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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 Gwydir subregion

Product 1.2 for the Gwydir subregion from the
Northern Inland Catchments Bioregional Assessment

23 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>>.

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Authorship is listed in relative order of contribution.

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Cover photograph

Gwydir River near Pallamallawa

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

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This technical product was reviewed by several groups:

- Discipline Leaders: Steven Lewis (geology, Geoscience Australia)
- Senior Science Leaders: David Post (Projects Director, CSIRO), 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.

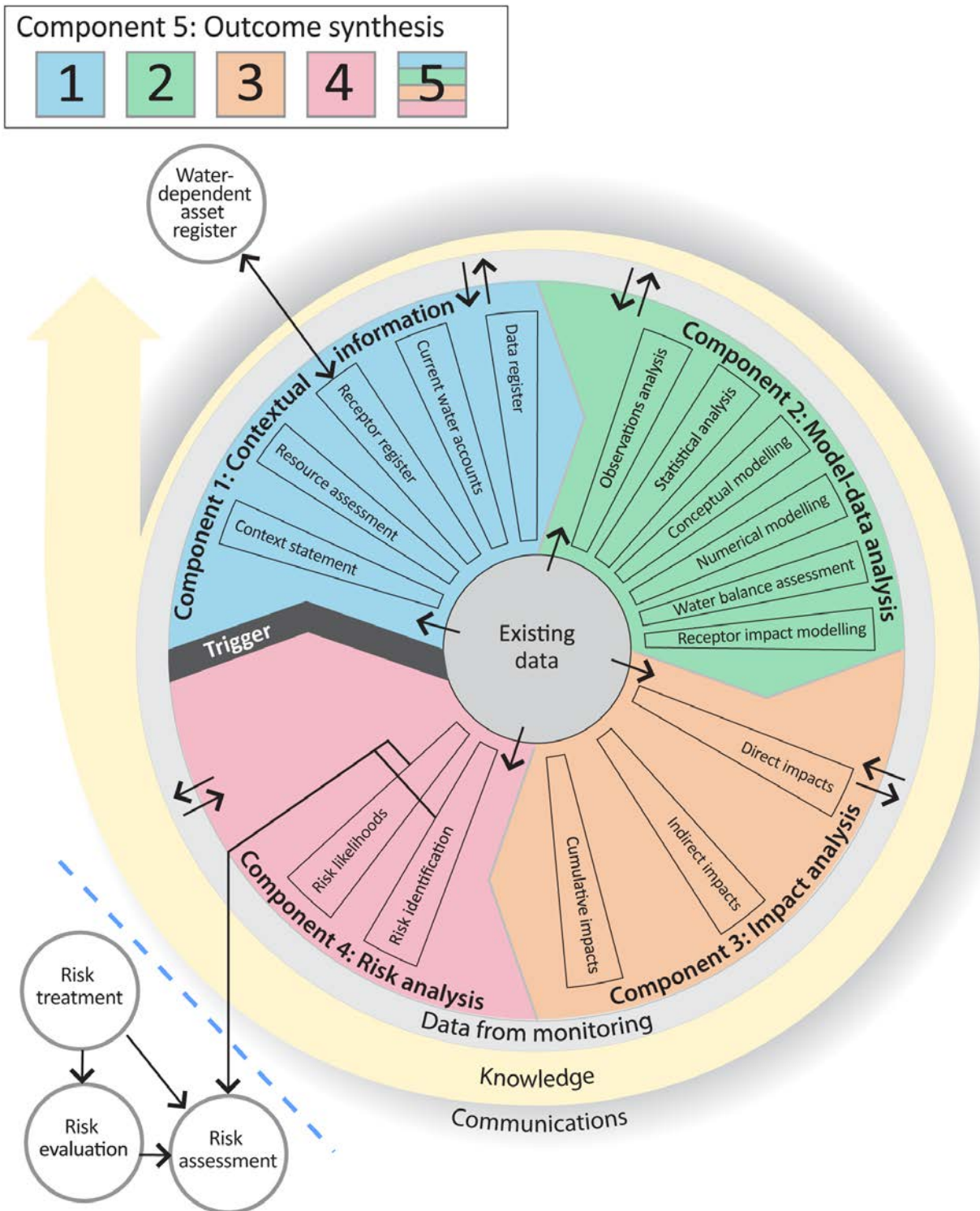


Figure 1 Schematic diagram of the bioregional assessment methodology

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	<i>Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources</i>	A high-level description of the scientific and intellectual basis for a consistent approach to all bioregional assessments	All
M02	<i>Compiling water-dependent assets</i>	Describes the approach for determining water-dependent assets	1.3 Description of the water-dependent asset register
M03	<i>Assigning receptors and impact variables to water-dependent assets</i>	Describes the approach for determining receptors associated with water-dependent assets	1.4 Description of the receptor register
M04	<i>Developing a coal resource development pathway</i>	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	<i>Developing the conceptual model for causal pathways</i>	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	<i>Surface water modelling</i>	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	<i>Groundwater modelling</i>	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	<i>Receptor impact modelling</i>	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	<i>Propagating uncertainty through models</i>	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	<i>Risk and cumulative impacts on receptors</i>	Describes the process to identify and analyse risk	3 Impact analysis 4 Risk analysis
M11	<i>Hazard identification</i>	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	<i>Fracture propagation and chemical concentrations</i>	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>.

