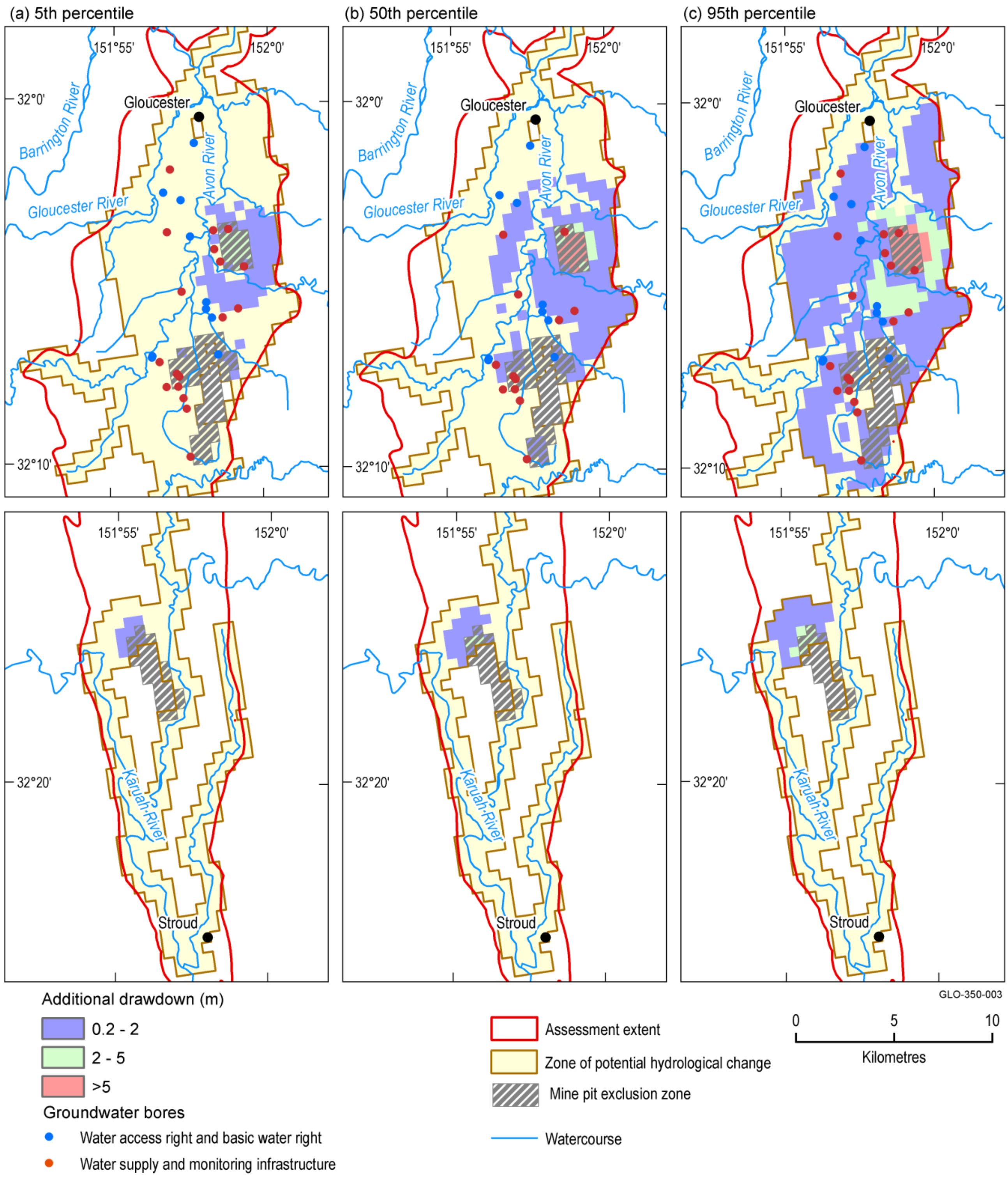

Figure 58 Bores that experience a greater than 2 m decline in the watertable due to additional coal resource development (5th, 50th and 95th percentiles)

Data: Bioregional Assessment Programme (Dataset 1, Dataset 4, Dataset 7)

