Australian Government

BIOREGIONAL ASSESSMENTS

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

Coal and coal seam gas resource assessment for the Gloucester subregion

Product 1.2 for the Gloucester subregion from the Northern Sydney Basin Bioregional Assessment

27 October 2014

A scientific collaboration between the Department of the Environment, 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 direct, indirect and cumulative 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. The Department of the Environment, 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

The Office of Water Science, within the Australian Government Department of the Environment, is strengthening the regulation of coal seam gas and large coal mining development by ensuring that future decisions are informed by substantially improved science and independent expert advice about the potential water related impacts of those developments. For more information, visit <http://www.environment.gov.au/coal-seam-gas-mining/>.

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ISBN-PDF 978-1-4863-0383-0

Citation

Hodgkinson JH, Pinetown KL, Wilkes PG, McVicar TR and Marvanek SP (2014) Coal and coal seam gas resource assessment for the Gloucester subregion. Product 1.2 for the Gloucester subregion from the Northern Sydney Basin Bioregional Assessment. Department of the Environment, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia.

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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
Department of the Environment
Bureau of Meteorology
Geoscience Australia

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Contributors to the Technical Programme

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

Assistant Secretary	Department of the Environment: Gayle Milnes
Programme Director	Department of the Environment: Edwina Johnson
Technical Programme Director	Bureau of Meteorology: Bronwyn Ray
Projects Director	CSIRO: David Post
Principal Science Advisor	Department of the Environment: Peter Baker
Science Directors	CSIRO: Brent Henderson
	Geoscience Australia: Trevor Dhu
Integration Lead	Bureau of Meteorology: Richard Mount
Programme management	Bureau of Meteorology: Graham Hawke, Louise Minty
	CSIRO: Paul Hardisty, Warwick McDonald
	Geoscience Australia: Stuart Minchin
Project Leaders	CSIRO: Alexander Herr, Tim McVicar, David Rassam
	Geoscience Australia: Hashim Carey, Kriton Glenn
Assets and receptors	Bureau of Meteorology: Richard Mount
	Department of the Environment: Rachel Carter, Larry Guo, Brad Moore, Jin Wang
	Geoscience Australia: Joe Bell
Bioregional Assessment Information Platform	Bureau of Meteorology: Brian Cannell, Trevor Christie-Taylor, Mark Hatcher
	CSIRO: David Lemon
	Department of the Environment: Geraldine Cusack
	Geoscience Australia: Neal Evans
Communications	Bureau of Meteorology: Mel Martin
	CSIRO: Tsuey Cham, Leane Regan
	Department of the Environment: Sophie Alexander, Milica Milanja, Kirsty Rolls
	Geoscience Australia: David Beard, Chris Thompson

Coordination	Bureau of Meteorology: Julie Burke, Sarah van Rooyen CSIRO: Ruth Palmer Department of the Environment: James Hill, Sunita Johar, Broni McMaster, Carolyn Paris, Craig Watson Geoscience Australia: Tenai Luttrell
Ecology	CSIRO: Tanya Doody, Brendan Ebner, Kate Holland, Craig MacFarlane, Tracey May, Patrick Mitchell, Justine Murray, Anthony O'Grady, Chris Pavey, Jodie Pritchard, Nat Raisbeck-Brown, Ashley Sparrow, Georg Wiehl
Geology	CSIRO: Deepak Adhikary, Luke Connell, Emanuelle Frery, Jane Hodgkinson, James Kear, Zhejun Pan, Kaydy Pinetown, Matthias Raiber, Hayley Rohead-O'Brien, Regina Sander, Peter Schaubs, Garth Warren, Paul Wilkes, Andrew Wilkins, Yanhua Zhang Geoscience Australia: Tim Evans, Steven Lewis, John Magee, Martin Smith
Geography	Bureau of Meteorology: Natasha Herron
Geographic information systems	CSIRO: Caroline Bruce, Jody Bruce, Malcolm Hodgen, Steve Marvanek Geoscience Australia: Gerard Stewart, Kirsten Walker
Groundwater modelling	CSIRO: Olga Barron, Russell Crosbie, Tao Cui, Warrick Dawes, Lei Gao, Sreekanth Janardhanan, Luk Peeters, Praveen Kumar Rachakonda, Wolfgang Schmid, Saeed Torkzaban, Chris Turnadge, Binzhong Zhou Geoscience Australia: Wenping Jiang
Hydrogeology	CSIRO: Konrad Miotlinski Geoscience Australia: Rebecca Cassel, Jim Kellett, Sarah Marshall, Rebecca Norman, Jessica Northey, Tim Ransley, Martin Smith, Baskaran Sundaram, KokPiang Tan, Luke Wallace, Gabrielle Yates
Information management	Bureau of Meteorology: Belinda Allison, Jill McNamara, Brendan Moran CSIRO: Nick Car, Phil Davies, Andrew Freebairn, Mick Hartcher, Geoff Hodgson, Brad Lane, Ben Leighton, Trevor Pickett, Ramneek Singh, Matt Stenson, Garry Swan Geoscience Australia: Luke Caruana, Penny Kilgour, Matti Peljo
Products	CSIRO: Maryam Ahmad, Daniel Aramini, Heinz Buettikofer, Simon Gallant, Karin Hosking, Frances Marston, Linda Merrin, Becky Schmidt, Sally Tetreault-Campbell, Catherine Ticehurst Geoscience Australia: Veronika Galinec, Daniel Rawson
Risk and uncertainty	CSIRO: Simon Barry, Jeffery Dambacher, Jess Ford, Keith Hayes, Geoff Hosack, Yang Liu, Warren Jin, Dan Pagendam, Carmel Pollino
Surface water hydrology	CSIRO: Santosh Aryal, Mat Gilfedder, Fazlul Karim, Lingtao Li, Dave McJannet, Jorge Pena Arancibia, Xiaogang Shi, Tom Van Niel, Neil Viney, Bill Wang, Ang Yang, Yongqiang Zhang

Acknowledgements

This technical product was reviewed by several groups:

- Discipline Leaders: Russell Crosbie (hydrogeology, CSIRO) and Jim Kellett (hydrogeology, Geoscience Australia), Alexander Herr (ecology, CSIRO), Steven Lewis (geology, Geoscience Australia), Neil Viney (surface water hydrology, CSIRO)
- Senior Science Leaders: David Post (Projects Director), Trevor Dhu (Science Director, Geoscience Australia), Brent Henderson (Science Director, CSIRO), Becky Schmidt (products, CSIRO)
- Technical Assurance Reference Group: Chaired by Peter Baker (Principal Science Advisor, Department of the Environment), this group comprises officials from the NSW, Queensland, South Australian and Victorian governments.

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.

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 direct, indirect and cumulative impacts of CSG and coal mining development on water resources.

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

The Bioregional Assessment Programme

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

The Technical Programme, part of the Bioregional Assessment Programme, will undertake BAs for the following bioregions and subregions:

- 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.

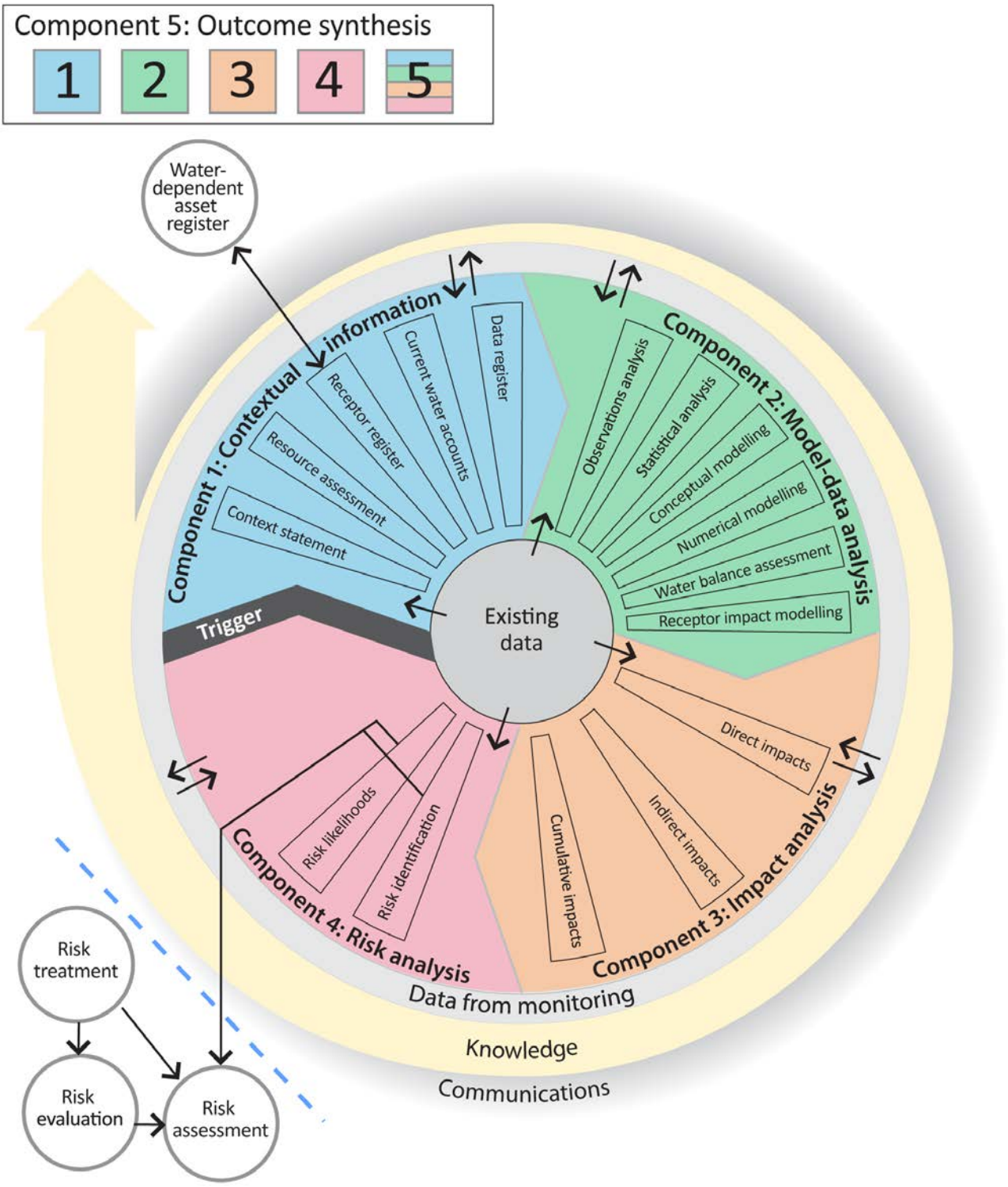


Figure 1 Schematic diagram of the bioregional assessment methodology

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

For transparency and to ensure consistency across all BAs, submethodologies have been developed to supplement the key approaches outlined in the Methodology for bioregional assessments of the impact of coal seam gas and coal mining development on water resources (Barrett et al., 2013). This series of submethodologies aligns with technical products as presented in Table 1. The submethodologies are not intended to be 'recipe books' nor to provide step-by-step instructions; rather they provide an overview of the approach to be taken. In some instances, methods applied for a particular BA may need to differ from what is proposed in the submethodologies – in this case an explanation will be supplied. Overall, the submethodologies are intended to provide a rigorously defined foundation describing how BAs are undertaken.