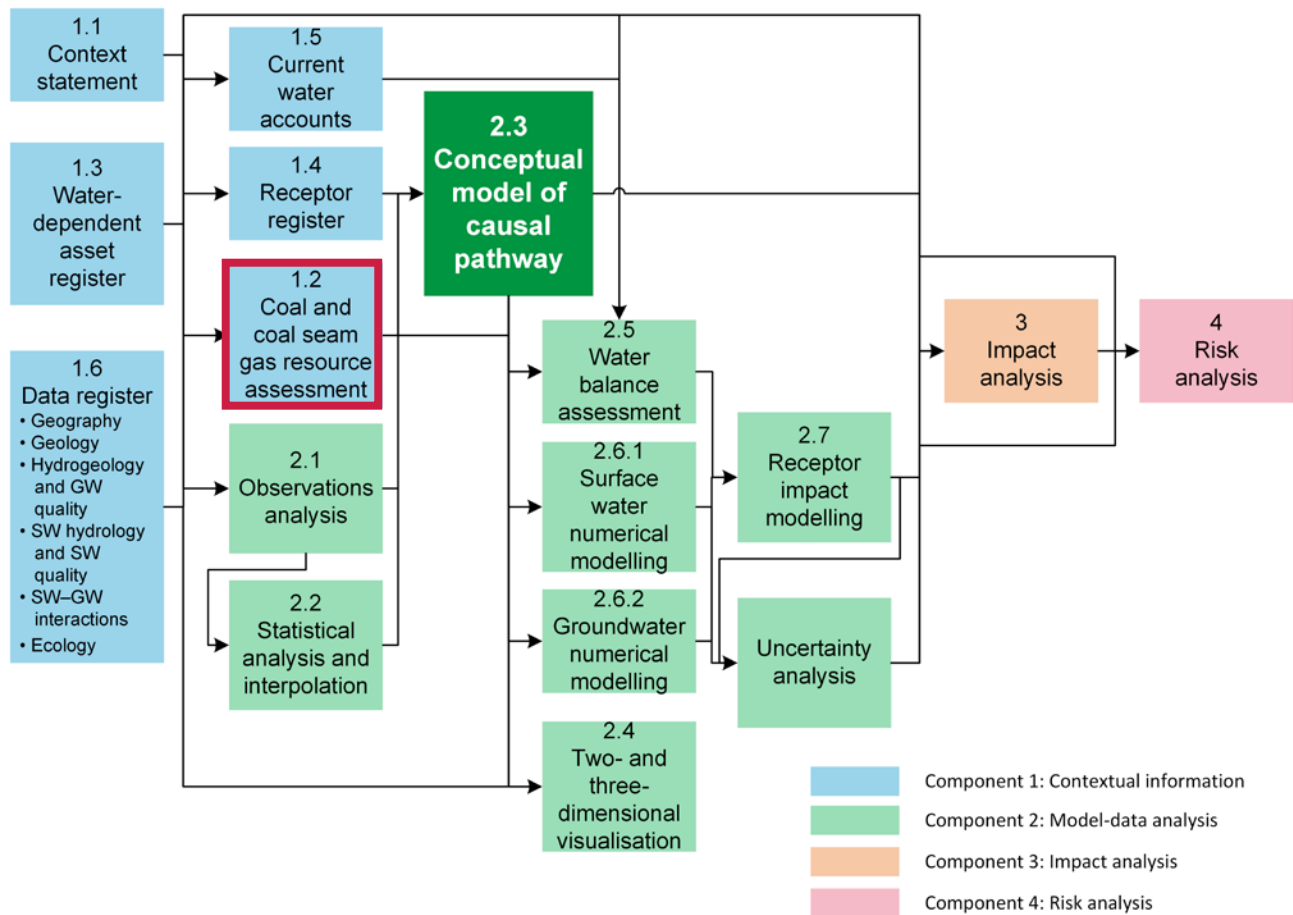


Figure 2 The simple decision tree indicates the flow of information through a bioregional assessment

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 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 Inland Catchments bioregion and two standard parallels of -18.0° and -36.0°.

Table 2 Technical products being delivered as part of the Northern Inland Catchments Bioregional Assessment

For each subregion in the Northern Inland Catchments 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 Gwydir 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 Gwydir 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 Gwydir subregion	3	Impact analysis	5.2.1	■
Component 4: Risk analysis for the Gwydir subregion	4	Risk analysis	2.5.4, 5.3	■
Component 5: Outcome synthesis for the Northern Inland Catchments bioregion	5	Outcome synthesis	2.5.5	■

^aBarrett et al. (2013)

^bThe 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 Gwydir 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 coal and coal seam gas (CSG) resources of the Gwydir subregion have not been extensively explored, thus limited published information is available on the distribution and properties of the subregion's resources. Currently no coal mining is taking place in the subregion, although coal seams are contained within the Bowen, Gunnedah and Surat geological basins in the subregion. Little is known about the coals hosted within the Kianga Formation of the Bowen Basin in this area. The main structural unit of the Gunnedah Basin within the subregion is