3.5.4 Sociocultural assets

Of the 19 sociocultural assets identified as water-dependent, for which spatial information was available, the ‘Washpool – locally significant heritage site’ in the Karuah River, north of the town site of Washpool (Figure 49), is the only one in the zone of potential hydrological change. This asset fell within the ‘Cultural’ subgroup and ‘Heritage site’ class of assets and was originally nominated by the Gloucester Shire Council owing to its history as a site where sheep were shorn and washed during the early period of settlement within the area. Its polygon intersects 40 m of the 'Perennial – high gradient bedrock confined streams' landscape class for which no qualitative or receptor impact model was developed. Surface water modelling results found no significant change (defined in Section 3.3.1.2, Table 5) in annual flow (AF) or high-flow days (FD) in the reaches immediately upstream or downstream of the Washpool (Figure 19 and Figure 22 in Section 3.3). There were potentially small increases (95% chance that any increase is less than 3 days) in the number of low-flow days per year (LFD) immediately upstream of the Washpool (Figure 16 in Section 3.3), but not at the nearest downstream node. Based on these small hydrological changes, any change in water level at the Washpool is unlikely to impact the social amenity provided by the Washpool.

Fifteen indigenous assets were included in the sociocultural asset register. These included 11 assets for which locations were not provided. Based on the association of these assets with marine and estuarine environments, it is unlikely that these assets would be impacted. Information on indigenous water assets is also available in the Aboriginal Cultural Water Values – Gloucester subregion report (Constable and Love, 2015).

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3.6 Commentary for coal resource developments that were not modelled

Summary

When the coal resource development pathway (CRDP) for the Gloucester subregion was finalised in October 2015, the Gloucester Gas Project Stage 2 and beyond was identified as an additional coal resource development. Yet due to quantitative information (such as (i) geographic location(s) of the subsequent stage(s), (ii) number of wells in the subsequent stage(s), and (iii) depth of coal seam gas (CSG) wells in subsequent stage(s)), not being publicly available at the time, the Gloucester Gas Project Stage 2 and beyond were not able to be numerically modelled. Due to operational factors, if such subsequent stage(s) were to go ahead they would likely be located to the west and south of Gloucester Gas Project Stage 1. The hydrological effects of these subsequent stage(s) can be evaluated with the model framework documented in companion product 2.6.2 for the Gloucester subregion (Peeters et al., 2018), provided production bore locations and timing are known.

In February 2016 AGL formally announced that they were not pursuing the Gloucester Gas Project.

When the coal resource development pathway (CRDP) for the Gloucester subregion was finalised in October 2015 (see Table 8 in Section 2.3.4.1 in companion product 2.3 for the Gloucester subregion (Dawes et al., 2018)), the Gloucester Gas Project Stage 2 and beyond was identified as an additional coal resource development. Yet due to quantitative information (such as (i) geographic location(s) of the subsequent stage(s), (ii) number of wells in the subsequent stage(s), and (iii) depth of coal seam gas (CSG) wells in subsequent stage(s)), not being publicly available at the time of the CRDP finalisation, the Gloucester Gas Project subsequent stage(s) were not able to be numerically modelled.

If subsequent stage(s) of the Gloucester Gas Project were implemented, it is envisaged that they would be located to the west of and further south of Stage 1 for a number of reasons. Firstly, part of the Gloucester Gas Project Stage 1 plan was to build a pipeline south from Gloucester to Hexham (near Newcastle) for post-extraction processing/purification, so any subsequent stages would likely be south of Stage 1 to optimally connect to this pipeline. Secondly, Stage 1 is located in the north-east of PEL285 and the NSW Government exclusion zone around urban areas, including the town of Gloucester, essentially diminishes the likelihood of CSG development north of the town where the geological Gloucester Basin narrows (Dawes et al., 2018, Section 2.3.4.1, p. 51). In other words, going north from Stage 1 would mean additional pipeline would need to be built and, with limited areas from which to extract CSG, this appears to be not economically viable.

Groundwater numerical modelling for the Gloucester Basin (companion product 2.6.2 for the Gloucester subregion (Peeters et al., 2018)) does not allow for attributing drawdown or changes in surface water – groundwater flux to individual developments. It is therefore not possible to separate the hydrological impacts of CSG extraction from those of coal mining. It is therefore not possible to extrapolate the current model results to provide an indication of what the hydrological impacts of subsequent Gloucester Gas Project stage(s) would be, although the model framework can be used to simulate these changes if bore locations and production schedules are known.