Table 1 Methodologies and associated technical products listed in Table 2

Code	Proposed title	Summary of content	Associated technical product
M01	*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	All
M02	*Compiling water-dependent assets*	Describes the approach for determining water-dependent assets	1.3 Description of the water-dependent asset register
M03	*Assigning receptors and impact variables to water-dependent assets*	Describes the approach for determining receptors associated with water-dependent assets	1.4 Description of the receptor register
M04	*Developing a coal resource development pathway*	Specifies the information that needs to be collected and reported in product 1.2 (i.e. known coal and coal seam gas resources as well as current and potential resource developments). Describes the process for determining the coal resource development pathway (reported in product 2.3)	1.2 Coal and coal seam gas resource assessment 2.3 Conceptual modelling
M05	*Developing the conceptual model for causal pathways*	Describes the development of the conceptual model for causal pathways, which summarises how the 'system' operates and articulates the links between coal resource developments and impacts on receptors	2.3 Conceptual modelling
M06	*Surface water modelling*	Describes the approach taken for surface water modelling across all of the bioregions and subregions. It covers the model(s) used, as well as whether modelling will be quantitative or qualitative.	2.6.1 Surface water numerical modelling
M07	*Groundwater modelling*	Describes the approach taken for groundwater modelling across all of the bioregions and subregions. It covers the model(s) used, as well as whether modelling will be quantitative or qualitative. It also considers surface water – groundwater interactions, as well as how the groundwater modelling is constrained by geology.	2.6.2 Groundwater numerical modelling

Code	Proposed title	Summary of content	Associated technical product
M08	*Receptor impact modelling*	Describes how to develop the receptor impact models that are required to assess the potential impacts from coal seam gas and large coal mining on receptors. Conceptual, semi-quantitative and quantitative numerical models are described.	2.7 Receptor impact modelling
M09	*Propagating uncertainty through models*	Describes the approach to sensitivity analysis and quantifying uncertainty in the modelled hydrological response to coal and coal seam gas development	2.3 Conceptual modelling 2.6.1 Surface water numerical modelling 2.6.2 Groundwater numerical modelling 2.7 Receptor impact modelling
M10	*Risk and cumulative impacts on receptors*	Describes the process to identify and analyse risk	3 Impact analysis 4 Risk analysis
M11	*Hazard identification*	Describes the process to identify potential water-related hazards from coal and coal seam gas development	2 Model-data analysis 3 Impact analysis 4 Risk analysis
M12	*Fracture propagation and chemical concentrations*	Describes the likely extent of both vertical and horizontal fractures due to hydraulic stimulation and the likely concentration of chemicals after production of coal seam gas	2 Model-data analysis 3 Impact analysis 4 Risk analysis

Each submethodology is available online at <http://www.bioregionalassessments.gov.au>. Submethodologies might be added in the future.

Technical products

The outputs of the BAs include a suite of technical products variously presenting information about the ecology, hydrology, hydrogeology and geology of a bioregion and the potential direct, indirect and cumulative 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 information flow within a BA. 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 rectangles in both Figure 2 and Table 2 indicate the information included in this technical product.

This technical product is delivered as a report (PDF). Additional material is also provided, as specified by the BA methodology:

- all unencumbered data syntheses and databases
- unencumbered tools, model code, procedures, routines and algorithms
- unencumbered forcing, boundary condition, parameter and initial condition datasets
- the workflow, comprising a record of all decision points along the pathway towards completion of the BA, gaps in data and modelling capability, and provenance of data.

The PDF of this technical product, and the additional material, are available online at <http://www.bioregionalassessments.gov.au>.

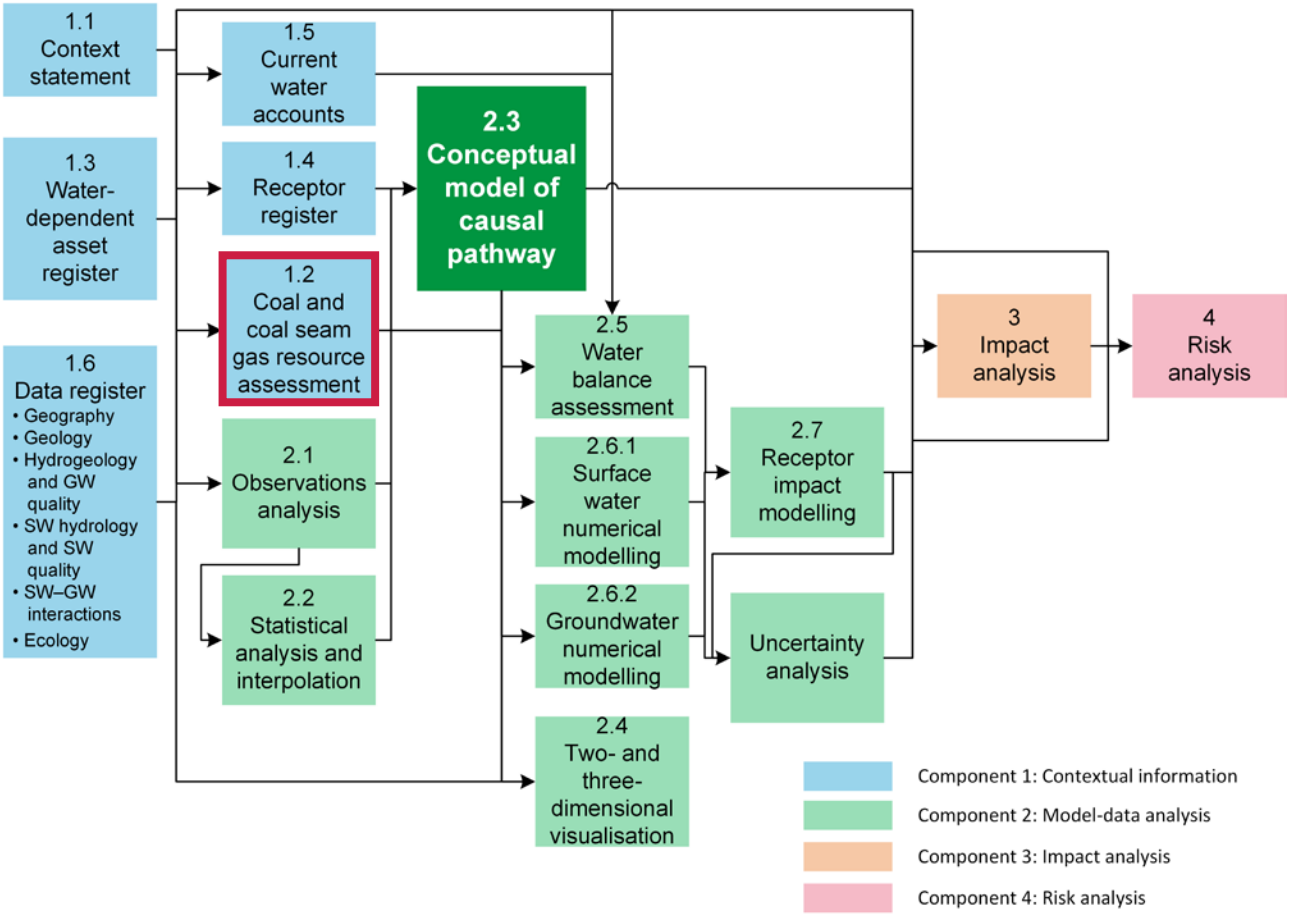


Figure 2 The simple decision tree indicates the flow of information through a bioregional assessment

The red rectangle indicates the information included in this technical product.

About this technical product

The following notes are relevant only for this technical product:

- 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°.
- All reasonable efforts were made to provide all material under a Creative Commons Attribution 3.0 Australia Licence. The copyright owner of the following figure, however, did not grant permission to do so: Figure 3. It should be assumed that third parties are not entitled to use this material without permission from the copyright owner.

Table 2 Technical products being delivered as part of the Northern Sydney Basin Bioregional Assessment

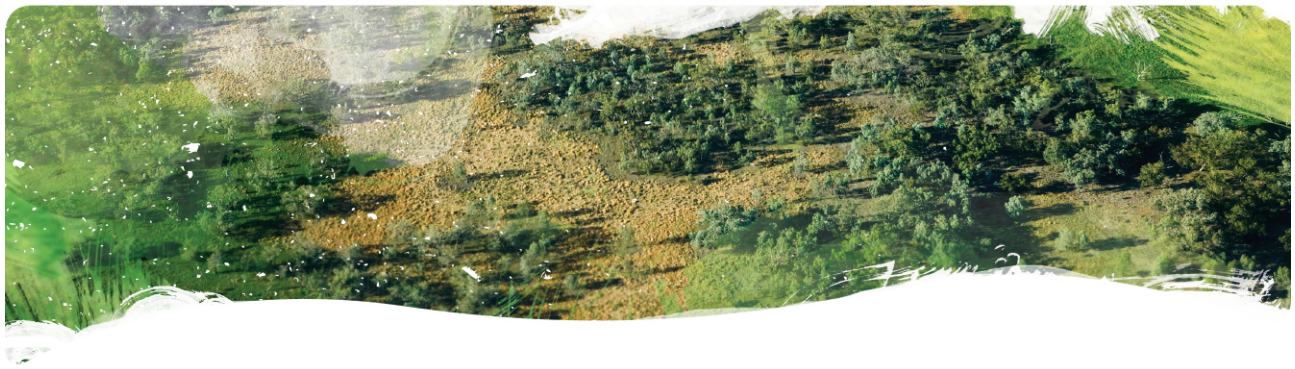
For each subregion in the Northern Sydney Basin Bioregional Assessment, technical products will be delivered as data, summaries and reports (PDFs) as indicated by ■ in the last column of Table 2. The red rectangle indicates the information covered in this technical product. A suite of other technical and communication products – such as maps, registers and factsheets – will also be developed through the bioregional assessments.

Component	Product code	Information	Section in the BA methodology[a]	Report
Component 1: Contextual information for the Gloucester subregion	1.1	Context statement	2.5.1.1, 3.2	■
	1.2	Coal and coal seam gas resource assessment	2.5.1.2, 3.3	■
	1.3	Description of the water-dependent asset register	2.5.1.3, 3.4	■
	1.4	Description of the receptor register	2.5.1.4, 3.5	■
	1.5	Current water accounts and water quality	2.5.1.5	■
	1.6	Data register	2.5.1.6	
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	■
	2.3	Conceptual modelling	2.5.2.3, 4.3	■
	2.4	Two- and three-dimensional representations	4.2	[b]
	2.5	Water balance assessment	2.5.2.4	■
	2.6.1	Surface water numerical modelling	4.4	■
	2.6.2	Groundwater numerical modelling	4.4	■
	2.7	Receptor impact modelling	2.5.2.6, 4.5	■
Component 3: Impact analysis for the Gloucester subregion	3	Impact analysis	5.2.1	■
Component 4: Risk analysis for the Gloucester subregion	4	Risk analysis	2.5.4, 5.3	■
Component 5: Outcome synthesis for the Northern Sydney Basin bioregion	5	Outcome synthesis	2.5.5	■

[a]Barrett et al. (2013)
[b]The two- and three-dimensional representations will be delivered in products such as 2.3, 2.6.1 and 2.6.2.