In general, the groundwater modelling results (from this subregion and other regions) indicate that open-cut coal mining results in large drawdowns in close proximity to the mine footprints, whereas CSG operations tend to result in smaller drawdowns, but with a larger spatial extent.

In February 2016, AGL formally announced that they were not pursuing the Gloucester Gas Project (AGL Energy Limited, 2016). As a result, neither Stage 1 nor Stage 2 are likely to proceed.

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3.7 Conclusion

Summary

Overall, additional coal resource development in the Gloucester subregion is predicted to lead to changes in groundwater drawdown and streamflow that are small in both magnitude and area. While there is large uncertainty in future ecological trends, the changes in hydrology due to additional coal resource development are generally so small that adverse ecological impacts are unlikely. There are some stream reaches in the vicinity of the Rocky Hill, Stratford and Duralie mines where hydrological changes were not able to be quantified. The possibility of significant ecological impacts in these streams cannot be ruled out.

These regional-scale results do not replace the need for detailed site or project specific studies, nor should they be used to pre-empt the results of detailed studies that may be required under NSW legislation. Where potentially significant impacts are identified from the regional scale analysis, local scale information should be used to better define the risk.

There is much more confidence around the areas and assets that are *very unlikely* to be impacted (those outside the zone of potential hydrological change). Within the zone, any further monitoring to determine potential impacts of additional coal resource development 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.

To increase confidence in groundwater, surface water and receptor impact modelling, the focus should be on better characterisation of hydraulic properties; improving understanding of the role of faults in conducting or retarding groundwater flows; mapping depth to groundwater; and improving the mapping, identification and characterisation of groundwater-dependent ecosystems in the subregion.

Future cumulative impact assessments should also explicitly assess the cumulative impacts of baseline coal mines, as well as changes in other land uses and include climate variability and change.

3.7.1 Key finding

Overall, additional coal resource development in the Gloucester subregion is predicted to lead to changes in groundwater drawdown and streamflow that are small in both magnitude and area. While there is large uncertainty in future ecological trends, the changes in hydrology due to additional coal resource development are generally so small that adverse ecological impacts are unlikely. There are some stream reaches in the vicinity of the Rocky Hill, Stratford and Duralie mines where hydrological changes were not able to be quantified. The possibility of significant ecological impacts in these streams cannot be ruled out.

3.7.2 Future monitoring

Post-assessment monitoring is important to test and (in)validate the risk predictions of the Assessment. At the highest level, monitoring efforts should reflect the risk predictions, and focus the effort where the changes are expected to be the largest. However, it is important to place some monitoring effort at locations with lower risk predictions so as to confirm the range of potential impacts and identify unexpected outcomes.

The bioregional assessment for the Gloucester subregion indicated limited potential for hydrological or ecosystem impacts due to the additional coal resource development beyond some localised changes, particularly in the north. Therefore, from a management perspective, there might not be a strong motivation to invest in new monitoring to determine regional effects, beyond the more local monitoring required by mining proponents under their conditions of operation. Monitoring to address knowledge gaps, such as the role of faults in groundwater – surface water connectivity or the effect of aquitards could contribute to reducing predictive uncertainty in the modelling.

Any groundwater monitoring effort should be directed to the area surrounding the Rocky Hill, Gloucester Gas Project and Stratford mine developments, where modelling indicates some potential for cumulative drawdown effects. Changes to the coal resource development pathway in the Gloucester subregion, such as AGL's decision to not proceed with the Gloucester Gas Project, should be factored into any groundwater monitoring planning.

Any future surface water monitoring should also be directed to streams in this area to better understand the connection between changes in groundwater level and streamflow regimes and the relative contributions to changes in streamflow from groundwater drawdown and changes in catchment runoff. Local information on, for example, stream condition, habitat value, recovery potential and existence of other stressors, is needed to determine actual priorities. Better condition streams, such as Waukivory Creek and the Avon River downstream of the Stratford mine, which have been mapped as being in moderate geomorphic condition and which support a relatively continuous fringe of forested wetlands, are likely to be a higher priority for protection and management than more degraded streams such as Avondale Creek and Dog Trap Creek, which are mapped as being in poor geomorphic condition and having a patchier distribution of forested wetlands.

3.7.3 Using this impact and risk analysis

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 emphasised through the 'rule-out' process, which focuses on areas where hydrological changes are predicted. In doing so, the Gloucester subregion bioregional assessment 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 predicts the likelihood of exceeding levels of potential hydrological change at a regional level. It also provides important context to identify potential issues that may need to be addressed in local-scale environmental impact assessments of new coal resource developments. It should help project proponents to meet legislative requirements to describe the environmental values that may be affected by the exercise of underground water rights, and to adopt strategies to avoid, mitigate or manage the predicted impacts. These assessments do not investigate the broader social, economic 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 (CSG) extraction projects under Australian or state environmental law. Such assessments may use finer-scale groundwater and surface water models and, using other data / modelling approaches, 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.

Bioregional assessments have been developed with the ability to be updated, for example, to incorporate new coal resource developments in the groundwater model. Existing datasets such as the water-dependent asset register remain relevant for future assessments. 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 (CRDP). It may also be applicable for other types of resource development.

The full suite of information, including information for individual assets, is provided at www.bioregionalassessments.gov.au. Access to underpinning datasets, including shapefiles of 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 detailed scientific submethodologies (Table 1).

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.

3.7.4 Gaps, limitations and opportunities

This impact and risk analysis allows governments, industry and the community to focus on areas that are potentially impacted when making regulatory, water management and planning decisions. Due to the conservative nature of the modelling, the greatest confidence in results is for those areas that are *very unlikely* to be impacted (that is, outside the zone of potential hydrological change). Where potential impacts have been identified, further work may be required to obtain better predictions of the potential magnitude of impacts to ecosystems and individual assets.

Key knowledge gaps have been identified in each of the Gloucester reports. This section provides a summary of the key knowledge gaps where understanding the potential impacts of coal resource developments can be improved through further work.

3.7.4.1 Overall

Additional coal resource development is likely to be in the northern half of the subregion, with an expansion of the Stratford mine and a new mine at Rocky Hill, along with Stage 1 of the Gloucester Gas Project. As a result, groundwater drawdown and changes in streamflow are also greater in this part of the subregion potentially impacting an area north-east of Stratford and including Avondale Creek, Dog Trap Creek, Waukivory Creek, Oaky Creek and the Avon River. Any additional monitoring of groundwater levels and/or surface water should therefore focus on these areas.

3.7.4.2 Assessing ecological impacts

Additional vegetation mapping and ongoing research to identify groundwater-dependent ecosystems in the subregion would improve assessment of impacts on water-dependent assets. Additionally, tracking the biophysical processes, such as rate of actual evapotranspiration and vegetation growth rates, of the groundwater-dependent ecosystems and interpreting these in an ecohydrological framework will improve understanding of the interactions between changes in groundwater availability and the health of terrestrial vegetation that relies on groundwater. This can be performed by field measurement and/or use of time series remote sensing.

As actual water requirements of different plant communities are only approximately known, future assessments would be assisted by more work to identify suitable bio-indicators of ecosystem condition, or alternative methods of assessing the condition of water-dependent ecosystems. Again, this is likely best performed using field measurement and/or time series remote sensing.

3.7.4.3 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 knowledge of groundwater recharge processes and interactions between rivers and groundwater. However, this information provides limited understanding of deeper groundwater systems which are targeted by CSG 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.

Also, future investigations of the mapping of depth to groundwater, and its spatial and temporal variation, 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 groundwater changes at different depths.

3.7.4.4 Geology

Groundwater modelling conducted in this assessment demonstrates that faults are likely to have minimal impact on changes in groundwater due to additional coal resource development. However, there remains a knowledge gap in the geological understanding of the Gloucester geological basin regarding the number of faults, their orientations and other physical characteristics.

The modelling did highlight that improved characterisation of hydraulic properties of the surface weathered and fractured rock layer and more detailed information of local geology around developments have the most potential to reduce predictive uncertainty.