References

Barrett DJ, Couch CA, Metcalfe DJ, Lytton L, Adhikary DP and Schmidt RK (2013) Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources. A report prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development through the Department of the Environment. Department of the Environment, Australia. Viewed 23 October 2014, <http://www.environment.gov.au/coal-seam-gas-mining/pubs/methodology-bioregional-assessments.pdf>.



1.2 Coal and coal seam gas resource assessment for the Gloucester subregion

The coal and coal seam gas resource assessment summarises the known coal and coal seam gas resources, and developments both now and potentially in the future. The following data and information are presented:

- the geology and spatial distribution of known coal resources
- the baseline of current coal and coal seam gas extraction
- exploration and mining tenements
- proposed future developments (both new developments and expansion or closure of existing developments), including details of location, timing, methods and extraction volumes as determined from proposed development plans.

This information will be used to develop the coal resource development pathway (as reported in product 2.3), which articulates the most likely combination of developments at a subregion or bioregion scale, including all individual coal and coal seam gas resource projects that are expected.

1.2.1 Available coal and coal seam gas resources

Summary

The Gloucester subregion is underlain by the geological Gloucester Basin which is the focus of this Section 1.2.1. The oldest coal measures are in the Alum Mountain Volcanics and are followed by coals in the Dewrang Group, the Avon and Craven subgroups. Coal occurrence in each of these four major geological units is documented.

Reserves of 83.6 Mt and in situ resources of 357.9 Mt of coal have been reported for the Gloucester Basin in 2012.

Numerous conventional and unconventional hydrocarbon occurrences have been reported in the Gloucester Basin. Gas hydrocarbons, mainly methane (CH_4) with traces of carbon dioxide (CO_2) and nitrogen (N_2) have been identified, encouraging more recent exploration efforts by coal seam gas (CSG) operators. AGL Energy Limited (AGL; known as the Australian Gas Light Company prior to October 2006) in their Annual Report (AGL Energy Limited, 2013) cite proved and probable (2P) CSG reserves of 454 PJ within those areas of the Gloucester Basin investigated by AGL Energy Limited up to the end of 2013.

1.2.1.1 Coal

Most of the numerous coal seams present in the Gloucester Basin (a geological basin which underlies the Gloucester subregion) are contained within the Craven and Avon subgroups of the Gloucester Coal Measures, along with a few seams in Dewrang Group and Alum Mountain Volcanic (Figure 3 and Figure 4). The coals were deposited during the Permian Period with deposition of the Gloucester Coal Measures ending towards the Upper Permian (260 to 250 million years ago) (Hughes, 1995, p. 423). Hughes (1995, p. 424) recognised over 50 individual coal seams in the basin with only 20 that have been named and at least five that appear to be associated with some depositional hiatus. The coals are thicker and of better quality on the eastern margins of the Gloucester Basin. They are classified as medium to high volatile bituminous coals, with generally high raw ash contents, high specific energy and medium to high volatile matter contents. Apart from seams associated with marine transgressions, the sulfur contents of these coals are generally less than 0.7% (Hughes, 1995, p. 424–425). For washed coals the vitrinite contents generally range from 65 to 75%, except for the Bowens Road Coal Member which is predominantly dull coal. Vertical vitrinite reflectance gradients are around 0.4% per 100 m in the north, 0.06% per 100 m in the central region and 0.04% per 100 m along the western margin of the basin, and lateral variations in rank have been noted (Hughes, 1995, p. 425). Ranges for the coal properties are provided in Hughes (1995, p. 425). Reserves of 83.6 Mt and in situ resources of 357.9 Mt of coal have been reported for the Gloucester Basin (Gloucester Coal Ltd, 2012; R.W. Corkery and Co. Pty. Limited, 2012).

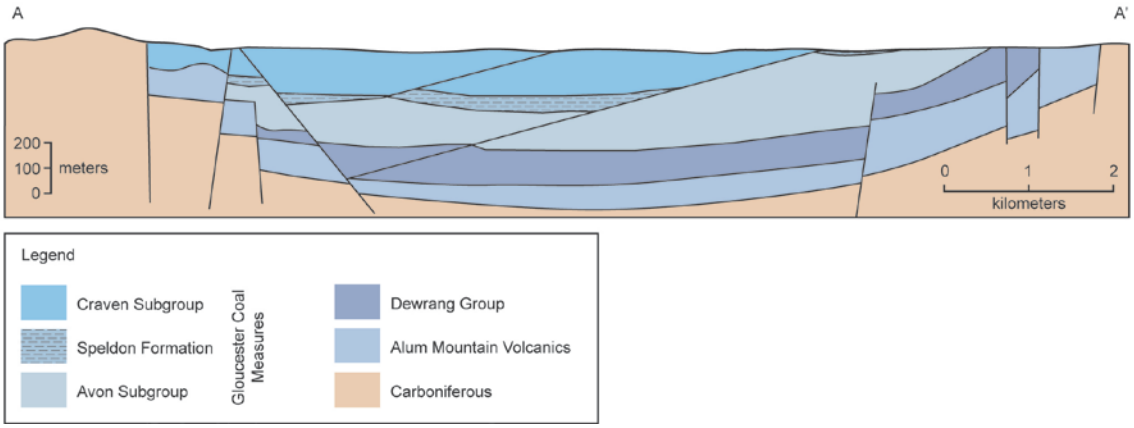


Figure 3 Simplified regional cross-section for the Gloucester Basin

The Quaternary alluvium is not shown. Location of the cross-section 'A–A' within the Gloucester Basin is shown in Figure 22 of companion product 1.1.3 for the Gloucester subregion (McVicar et al., 2014). Source: Roberts et al. (1991). Note that this figure is not covered by a Creative Commons Attribution licence. It has been reproduced with the permission of NSW Trade & Investment.

AGE			FORMATION	LITHOLOGY	HYDROSTRATIGRAPHY	ENVIRONMENT	THICKNESS (m)		THICKNESS COAL BEARING INTERVAL (m)	FAULT ACTIVITY
Quater			Alluvium	sand, gravel	aquifer				UC	
Late Permian	Gloucester Coal measures	Croven Subgroup	Crowthers Road Conglomerat	conglomerat, minor sandstone	interburden or aquifer if fractured	Alluvial plain	350			
			Leloma Formation	sandstone, minor siltstone and coal	interburden or aquifer if fractured		585			
				Linden Coal Member	water bearing zone			2.5	5.2	
				marker/JD Coals Member	water bearing zone					
				Jo Doth Tuff	interburden (as aquitard)					
				Bindaboo Coal Member	water bearing zone			3.3	36.1	
				Deards Coal Member	water bearing zone			3.7	21.5	
				sandstone, minor siltstone and coal	interburden (as aquitard)					
			Jilleon Formation	Cloverdale Coal Member	water bearing zone		175	0.7	7.7	
				conglomerat, sandstone, siltstone	interburden (as aquitard)	Alluvial Plain				
				Roseville Coal Member	water bearing zone			1.6	2.5	
				Fairbairns Lane - Tereel Coal Member	water bearing zone					
			Wards River Conglomerate	conglomerate, sandstone	interburden (as aquitard)	Distal alluvial fan	variable			fault activity
			Wenham Formation	Bowen Road Coal Member	water bearing zone	Back barrier coal	24	4.7	10.3	
				siltstone	interburden (as aquitard)	Marsh				
			Speldon Formation	marine influenced sandstone	interburden (as aquitard)	Marginal marine, pro delta	76.8			
		Avon Subgroup	Dog Trap Creek Formation	Glenview Coal Member	water bearing zone	Back barrier coal	126	1.8	3	
				Bucketts Way Coal Member						
				Marker Two Coal Member						
				sandstone, siltstone	interburden (as aquitard)	Lower delta plain				
			Waukivory Creek Formation	Avon Coal Member[1]	water bearing zone		326	5.1	17.2	
				Triple Coal Member	water bearing zone	Upper delta plain		2.3	3	
				Rombo Coal Member	water bearing zone			1.4	12.9	
				Glen Road Coal Member	water bearing zone			1.3	7.7	
				sandstone, siltstone	interburden (as aquitard)					
				Valley View Coal Member	water bearing zone			0.9	4.3	
				Parkers Road Coal Member	water bearing zone			4.0	10.3	
				siltstone, mudstone	interburden (as aquitard)	Transitional				
Late Permian	Dewrang Group		Mammy Johnsons Formation	sandstone, siltstone, mudstone	interburden (as aquitard)	Marginal marine, barrier, wave dominated delta	300			
				Intra-Mammy Johnsons Member	water bearing zone	Back barrier coal				
				bioturbated sandstone	interburden (as aquitard)	Marginal marine, barrier, wave dominated delta				
			Weismantels Formation	siltstone, mudstone	interburden (as aquitard)	Back barrier lagoon	20			
				Weismantels Coal Member	water bearing zone	Back barrier coal		8.0	10.0	
			Durallie Road Formation	marine sandstone, conglomerate	interburden (as aquitard)	Marginal marine, delta fan	250		UC	
Early Perm			Alum Mountain Volcanics	Clareval Coal Member	water bearing zone					
				conglomerate, coal	interburden (as aquitard)	Distal alluvial fan				
				ryholite, basalt, welded tuff	interburden (as aquitard)					
				basal Coal Member	water bearing zone				UC	
Carbo			Carboniferous Sequences							

Figure 4 Permian lithostratigraphy in the Gloucester Basin

The duplicate use of Avon is not formally recognised in the Australian Stratigraphic Units Database
Source data: (i) Brown et al. (1996), (ii) AECOM (2009), (iii) SRK Consulting (2010), (iv) Pells Consulting (2012) and (v) the Australian Stratigraphic Names Database

1.2.1.1.1 Alum Mountain Volcanics

The Early Permian aged sequence of the Alum Mountain Volcanics (Figure 3 and Figure 4) has four discrete members, including one coal member (Clareval Coal Member). According to Hughes (1995, p. 418) the Alum Mountain Volcanics (also referred to as the Stroud Volcanics by Hughes (1995, p. 418) and Brakel (1989, p. 59)) is coal-barren, although Roberts et al. (1991, p. 164) notes the presence of a basal coal measure sequence with a fine pebble conglomerate overlain by a thick, deformed coal seam in the south. The presence of two correlatable coal seams, namely the Basal and Clareval coal members, are noted in stratigraphic columns in AGL Energy Limited (2009) and SRK Consulting (2010, p. 9). Roberts et al. (1991, p. 164) mentions that the coal seam in the Alum Mountain Volcanics contains shale and conglomerate lenses, but little is known about the coal quality, thickness or distribution of coals in this formation. According to Australasian

Groundwater and Environment (AGE) (AGE, 2013, p. 4–34) coal is extracted from the Clareval Coal Member (Figure 2) at Duralie Coal Mine in the south of the Gloucester Basin.