3.7.4.5 Water quality

Changes in water quality parameters that could occur with a shift in the relative contributions of surface runoff and groundwater to streamflow or due to enhanced connectivity between aquifers of differing water quality, for example, are not represented in the models. Modelling the changes in water quality was not part of the scope of the bioregional assessments. Some inferences about potential changes in stream salinity were made in Section 3.3.4; the relatively small changes in hydrology were not expected to lead to significant changes in stream salinity at a regional scale.

3.7.4.6 Climate change and land use

In comparing results under two different futures in this assessment, factors such as climate change and land use are held constant. Future assessment iterations could look to include these and other stressors to more fully predict cumulative impacts on a landscape scale. There is a relatively low density of meteorological stations in the subregion and to increase the level of predictability of rainfall estimates for rainfall-runoff modelling, it would be beneficial if additional rainfall gauges were installed in the mountain ranges along the eastern edge of the Gloucester subregion. While other meteorological variables would also benefit from being measured with enhanced spatial density, the overall gain would be minimal when compared to measuring rainfall with greater accuracy.

Glossary

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

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

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

analytic element model: a groundwater model in which the groundwater flow equations are solved based on the representation of internal boundary conditions, points, lines or polygons where constant groundwater level, constant flux or flux dependence on groundwater level is imposed (Bakker, 2013). The resulting groundwater flow equations can be evaluated at arbitrary points in space and time. The solution is therefore independent of a spatial discretisation of the model domain into grids, and a temporal discretisation into time steps, as is necessary for finite element or finite difference groundwater models.

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

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

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

assessment unit: for the purposes of impact analysis, a geographic area that is used to partition the entire assessment extent into square polygons that do not overlap. The spatial resolution of the assessment units is closely related to that of the bioregional assessment groundwater modelling and is, typically, 1 x 1 km. Each assessment unit has a unique identifier. The partitioned data can be combined and recombined into any aggregation supported by the conceptual modelling, causal pathways and model data.

asset: an entity that has value to the community and, for bioregional assessment purposes, is associated with a subregion or bioregion. Technically, an asset is a store of value and may be managed and/or used to maintain and/or produce further value. Each asset will have many values associated with it and they can be measured from a range of perspectives; for example, the values of a wetland can be measured from ecological, sociocultural and economic perspectives.

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

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

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

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

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

dataset: a collection of data in files, in databases or delivered by services that comprise a related set of information. Datasets may be spatial (e.g. a shape file or geodatabase or a Web Feature Service) or aspatial (e.g. an Access database, a list of people or a model configuration file).

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)

dmax: maximum difference in drawdown, obtained by choosing the maximum of the time series of differences between two futures. For example, to calculate the difference in drawdown between the coal resource development pathway (CRDP) and baseline, use the equations dmax = max (dCRDP(t) – dbaseline(t)) where d is drawdown, or dmax = max (hbaseline(t) – hCRDP(t)) where h is groundwater level and t is time.

dmaxRef: maximum difference in drawdown under the baseline future or under the coal resource development pathway future relative to the reference period (1983 to 2012). This is typically reported as the maximum change due to additional coal resource development.

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

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

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

EventsR0.3: the mean annual number of events with a peak daily flow exceeding the threshold (the peak daily flow in flood events with a return period of 0.3 years as defined from modelled baseline flow in the reference period (1983 to 2012)). This metric is designed to be approximately representative of the number of overbench flow events in future 30-year periods. This is typically reported as the maximum change due to additional coal resource development.

EventsR3.0: the mean annual number of events with a peak daily flow exceeding the threshold (the peak daily flow in flood events with a return period of 3.0 years as defined from modelled baseline flow in the reference period (1983 to 2012)). This metric is designed to be approximately representative of the number of overbank flow events in future 30-year periods. This is typically reported as the maximum change due to additional coal resource development.

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

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).

impact mode: the manner in which a hazardous chain of events (initiated by an impact cause) could result in an effect (change in the quality and/or quantity of surface water or groundwater). There might be multiple impact modes for each activity or chain of events.

Impact Modes and Effects Analysis: a systematic hazard identification and prioritisation technique based on Failure Modes and Effects Analysis

interquartile range (IQR): the interquartile range in daily flow (ML/day); that is, the difference between the daily flow rate at the 75th percentile and at the 25th percentile. This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102).