1.2.1.1.2 Dewrang Group

Hughes (1995, p. 418) notes that the Weismantel Coal Member is the thickest uniform seam in the Gloucester Basin with a thickness of up to 15 m in the area of Wards River (see Figure 22, Section 1.1.3), and up to 22 m thick in the Stratford area (see Figure 22, Section 1.1.3) as noted by Resource Strategies (2001, p. 3–3). Its moderately high sulfur content (1.8%) is the result of being developed in a back barrier environment and overlain by marine sediments, and the seam generally thins towards the north on both the eastern and western margins of the basin. In the Rocky Hill Coal Project area (see Figure 9, Section 1.2.4) the seam consists of five main plies (AGE, 2013, p. 4-45). Although coal rank varies laterally and vertically across the basin, Hughes (1995, p. 425) notes a mean maximum reflectance of vitrinite ($R_{v,max}$) of 0.71% for the Weismantel Coal Member in the south. Roberts et al. (1991, p. 171) regard this bright coal to be of medium to high bituminous rank.

SRK Consulting (2010, p. 8) mentions that the coal in the Mammy Johnsons Formation (Figure 4) is thick and discontinuous and Roberts et al. (1991, p. 171-174) note that locally it can be up to 10 m thick interspersed with sandstone and claystone.

1.2.1.1.3 Avon Subgroup

The Avon Subgroup (Figure 3 and Figure 4) forms the lower stratigraphic component of the Gloucester Coal Measures and has eight discrete coal members. Of the several coal members recognised in the Avon Subgroup, the Avon Coal Member, which occurs near the top of the Waukivory Creek Formation, is the most consistent recognisable seam, in the formation and in the entire Gloucester Basin (Hughes, 1995, p. 424). The Parkers Road and Avon coal members represent depositional hiatuses (i.e. sedimentation ceased), which were important events as they allowed much of the surface to be covered with coal-forming swamps, leading to the coal seams today (Roberts et al., 1991, p. 177). Hughes (1995, p. 425) recorded an $R_{v,max}$ for the Parkers Road Coal Member in the Stratford area of 0.71%.

The Avon Coal Member is present along the eastern margin and in the northern and southern areas (refer to Figure 22 of companion product 1.1.3 for the Gloucester subregion (McVicar et al., 2014)). It is a banded coal ranging in thickness from 20 m in the Stratford area to around 5 m in the south, and generally consists of a clean coal ply at the top with interbanded coal and non-coal material as the remainder. According to AGE (AGE, 2013, p. 4–45) the seam consists of five main plies in the Rocky Hill Coal Project area with an average combined net coal thickness of 7 m. Due to reverse faulting the maximum thickness recorded is approximately 60 m in some areas (Hughes, 1995, p. 424).

Roberts et al. (1991, p. 178) recognised the Marker Two and Glenview coal members within the Dog Trap Creek Formation. The Glenview Coal Member is the marker for the top of the formation and occurs as a single coal bed which developed in a back barrier environment, resulting in high but variable sulfur contents ranging from 0.7 to 7.5%. It has a maximum thickness of over 3 m and

is mainly developed to the north of the Stratford area, but is also present throughout a large part of the eastern margin of the Gloucester Basin (Hughes, 1995, p. 424).

1.2.1.1.4 Craven Subgroup

The Craven Subgroup (Figure 3 and Figure 4) has five constituent formations, three of which are coal-bearing and the other two conglomeratic. There are nine discrete coal members defined within the subgroup. The Bowens Road Coal Member is the lowermost seam in the Craven Subgroup and recognisable throughout a substantial part of the Gloucester Basin. It is a very dull coal ranging in thickness from less than 1 m in some areas to greater than 12 m north of the Stratford area (Hughes, 1995, p. 424). Around the Bowens Road North Project area (Figure 6a), the Bowens Road Coal Member varies in thickness from 1 to 14 m where it consists of five main coal plies which are dipping to the west (Resource Strategies, 2001, p. 2–1). In the northern part of the Bowens Road North Project area it is relatively flat near the surface and steepens with depth, whereas in the southern project area it is generally steeper (Resource Strategies, 2001, p. 3–3). In the Rocky Hill Coal Project area it consists of six main plies with an average combined net coal thickness of 9.2 m (AGE, 2013, p. 4–45).

Coals below the Bowens Road Coal Member have higher proportions of inherent mineral matter which is often retained during washing, whereas those above are discretely banded with lower inherent mineral matter contents (Hughes, 1995, p. 424).

The Roseville seam is up to 16 m thick with an average thickness of 3.7 m in the Rocky Hill Coal Project area (see Figure 7, Section 1.2.3). Like the overlying Cloverdale Coal Member the coal is interbedded with upward coarsening sandstone and minor siltstone (AGE, 2013, p. 4–45). The Cloverdale Coal Member varies between 5 and 10 m in thickness, consists of variable coal and stone bands, and, according to Hughes (1995, p. 424), is the uppermost seam in the coal measure sequence to show significant thickness over large areas. This banded seam is present over almost all of the eastern margin. In the Rocky Hill Coal Project area it comprises four main plies with an average combined net coal thickness of 7.8 m (AGE, 2013, p. 4–45). The development of the Cloverdale Coal Member represents a considerable time either during tectonic hiatus or a period when contributory channels did not readily flood and only introduced clay and silt-sized sediment into peat swamps (Roberts et al., 1991, p. 186).

The Bindaboo and Deards coal members are part of the Leloma Formation, whereas the Cloverdale and Roseville members are part of the Jilleon Formation. The Bindaboo, Deards, Cloverdale, and Roseville coal members, which were intercepted in the monitoring bore drilling program for AGL's Stage 1 Gas Field Development, vary in thickness from 3 to 18 m and comprise thin coals interbedded with dark organic siltstones and shale (Parsons Brinckerhoff, 2012, p. 68).

1.2.1.2 Coal seam gas

Numerous conventional and unconventional hydrocarbon occurrences have been reported in the Gloucester Basin, with the marine influenced Durallie Road and Speldon formations (Figure 3 and Figure 4) reported to contain some oil occurrences (Hughes, 1995, p. 424). Gaseous hydrocarbons, mainly methane (CH_4) with traces of carbon dioxide (CO_2) and nitrogen (N_2), have been identified, encouraging more recent exploration efforts by coal seam gas (CSG) operators.

The top 200 m of the Avon Subgroup and the basal 250 m of the Craven Subgroup are considered the best-known CSG resources in the Gloucester Basin (Gurba and Weber, 2001), with gas contents of less than 10 m^3/t (dry, ash-free) for coals shallower than 200 m and 20 to 25 m^3/t at around 600 m depth. The CSG comprises 95 to 100% CH_4 with minor amounts of CO_2 and N_2 (Gurba and Weber (2001) as cited in Ward and Kelly (2013, p. 57)).

Gas exploration on Petroleum Exploration Licence tenement 285 (PEL 285), which was conducted by Lucas Energy Pty Limited in 2004, investigated 200 km^2 of coal-bearing strata, targeting 11 major coal seams of greater than 2.5 m thick and an average total thickness of 30 to 60 m. Dry, ash-free gas contents for this investigation reported by Bilston (2008, p. 7) range between 12 and 25 m^3/t; although Ward and Kelly (2013, p. 57) suggest that in situ gas contents will be somewhat lower as the coals are relatively high in ash. Initial reserves of 14.9 billion cubic feet (bcf) (1P, proved reserves), 170.2 bcf (2P, proved plus probable) and 359.2 bcf (3P, proved plus probable plus possible), with a contingent resource of 166.2 bcf, were reported by Bilston (2008, p. 7).

SRK Consulting (2010, p. 21) reported results from coal seam intrinsic permeability testing, conducted by Pacific Power in 1999, noting that permeability decreases sharply with increasing depth in the basin. Permeabilities at approximately 100 m depth are on average 100 millidarcy and drop significantly to between 7 and 27 millidarcy at 300 m depth, with a value of 0.56 millidarcy measured at 500 m. Porosity provides information about storage capacity of gas in the coal whereas permeability defines the transportability of that gas (Moore, 2012).

AGL Energy Limited recently reported 2P reserves of 454 PJ of gas for the Gloucester Basin CSG Project (PEL 285) (AGL Energy Limited, 2013). Gas samples from shallow monitoring wells were collected in 2011 for AGL's Stage 1 Gas Field Development Area (see Figure 9, Section 1.2.4) and reported by Parsons Brinkerhoff (2012, p. 122). The gas at shallow depths consists of low concentrations of oxygen (O_2), argon (Ar), nitrogen (N_2), which are typical of air, and only slightly elevated CO_2 concentrations. Methane concentrations range from 16 to 138 ppm (Parsons Brinckerhoff, 2012, p. 122).

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1.2.2 Current activity and tenements

Summary

In the geological Gloucester Basin, coal is largely situated in seams of 30 m average thickness, at depths of 200 to 700 m. It is currently mined at shallower depths of up to around 190 m. The seams are discontinuous both horizontally and vertically. This may reduce the potential for development although further investigation is required to better constrain the known extent. Coal is situated within the Avon Subgroup and the Craven Subgroup of the Late Permian Gloucester Coal Measures and Dewrang Group. Open-cut mining is operating in the Gloucester subregion at Duralie and the Stratford Mining Complex. Both mines are operated by Yancoal Australia Ltd (Figure 5). Excavation of a previously mined and backfilled Roseville Pit to access deeper coal is planned, in addition to new mining activities to extend the Stratford Mining Complex (Stratford Coal, 2012b, p. 2–25).

Coals of the Dewrang Group may contain gas (Ward and Kelly, 2013, p. 56) but the best-known coal seam gas (CSG) resources occur in the Gloucester Coal Measures, towards the upper 200 m of the Avon Subgroup and the bottom 250 m of the Craven Subgroup (Gurba and Weber, 2001 cited in Ward and Kelly, 2013, p. 55). Although there are no full-scale CSG operations in the Gloucester subregion, a pilot project was reported in 2008 at Petroleum Exploration Licence tenement 285 (PEL 285; jointly owned by Lucas Energy Pty Limited and Molopo Australia Limited), and future testing of 4 of 15 wells already drilled by AGL Energy Limited (AGL; known as the Australian Gas Light Company prior to October 2006) (see Figure 6 in Section 1.2.3), is planned under the name of the Waukivory Project, owned by AGL, and described in more detail in Section 1.2.3.

1.2.2.1 Coal

Raw coal production from the Gloucester coalfield in 2008 to 2009 was reported as 2.56 Mt (saleable 1.74 Mt) (Ward and Kelly, 2013, p. 29). Active open-cut coal mining occurs at Stratford and Duralie (Figure 5).

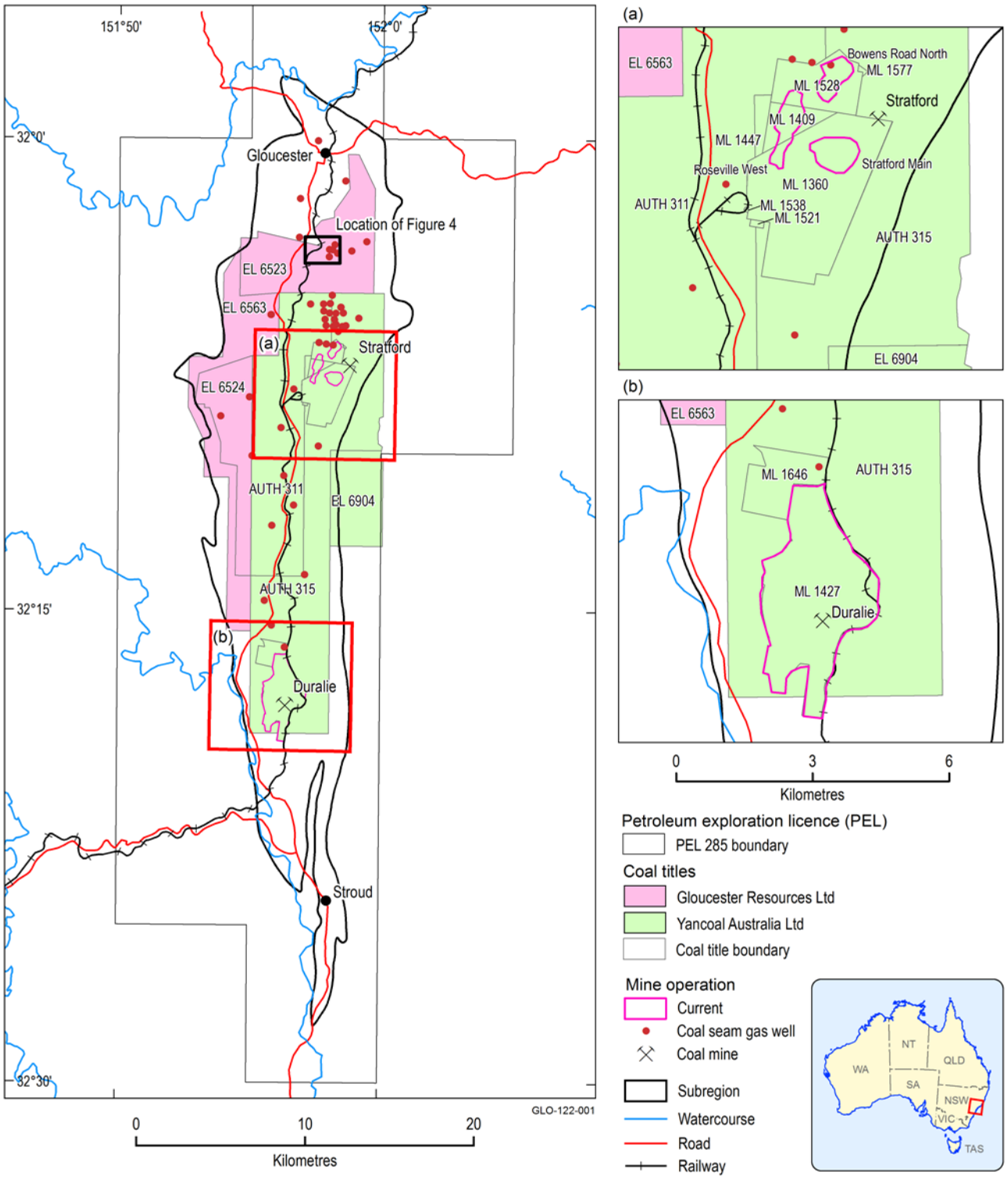

Figure 5 Locations of open-cut mining (identified by owner) and Petroleum Exploration Licence 285 (PEL 285) in the Gloucester subregion

EL = exploration licence; ML = mining lease; AUTH = authorisation

1.2.2.1.1 Currently operating coal mines

The Stratford Mining Complex is an open-cut mining operation owned by Stratford Coal Pty Ltd, which is a wholly owned subsidiary of Yancoal Australia Ltd (Yancoal). The Stratford Mining Complex commenced in 1995 with production of coal at the Stratford Main Deposit (AEMC, 2011), which continued operations until 2003. Other pits mined in the complex include Roseville Pit, Roseville West Pit and Bowens Road North Open Cut Pit although Roseville West Pit (in operation since 2009) and Bowens Road North Open Cut Pit (operating since 2003) are now the only pits in operation. Additionally, small quantities (up to approximately 0.2 Mt/year) are recovered from the coal handling and processing plant rejects (Stratford Coal, 2012b, p. 2–1).

Conventional open-cut mining processes are used at the Stratford mining complex (Stratford Coal, 2012b, p. 2–1 to 2–3). Due to there being steeply dipping, thin coal seams, the mine uses relatively small mining equipment that has the ability to selectively mine thin seams (Yancoal, 2013, p. 1). Mining methods include vegetation clearance and topsoil removal that will be used in rehabilitation, overburden removal by excavator and haul truck and drilling and blasting of consolidated overburden. Overburden is then removed by excavator and truck and rock is stored for progressive mine void filling. Exposed coal is excavated and loaded into haul trucks for transport to stockpiles before being moved to the coal handling and preparation plant (Stratford Coal, 2012b, p. 2–1 to 2–3).

Approximately 3.3 Mt/year of coal products are produced at the Stratford Mining Complex including thermal and coking coal. Coal is processed at the Stratford Coal Mine coal handling and preparation plant (CHPP), which is owned by Stratford Coal Pty Ltd (Gloucester Coal, 2010a, p. ES-4) and is approved to operate 24 hours/day, seven days/week (Stratford Coal, 2012b, p. 2–1). Coal handling and preparation plant design capacity at the complex is 750 t/hour (Gloucester Coal, 2010a, p. ES-4). The previously mined Stratford Main Deposit Pit is currently used for rock backfill waste and water storage. The Roseville Pit has been backfilled and is undergoing rehabilitation whilst the Roseville Extended Pit is currently being backfilled (Stratford Coal, 2012b, p. 2.1). Product coal is transported via the North Coast Railway to Newcastle for the domestic and international markets (Stratford Coal, 2012a, p. 2–3). Mine waste rock is used for fill behind advancing mining operations or in out-of-pit waste emplacements.

Situated 20 km south of the Stratford Mining Complex (Stratford Coal, 2012a, p. ES-1) (Figure 5), Duralie Coal Pty Ltd is an open-cut mine owned by Yancoal. The Duralie operation started in March 2003, owned by Gloucester Coal Ltd until 2012 when Gloucester Coal merged with Yancoal (Nedlands, 2013). The mine is currently operated by Leighton Mining under contract to Yancoal. Currently the Weismantel Coal Seam and the Clareval Seam are being mined (Duralie Coal Pty Ltd, n.d.). Conventional open-cut mining processes are being performed at Duralie Coal Mine. These include stripping and stockpiling of topsoil for rehabilitation, excavation and removal of weathered overburden and then drilling and blasting of consolidated overburden prior to its excavation and removal. Overburden is stored in stock piles for back filling although any rock that is identified as being potentially acid-forming is additionally treated with limestone within the waste rock emplacement. Coal is transported by rail to the Stratford Coal Mine CHPP (Gloucester Coal, 2010a, p. ES-4; 2010b, p. 2–1).

Combined, the Duralie and Stratford produced and sold approximately 2.0 to 2.3 Mt of coal in 2013 (Yancoal, 2013). The mines produce two key products: a semi hard coking coal and a high ash thermal coal that can be blended with other coals, although the coal is known to have high sulfur levels that can limit its use (Yancoal, 2013, p. 2). Both the mined Weismantel and Clareval seams have consistent thickness of 10 to 12 m, split into four main plies of 0.8 to 7.5 m. Coal is transported by train to the Port of Newcastle for export or domestic use (Duralie Coal Pty Ltd, n.d.).

1.2.2.2 Coal seam gas

To date, most CSG exploration has focused on a small area, east of Stratford, where up to 11 major (in this context, >2.5 m thick) seams and numerous minor seams (≤2.5 mm thick) occur, with an average total thickness of up to 60 m (Bilston, 2008, p. 7; Ward and Kelly, 2013, p. 57). Most methane is thermogenic although some minor biogenic gas is found at shallow depths (Ward and Kelly, 2013, p. 57). The best known CSG resource in the Gloucester subregion is in the Gloucester Coal Measures (O'Kane, 2013, p.57; Ward and Kelly, 2013). AGL indicated that, as at 30 June 2013, the Gloucester Basin has current proved and probable (2P) reserves of 454 PJ and proved, probable and possible (3P) reserves of 565 PJ (AGL Energy Limited, 2013a, p. 20). Gas content of the coal in the Gloucester Basin sequence increases with depth from less than 10 m^3/t at depths of less than 200 m, to 25 m^3/t at depths of 600 m (Gurba and Weber, 2001 cited in Ward and Kelly, 2013, p. 56).

1.2.2.2.1 Current coal seam gas operations

Full-scale CSG operations in the Gloucester subregion have not been developed. However, in 2008, Lucas Energy Pty Limited reported on a pilot CSG project at Stratford (Stratford Pilot) at PEL 285 (jointly owned by Lucas Energy Pty Limited and Molopo Australia Limited). The report stated that the wells produced encouraging results, and that wells dewatered quickly and produced 1050 thousand cubic feet per day (mcfd) during initial flow testing (Bilston, 2008, p. 7, 9). PEL 285 was sold to AGL in 2008. In 2009, AGL conducted drilling activities and high gas content was confirmed in all 18 core holes drilled as part of the exploration program (AGL Energy Limited, n.d.-b). AGL extended Lucas Energy's earlier, deep drilling project under the name of the Waukivory Pilot Project, which has demonstrated gas contents of 12 to 25 m^3/t and well LMG03 also achieved production flow rates of more than 1050 mcfd (O'Neill and Danis, 2013, p. 72). As part of the Waukivory Pilot Project, four wells that were drilled in 2012 (Waukivory 11, Waukivory 12, Waukivory 13 and Waukivory 14; see Figure 6) (AGL Energy Limited, 2013b, p. 9) will be tested over a 12 to 18 month period once testing commences (AGL Energy Limited, 2013b, p. 33) using perforating and fracture stimulation techniques (AGL Energy Limited, 2013b, p. ES 1). Previously, gas flow was enhanced through fracture stimulation of the coal seams in four other wells (AGL Energy Limited, n.d.-b).