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

length of low-flow spell (LLFS): the length (days) of the longest low-flow spell each year. This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102).

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.

low-flow spells (LFS): the number of low-flow spells 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). A spell is defined as a period of contiguous days of flow below the 10th percentile threshold.

material: pertinent or relevant

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: flood condition where water flows beyond and sub-parallel to the main channel of a river, but within the bounding floodplain

P01: the daily flow rate at the 1st percentile (ML/day). This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102).

P99: the daily flow rate at the 99th percentile (ML/day). This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102).

percentile: a specific type of quantile where the range of a distribution or set of runs is divided into 100 contiguous intervals, each with probability 0.01. An individual percentile may be used to indicate the value below which a given percentage or proportion of observations in a group of observations fall. For example, the 95th percentile is the value below which 95% of the observations may be found.

preliminary 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 PAE is estimated at the beginning of a bioregional assessment, and is updated to the 'assessment extent' on the basis of information from Component 1: Contextual information and Component 2: Model-data analysis.

probability distribution: the probability distribution of a random variable specifies the chance that the variable takes a value in any subset of the real numbers. It allows statements such as 'There is a probability of x that the variable is between a and b'.

QBFI: ratio of total baseflow generation to total streamflow generation, averaged over a 30-year period. This is typically reported as the maximum change due to additional coal resource development.

quantile: a set of values of a variate that divide the range of a probability distribution into contiguous intervals with equal probabilities (e.g. 20 intervals with probability 0.05, or 100 intervals with probability 0.01). Within bioregional assessments, probability distributions are approximated using a number of runs or realisations.

receptor: a point in the landscape where water-related impacts on assets are assessed

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

riparian: An area or zone within or along the banks of a stream or adjacent to a watercourse or wetland; relating to a riverbank and its environment, particularly to the vegetation.

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.

severity: magnitude of an impact

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

stressor: chemical or biological agent, environmental condition or external stimulus that might contribute to an impact mode

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

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

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 spells (LFS)), the threshold is a 5% chance of a change of 2 spells per year.

tmaxRef: the year that the maximum difference in drawdown relative to the reference period (1983 to 2012) (dmaxRef) occurs transparency: a key requirement for the Bioregional Assessment Programme, achieved by providing the methods and unencumbered models, data and software to the public so that experts outside of the Assessment team can understand how a bioregional assessment was undertaken and update it using different models, data or software

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 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-dependent asset register: a simple and authoritative listing of the assets within the preliminary assessment extent (PAE) that are potentially subject to water-related impacts

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

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

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).

Landscape classification

Definitions for landscape classes and landscape groups for the Maranoa-Balonne-Condamine subregion are provided below. The register of terms and definitions for the landscape classification for each bioregion and subregion in the Bioregional Assessment Programme is available online at http://environment.data.gov.au/def/ba/landscape-classification.

- 'Economic land use' landscape group: Landscape classes managed primarily for economic activities
  - 'Dryland agriculture' landscape class: The 'Dryland agriculture' landscape class includes land that is used principally for primary production, based on dryland farming systems. Native vegetation has largely been replaced by introduced species through clearing, the sowing of new species, the application of fertilisers or the dominance of volunteer species. The range of activities in this category includes pasture production for stock, cropping and fodder production, and a wide range of horticultural production.
  - 'Intensive uses' landscape class: The 'Intensive uses' landscape class includes land uses that involve high levels of interference with natural processes, generally in association with closer settlement. The level of intervention may be high enough to completely remodel the natural landscape – the vegetation, surface water and groundwater systems, and the land surface.
  - 'Irrigated agriculture' landscape class: The 'Irrigated agriculture' landscape class includes agricultural land uses where water is applied to promote additional growth over normally dry periods, depending on the season, water availability and commodity prices. This includes land uses that receive only one or two irrigations per year, through to those uses that rely on irrigation for much of the growing season.
  - 'Plantation or production forestry' landscape class: The 'Plantation or production forestry' landscape class includes land on which plantations of trees or shrubs (native and exotic species) have been established for production, or environmental and resource protection purposes.
  - 'Water' landscape class: The 'Water' landscape class includes water features important for natural resource management, agricultural production and as points of reference in the landscape. This landscape class includes both natural and artificial water bodies that are not otherwise defined in this classification.
- 'Estuarine' landscape group: Partially enclosed coastal water body, connected to the ocean with one or more streams flowing into it
  - 'Barrier river' landscape class: The 'Barrier river' landscape class includes permanently open systems that are typically mature barrier riverine estuaries or mature forms of wave-dominated estuaries. Dilution factors range from 0.1 to 3 and flush times range from 3 to 30 days. Estuarine barrier rivers occur towards the coast and the flow regimes are modified by tidal processes, they may have permanent pools, and the riverbed typically consists of fine-grained sedimentary material. Water will be saline to brackish depending on the input from upstream catchments. In the Gloucester subregion the estuarine reaches of the Karuah River are classified as a barrier river.

 - 'Saline wetlands' landscape class: Wetlands in the 'Saline wetlands' landscape class occur on areas of impeded drainage with high levels of salt such as estuarine areas or inland lakes where high levels of evaporation lead to the accumulation of surface salts. Saline wetlands are dominated by halophilic species, including mangroves and saltmarshes. In the Gloucester subregion saline wetlands are in the estuarine reaches of the Karuah River and are mainly mangroves with some saltmarshes. Saline wetlands are habitats for animals such as waterbirds and migratory birds, as well as fish and a diverse assemblage of invertebrates.
- 'Groundwater-dependent ecosystem' landscape group: Terrestrial ecosystems that rely on groundwater for some or all of their water requirements
  - 'Dry sclerophyll forests' landscape class: Forests in the 'Dry sclerophyll forests' landscape class are open forests (canopy cover >50%, <75%) that include a wide range of structural and floristic types. In general they occur on nutritionally poorer substrates or in relatively drier situations than the wet sclerophyll forests. On moderately poor soils these forests may develop a dense, grassy understorey with a more open shrub layer (shrub/grass subformation), while on the poorest substrates (sands and sandstones) a dense, sclerophyllous shrub layer dominates. Fire often plays an important role in the ecology of these forests. Groundwater is thought to play a role in the maintenance of the structure and function of this landscape class.
  - 'Forested wetlands' landscape class: The 'Forested wetlands' landscape class consists of various wetlands dominated by tree species occurring on major riverine corridors and floodplains. These communities are dominated by sclerophyllous species similar to those in drier sclerophyll communities, but with hydrophilic species dominating an inundated understorey.
  - 'Freshwater wetlands' landscape class: The 'Freshwater wetlands' landscape class includes areas where permanent inundation by water, either still or moving, dominates ecological processes. They occur in a range of environments where local relief and drainage result in open surface water at least part of the time and often play a range of vital roles in the functioning of ecosystems. The periodicity and duration of inundation in wetlands often determines to a large extent the suite of species present as do the extent and depth of water.
  - 'Rainforests' landscape class: The 'Rainforests' landscape class consists of forests with a closed canopy (>75%) generally dominated by non-eucalypt species with soft, horizontal leaves, although various eucalypt species may be present as emergents. Rainforests tend to be restricted to relatively fire-free areas of consistently higher moisture and nutrient levels than the surrounding sclerophyllous forests.

- 'Wet sclerophyll forests' landscape class: Forests in the 'Wet sclerophyll forests' landscape class are dominated by trees of the Myrtaceae family, particularly of the genera Eucalyptus, Angophora, Corymbia, Syncarpia and Lophostemon. Dominant tree species tend to have smaller, hard leaves and be adapted, to varying extents, to the occurrence of wild fires. Wet sclerophyll forests are restricted to areas of higher rainfall and moderate fertility and often include a dense understorey of soft-leaved rainforest shrubs and small trees in moister situations (shrubby subformation). In drier situations these forests may have an open, grassy understorey (grassy subformation) with a sparse, sclerophyllous shrub layer.