Figure 6 Location of Waukivory Pilot wells in the Gloucester subregion

Source: AGL Energy Limited (n.d.-a). © AGL, 2014

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1.2.3 Proposals and exploration

Summary

The Gloucester subregion is underlain by the geological Gloucester Basin which is the focus of Section 1.2.3. Hydrocarbon exploration in the Gloucester Basin commenced in the 1970s when approximately 300 shallow holes were drilled to search for coal deposits. Coal seam gas (CSG) exploration commenced in the 1980s when four holes were drilled to approximately 500 m depth. This exploration also provided more information about geology and for coal development. Current exploration permits and expansion plans under licence are listed in Table 3 and locations are displayed in Figure 7 and Figure 8.

Proposals have been submitted for expansion of open-pit coal mining at Duralie and Stratford mines by Yancoal Australia Ltd and a new mine at Rocky Hill in the north of the Gloucester Basin by Gloucester Resources Limited. AGL Energy Limited has proposed a CSG resource development known as the Gloucester Gas Project. This is targeting the Gloucester Coal Measures at depths in the range 200 to 1000 m below ground level. Up to 110 gas wells and associated infrastructure are proposed in Stage 1.

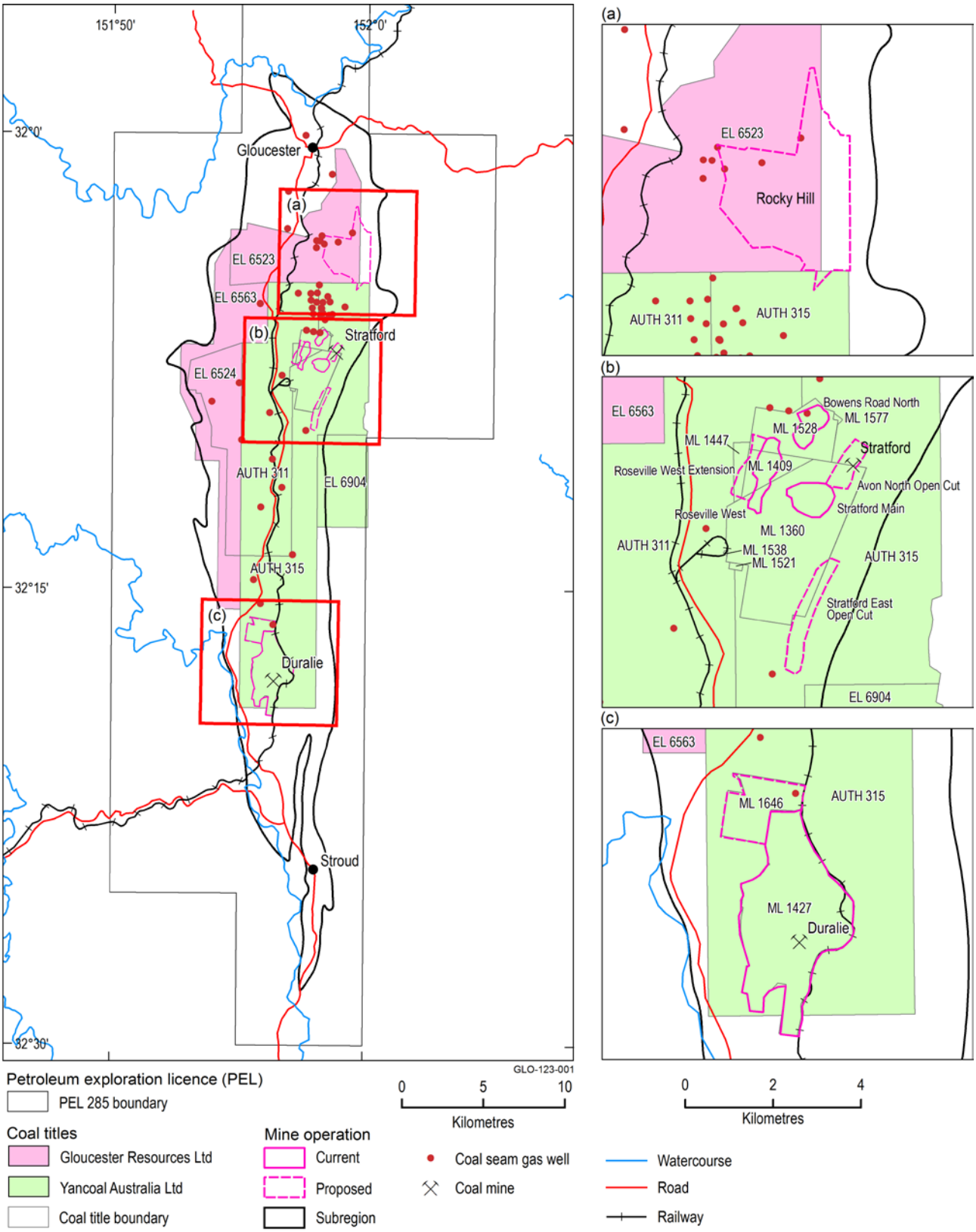

Figure 7 Coal titles in the Gloucester subregion

(a) Rocky Hill Coal Project, (b) Stratford Extension Plan and (c) Duralie Coal Extension Plan.
EL = exploration licence; ML = mining lease; AUTH = authorisation

1.2.3.1 Coal

Current proposals to extend current coal mines or develop new coal mines in the Gloucester subregion are listed in Table 3 and include the Stratford and Duralie extension and expansion plans (Yancoal) and the Rocky Hill mine (Gloucester Resources Limited). Their locations are shown in Figure 7.

Table 3 Current proposals for coal development in the Gloucester subregion

Project	Location	Company	Permits and licences
Stratford Extension Plan	Stratford Mining Complex	Yancoal Australia Ltd	EL 6904, EL 311, EL 315
Duralie Coal Extension Plan	Duralie Mine	Yancoal Australia Ltd	ML 1427
Rocky Hill Coal Project	Rocky Hill	Gloucester Resources Limited	EL 6523, EL 6524, EL 6563

Source: NSW Government Trade and Investment Resources and Energy (2013). EL = exploration licence; ML = mining lease

1.2.3.1.1 Stratford Extension Plan

Stratford Mining Complex is presently seeking to expand its activities (Stratford Coal, 2012a, 2012b). The proposed 11-year extension project plans to continue open-cut mining to the west and south of the existing pit (Stratford Coal, 2012a, p. ES-5; 2012b, p. 2–25) and would increase run-of-mine (ROM) coal production (raw coal prior to processing) from the currently approved 2.1 to 2.6 Mt/year (Stratford Coal, 2012b, p. 2–13). As open-cut mining progresses south, the previously mined and backfilled Roseville Pit would be excavated to reach the deeper Roseville Coal Member (Stratford Coal, 2012b, p. 2–25). Additionally, the new Avon North and Stratford East open-cut mines would be developed (Stratford Coal, 2012a, p. ES–4). Approximately 7.3 Mt ROM coal is planned to be mined from the extension of Roseville West Pit. The Roseville West Pit Extension would be approximately 1 km east of Stratford at its nearest point and no open-cut mining would be carried out within 40 m of Avondale Creek. Operations of the extended mine are expected to be 24 hours/day, seven days/week (Stratford Coal, 2012b, p. 2–25). As of August 2014, the proponent is responding to recommendations from the recently completed NSW Planning Assessment Commissions (PAC) review.

1.2.3.1.2 Duralie Coal Extension Plan

Proposed expansion activities within Mining Lease (ML) 1427 by Duralie Coal Pty Ltd, includes the drilling of ten holes of varying depths into known coal measure areas to further delineate open-cut activity (Duralie Coal Pty Ltd, 2006) of the currently operating Duralie Coal Mine. The extension will increase the mine's production from approximately 1.8 Mt/year ROM to up to 3 Mt/year ROM (Gloucester Coal, 2010, p. ES–4). On the basis that the extension project might pose a threat to the endangered giant barred frog *Mixophyes iteratus* (a declared endangered species under s178, s181 and s183 of the *Commonwealth's Environmental Protection and Biodiversity Conservation Act 1999*), the plan was declared a Controlled Action by the Australian Government (SEWPaC, 2010, NSW Department of Planning ,2011a, Nedlands, 2013). After extensive data proved the expansion would not threaten the habitat and having stated that monitoring will occur, Duralie Mine's environmental and planning approvals for the expansion project were granted in 2010 (SEWPaC,

2010). Extension activities will include mining of the Clareval Seam (Clareval North West) and extension of the existing approved open-cut in the Weismantel Seam (Weismantel Extension) (Gloucester Coal, 2010, p. 3).

1.2.3.1.3 Rocky Hill Coal Project

Gloucester Resources Limited are currently planning to develop Rocky Hill Coal Project, an open-cut coal mine 3.5 to 7 km south-east of the Gloucester urban area (RW Corkery and Co Pty Limited, 2013) within their licensed areas (Table 3). It is currently unclear when development may commence; currently several stages in the application and assessment process remain outstanding. After the environmental impact statement was provided for public exhibition (up to 28 October 2013) responses to issues arising were directed to the Department of Planning and Infrastructure who prepare an Assessment Report (not complete at the time of writing) (Rocky Hill Coal Project, 2014). The combined area of the three exploration licences covers approximately 112 km^2, however the mining area would cover an area of approximately 856 ha (RW Corkery and Co Pty. Limited, 2013). An on-site coal handling and preparation plant is also planned with an overland conveyor (approximately 3 km long) that would cross Waukivory Creek and the Avon River floodplains to the rail load-out facility that would be constructed as part of the development (RW Corkery and Co Pty Limited, 2013, p. ES–1, 4). Up to 2.6 Mt/year would be produced (RW Corkery and Co Pty. Limited, 2012, p. 5). Coal is planned to be extracted from four open pits from 70 to 190 m depth below surface, including two shallower and smaller sub-pits (RW Corkery and Co Pty. Limited, 2012, p. 33). Coal would be transported by rail to the Port of Newcastle.

1.2.3.1.4 Other

Gloucester Coal Ltd (now merged with Yancoal) announced in May 2008 a new coking coal discovery in the Grant and Chainey area about 7.5 km south of the Stratford open pit (Gloucester Coal, 1 May 2008 Market Release). This discovery is in the Clareval and Weismantel seams. Location and resource figures are included in Section 1.2.4. At May 2014, there is no publically released proposal for developing this resource.

Gloucester Coal announced in February 2012, resources and reserves for the Wenham Cox Road area adjacent to the Stratford mining area (Gloucester Coal, 2012). The location and resource figure for this deposit are included in Section 1.2.4. At August 2014, there is no publically released proposal for developing this resource.

1.2.3.2 Coal seam gas

In addition to the current activity of the Waukivory Pilot Project in the Gloucester subregion, AGL has a CSG resource development project known as the Gloucester Gas Project (owned by AGL Upstream Investments Pty Limited, an AGL subsidiary company).

AGL's Gloucester Gas Project is currently exploring CSG in the Gloucester Basin (Petroleum Exploration Licence (PEL) 285; see Figure 7; O'Kane, 2013, p. 44). Stage 1: Gas Field Development Area (Stage 1) of this project is targeting the deep and intermediate coal seams of the Gloucester Coal Measures, typically below depths of 200 to 1000 m below the depth of shallow fractured rock aquifers (O'Neill and Danis, 2013, p. 72; Parsons Brinckerhoff, 2012, p. 1, 6; NSW Department of Planning, 2010, p. 22). In addition to current wells drilled (Figure 8), Stage 1 has been approved by

the NSW Government Planning Assessment Commission to include the drilling of up to 110 gas wells and construction of associated infrastructure, central processing and electricity generation facilities within an area of approximately 209 km^2 (NSW Department of Planning, 2010, p. 3; NSW DTI, 2013). (). Proved and probable (2P) reserves of 454 PJ are reported for the Gloucester Basin (AGL Energy Limited, 2013a, 2013). Seismic surveys have been carried out by AGL and its predecessors (AGL Energy Limited, 2013b, p. 27) including a three-dimensional seismic survey that AGL performed to identify faulted areas and assist with well placement (AGL Energy Limited, 2013b, p. 93). Additionally, AGL is carrying out stress testing to build a mechanical Earth model and geophysical logging to assist fracture stimulation modelling (AGL Energy Limited, 2013b, Appendix B, p. 14).

The NSW Government's concept plan approval (NSW Department of Planning, 2011b, p.4) describes Stage 1 as:

> *110 gas wells and associated infrastructure including gas and water gathering lines, within an approximately 50 km^2 section of the overall 210 km^2 gas field development area, between the townships of Gloucester and just south of Stratford in the Gloucester local Government area*.

Although no additional wells have been planned or approved to date, Section 5.3 of the Gloucester Gas Project environment assessment states that 'based upon current knowledge, approximately 200 to 300 wells are likely to be developed in the Concept Area over a 20 year time period' (AECOM, 2009, p. 5–5). However, if AGL still proposes to drill 200 to 300 wells as part of a staged development, future applications will need to be lodged for those wells as part of the 'Subsequent Stages Project' described in the concept plan approval (NSW Department of Planning, 2011b; NSW Government Planning Assessment Commission, 2011) in order to obtain approval by the NSW Government. Approval may also be required under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* if the proposed development is deemed to have a significant impact on matters of national environmental significance.

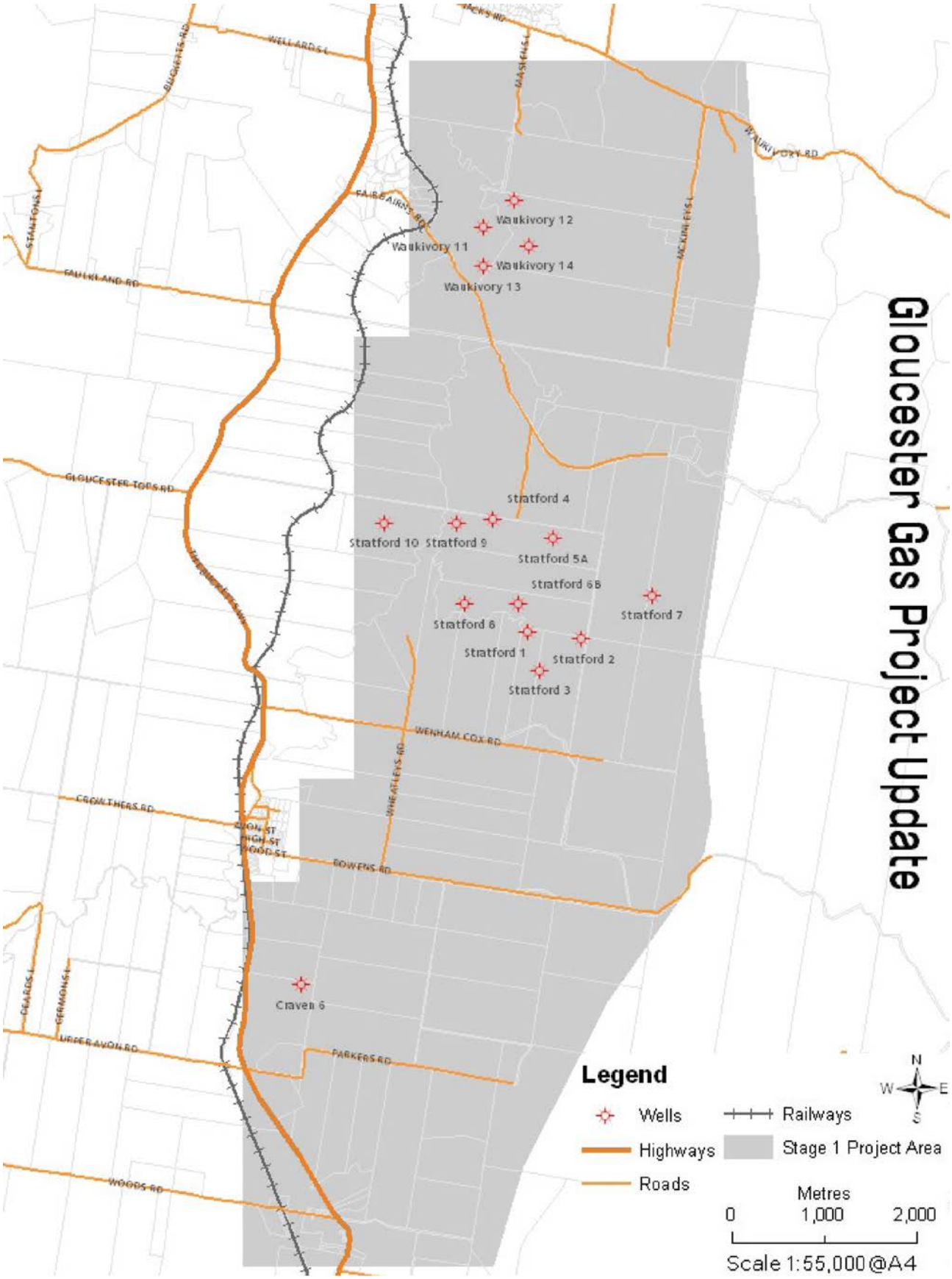

Figure 8 Location of wells for the Gloucester Gas Project

Source: AGL Energy Limited (n.d.). © AGL, 2014

The Subsequent Stages Project comprises:

> the pre-construction, construction, commissioning, operation, decommissioning and rehabilitation of gas wells and associated infrastructure including gas and water gathering lines and temporary construction facilities, within the remainder of the 210 km^2 gas field development area, in the Gloucester Shire and Great Lakes Shire local Government areas, which may be developed in one or more discrete stages (NSW Government Department of Planning, 2011, p.5).

With regards to the Subsequent Stages Project, operative provisions in the concept plan approval (NSW Department of Planning, 2011b) require, under Condition 2.1 of Part D, a set of requirements for the necessary environmental assessments and environmental impact statements to be established (NSW Department of Planning, 2011b, p. 6). Condition 2.2 of Part D (NSW Department of Planning, 2011b, p. 8) states that 'the proponent may choose to submit separate project applications for any one or a combination of discreet development stages associated with the Subsequent Stages Project'. Additionally, Condition 1.5 of Part C (NSW Department of Planning, 2011b, p. 6) states:

> to avoid any doubt, this concept plan approval does not permit the construction or operation of any projects associated with the Gloucester Gas Project. Construction cannot commence on any projects associated with this concept plan unless a separate project approval has been granted in relation to that project.

Project approval in this instance refers to 'approval granted for a project in accordance with section 75J of the *Environmental Planning and Assessment Act 1979*' (NSW Department of Planning, 2011b, p. 8).

In summary, the concept and project plan for Stage 1 was approved by NSW Government in 2011 (NSW Government Planning Assessment Commission, 2011). The then Minister for Sustainability, Environment, Water, Population and Communities, the Hon. Tony Burke, MP, approved the construction, operation and decommissioning of no more than 110 wells for Stage 1 on 11 February 2013 (SEWPaC, 2013).

At present, there is no plan for a Subsequent Stages Project (Gloucester Gas Project stages beyond Stage 1) in the public domain. It is understood that exploration is continuing with additional pilots proposed in financial years 2015 and 2016. There will be no firm number of additional proposed wells or locations until the exploration program has progressed and new environmental assessments have been completed. Subsequent stages may be south of Stage 1 and there may also be some expansion to the west, whilst expansion to the north of Stage 1 is unlikely, given the current NSW Government 2 km exclusion zone around residential areas.

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1.2.4 Catalogue of potential resource developments

Summary

Section 1.2.4 provides summary information in map and table form for potential coal and coal seam gas (CSG) resource developments within the Gloucester subregion. This section builds on information already provided in Section 1.2.3. The tables list locations, resource figures and development status relative to environmental impact statements (EIS). In some cases the current status is prior to an EIS being submitted and their inclusion in the table does not imply that development will be proposed. The area of AGL's proposed CSG stage 1 development area is also included in Figure 9. Coal mine expansion is planned at Yancoal Australia Ltd's Stratford and Duralie mines and a new coal mine is planned by Gloucester Resources Limited at Rocky Hill.

Figure 9 shows the location of coal deposits in the Gloucester subregion and the area proposed for stage 1 of AGL's CSG development.

Table 4 and Table 5 list potential developments with locations, resource figures and development status. Resources for coal are consistent (where possible) with the Joint Ore Reserve Committee (JORC) Code and include measured, indicated and inferred resources (inclusive of any reserves). CSG resources are reported as proved plus probable reserves (2P) using the Petroleum Resource Management System (PRMS).

Locations of the two currently operating coal mines and two coal deposits (Wenham Cox Road, Grant and Chaney) are derived from the OZMIN National Mineral Deposits Database (Geoscience Australia, 2013). The location of Rocky Hill coal deposit and AGL CSG stage 1 development area have been added from publically available company documents. Geoscience Australia supplied information from their in-house version of OZMIN.

Coal resource figures presented in Table 4 are from the OZMIN database with more recent updates added using information available from Yancoal Australian Stock Exchange 2013 releases and from the Gloucester Resources Limited (2013) environmental impact statement (EIS) for their proposed Rocky Hill coal development. CSG Resource figures in Table 5 are from AGL publically available documents.