- 'Non-GDE' landscape group: Native forests, open forests or other natural vegetation communities not dependent on groundwater
  - 'Native vegetation' landscape class: The 'Native vegetation' landscape class consists of native forests, open forests or other natural vegetation communities that are not dependent on groundwater.
- 'Riverine' landscape group: Related to, formed by, or resembling a river, or situated on the banks of a river or stream
  - 'Intermittent – gravel/cobble streams' landscape class: Streams in the 'Intermittent–gravel/cobble streams' landscape class are those where the streambed consists of mixed materials, mostly gravels ranging from 2 to 256 mm in size. The mixed substrate forms alternating pool and riffle sequences that increase the geomorphic and habitat complexity along the reach. The riverine environment is typically lined with riparian vegetation that increases bank stability and habitat heterogeneity. Streams in the Gloucester subregion are classified as being lowly intermittent, indicating that they have flows greater than 0 ML/day for more than 80% of the time. Groundwater discharge may contribute to baseflow but generally to a lesser extent than in perennial streams.
  - 'Intermittent – high gradient bedrock confined streams' landscape class: Streams in the 'Intermittent – high gradient bedrock confined streams' landscape class are typically upland streams where the streambed is in direct contact with the underlying bedrock for more than 90% of its length. These streams normally occur in tightly confined valleys and there is little floodplain development. Typically streams respond quickly to rainfall events in the catchment. Streams in the Gloucester subregion are classified as being lowly intermittent, indicating that they have flow greater than 0 ML/day for more than 80% of the time. Groundwater discharge may contribute to baseflow but generally to a lesser extent than in perennial streams.

- 'Intermittent – lowland fine streams' landscape class: Streams in the 'Intermittent – lowland fine streams' landscape class occur at lower elevations in the landscape, and typically have lower flow rates than rivers and streams at higher elevations. Pools are generally absent from river reaches in this landscape class, turbidity may be higher due to higher sediment loads and stream temperatures may be higher due to lower flow rates. Streams in the Gloucester subregion are classified as being lowly intermittent, indicating that they have flow greater than 0 ML/day for more than 80% of the time. Groundwater discharge may contribute to baseflow but generally to a lesser extent than in perennial streams. Streams in the 'Perennial – lowland fine streams' landscape class occur at lower elevations in the landscape, and typically have lower flow rates than rivers and streams at higher elevations. Pools are generally absent from river reaches in this landscape class, turbidity may be higher due to higher sediment loads and stream temperatures may be higher due to lower flow rates. Perennial streams are those where the flow is typically above 0 ML/day. Groundwater may contribute to maintaining baseflow.
- 'Perennial – gravel/cobble streams' landscape class: Streams in the 'Perennial – gravel/cobble streams' landscape class are those where the streambed consists of mixed materials ranging from 2 to 256 mm in size. The mixed substrate forms alternating pool and riffle sequences that increase the geomorphic and habitat complexity along the reach. The riverine environment is typically lined with riparian vegetation that increases bank stability and habitat heterogeneity. Perennial streams are those where the flow is typically above 0 ML/day. Groundwater may contribute to maintaining baseflow.
- 'Perennial – high gradient bedrock confined streams' landscape class: Streams in the 'Perennial – high gradient bedrock confined streams' landscape class are typically upland streams where the streambed is in direct contact with the underlying bedrock for more than 90% of its length. These streams normally occur in tightly confined valleys and there is little floodplain development. Typically streams respond quickly to rainfall events in the catchment and groundwater discharge may contribute to baseflow maintenance. Perennial streams are those where the flow is typically above 0 ML/day. Groundwater may contribute to maintaining baseflow.
- 'Perennial – lowland fine streams' landscape class: Streams in the 'Perennial – lowland fine streams' landscape class occur at lower elevations in the landscape, and typically have lower flow rates than rivers and streams at higher elevations. Pools are generally absent from river reaches in this landscape class, turbidity may be higher due to higher sediment loads and stream temperatures may be higher due to lower flow rates. Perennial streams are those where the flow is typically above 0 ML/day. Groundwater may contribute to maintaining baseflow.
- 'Perennial – transitional fine streams' landscape class: Streams in the 'Perennial – transitional fine streams' landscape class are those where the streambed consists mainly of fine-grained sedimentary material. These streams typically occur in mid catchment, between upland and lowland streams. Flow is perennial in nature, meaning that zero-flow days typically occur less than 20% of the time and groundwater discharge may contribute to maintaining baseflow.

4 Risk analysis for the Gloucester subregion

Originally the risk analysis was intended to be reported independently of the impact analysis. Instead it has been combined with the impact analysis as product 3-4 to improve readability. For risk analysis see Section 3 of this product.

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