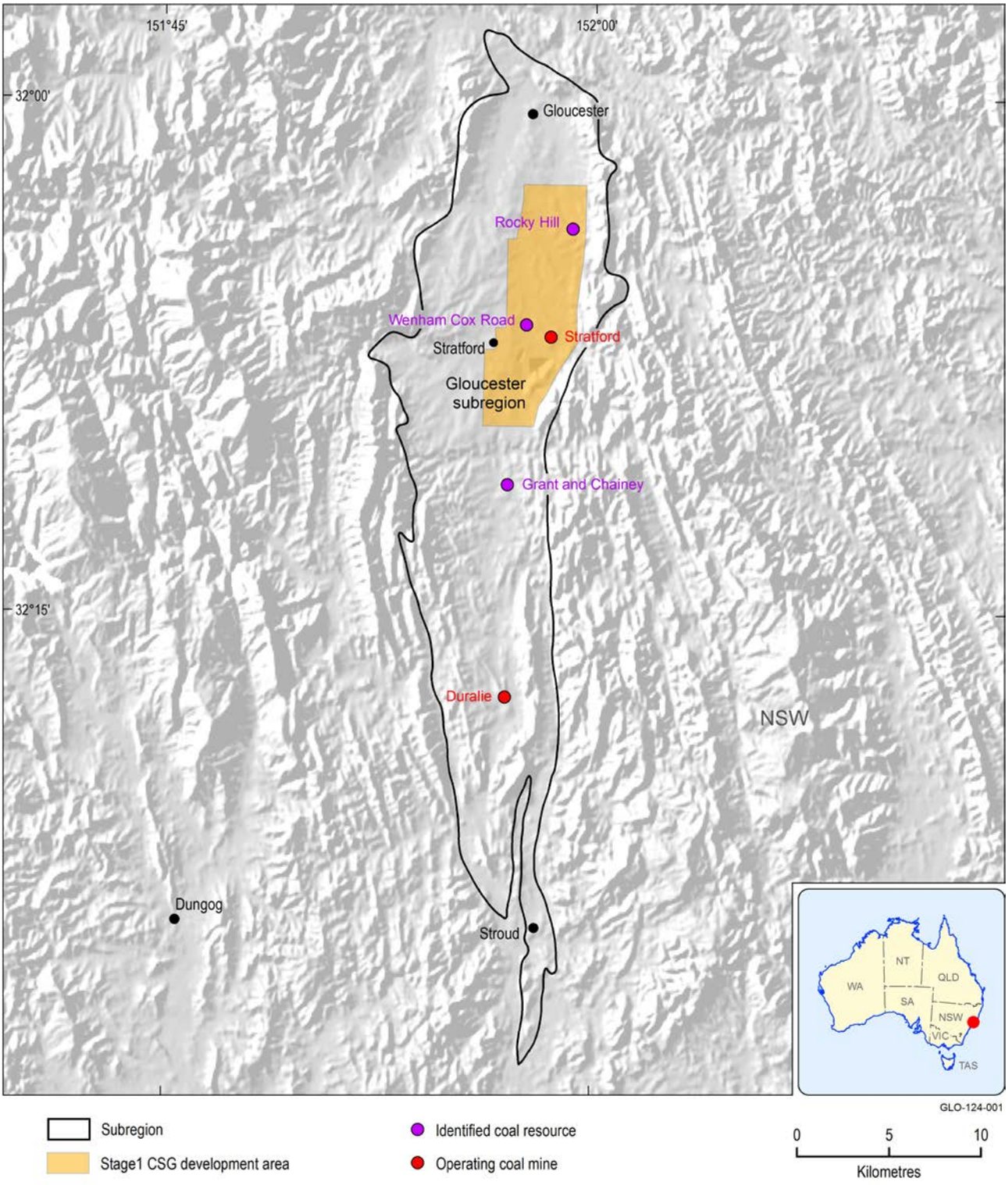

Figure 9 Coal and coal seam gas deposits in the Gloucester subregion

Locations for the Stratford and Duralie operating mines and the deposits at Wenham Cox Road and Grant and Chaney were extracted from the OZMIN database (Geoscience Australia, 2013). The location of Rocky Hill deposit and the AGL CSG stage 1 development area were obtained from publically available company documents. The background is shaded topography.

In late 2012, the NSW Government introduced its Strategic Regional Land Use Policy to protect valuable residential and agricultural land across the State from the impacts of mining and CSG activity (NSW Government, 2014). Information was released in January 2014, identifying the areas of Biophysical Strategic Agricultural Land – land of high quality soil and water resources capable of supporting high levels of agricultural production – across NSW, which are deemed necessary to

support the state's $12 billion per year agricultural industry. CSG exclusion zones were identified by Strategic Agricultural Lands in 2013 (NSW Government, 2013) (Figure 10).

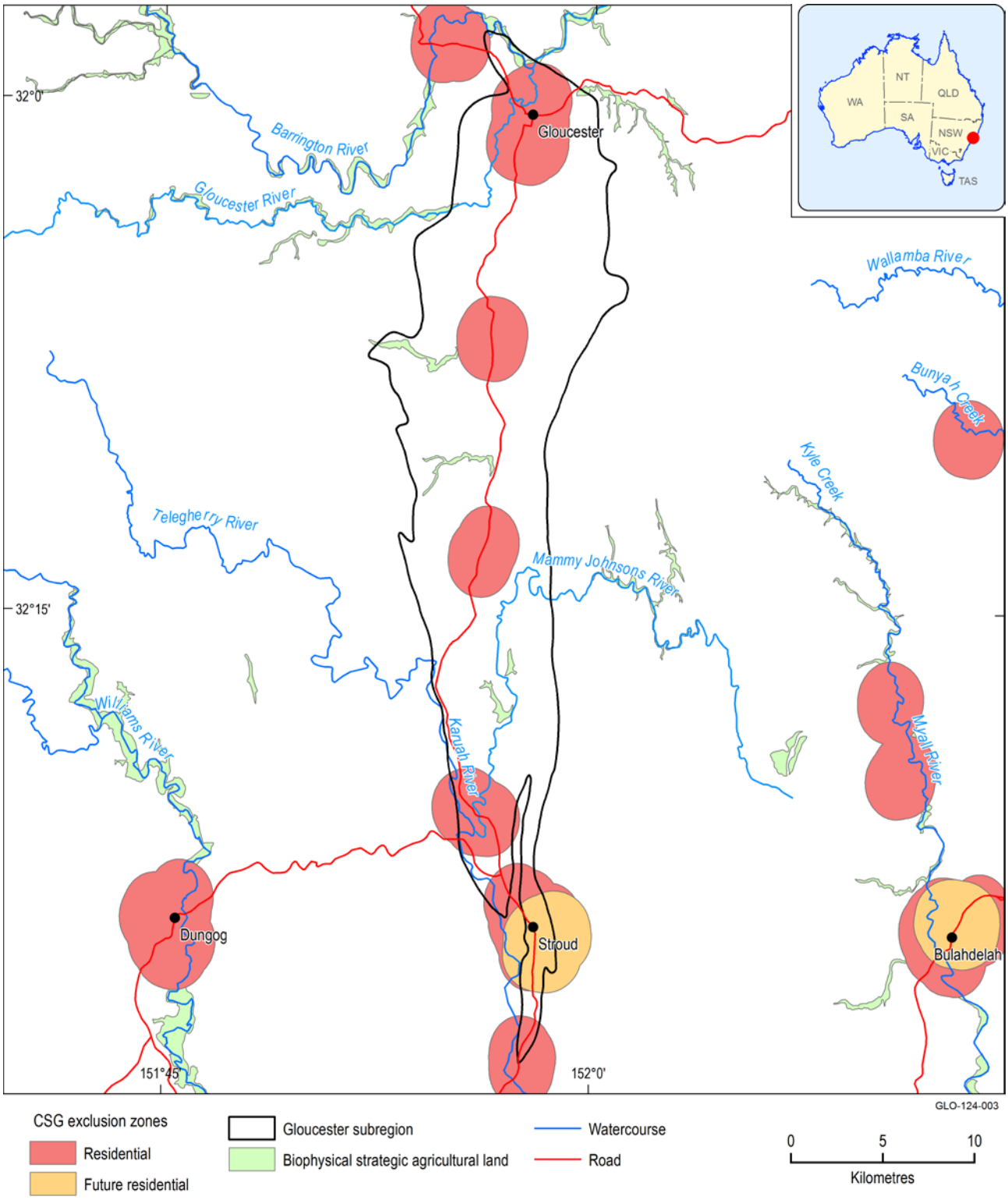

Figure 10 Coal seam gas exclusion zones in the Gloucester subregion

Source data: Strategic Agricultural Lands (NSW Government, 2013)

Table 4 Catalogue of potential coal resource developments in the Gloucester subregion

Project	Company	Longitude	Latitude	Record date[a]	Material[b]	Total coal resources[c] (Mt)	Status of EIS[d]	Notes
Duralie Coal Extension Plan	Yancoal Australia Ltd	151.950°	–32.291°	Sep 2012	Coking coal and thermal coal	148[e]	EIS approved	Resource figure is from Yancoal ASX[f] release March 2014
Grant and Chainey	Yancoal Australia Ltd	151.95°	–32.188°	Sep 2012	Coking coal	77	Pre-EIS	Resource figure is from Yancoal ASX release March 2014
Rocky Hill Coal Project	Gloucester Resources Limited	151.988°	–32.066°	Aug 2013	Coking coal and thermal coal	25	EIS under review	Resource figure quoted here is mineable reserves figure as per EIS
Stratford Extension Plan	Yancoal Australia Ltd	151.975°	–32.116°	Sep 2012	Coking coal and thermal coal	98[e]	EIS under assessment by NSW Planning and Environment as at October 2014	Resource figure is from Yancoal ASX release March 2014
Wenham Cox Road	Yancoal Australia Ltd	151.961°	–32.110°	Feb 2012	Thermal coal	37.1	Pre-EIS	Adjacent to Roseville west area of Stratford coal mine

[a]The record date is the most recent date for updated coal resource numbers.
[b]Materials fall into one of the following four classes: thermal coal, coking coal, pulverised coal injection (PCI) and unspecified.
[c]This is calculated by summing the resources with Joint Ore Reserves Committee (JORC) codes of measured, indicated and inferred.
[d]The status of the project within an environmental impact statement (EIS): pre-EIS, EIS in preparation, EIS submitted, EIS closed, supplementary EIS and EIS approved.
[e]Resources figures above for Duralie and Stratford are total resources at those mine sites and are not the figures for extensions.
[f]Australian Stock Exchange (ASX)

Table 5 Catalogue of potential coal seam gas resource developments in the Gloucester subregion

Project	Company	Longitude	Latitude	Record date[a]	2P coal seam gas reserves[b] (PJ)	Status of EIS[c]	Notes
Gloucester Gas Project: Stage 1	AGL	151.98° (approx)	–32.12° (approx)	Dec 2013	454 PJ for Gloucester Basin exploration to December 2013. See also note below.	EIS approved subject to conditions	Waukivory Pilot Project approved August 2014
Gloucester Gas Project: Stages 2 and beyond	AGL	Not available	Not available	Dec 2013	Included with stage 1 in the figure of 454 PJ for Gloucester Basin exploration to December 2013	Pre-EIS	Conceptual only as at October 2014. Mainly south of Stage 1

[a]The record date is the most recent date for updated coal seam gas resource numbers.
[b]The Petroleum Resource Management System of the Society of Petroleum Engineers (PRMS-SPE) code 2P refers to estimated quantities of Proved reserves plus Probable reserves.
[c]The status of the project within an environmental impact statement (EIS): pre-EIS, EIS in preparation, EIS submitted, EIS closed, supplementary EIS and EIS approved.

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