the Bellata Trough, which hosts coal deposits of the Maules Creek Formation and the Black Jack Group. The limited drilling data available shows that Gunnedah Basin coals are of high volatile bituminous rank with vitrinite reflectance values between 0.55 and 0.69%. The production of thermogenic gas begins to evolve at a coal rank of 0.5 to 0.6% vitrinite reflectance. However, biogenic gas, derived from naturally occurring microbes, may be present below this rank. In the Surat Basin coals are present within the Bungil and Orallo formations, as well as the Walloon Coal Measures. Although the Walloon Coal Measures occur over a large area, their thickness, depth and lateral extent is not precisely known.

In the Gunnedah-Bowen Basin in the Gwydir subregion the Hoskissons Coal of the Late Permian Black Jack Group, the Early Permian Maules Creek Formation of the Bellata Group, and the Middle Triassic Moolayember Formation have been targeted to assess their CSG potential. The Hoskissons Coal was found to be less than 3 m in thickness with a gas content of 5.9 m³/t (composition more than 90% methane). The coals of the Bohena Seam of the Maules Creek Formation are thick (14.8 m) with a high gas content (14.2 m³/t), but a very high carbon dioxide content (more than 80%). Both coal seams have low reservoir permeability. Exploration of the Moolayember Formation indicated net coal seam thickness ranging from 3.3 to 8.5 m, low reservoir permeability, and a mean gas content of more than 4 m³/t (gas composition not reported). In the Surat Basin some exploration has occurred in the Middle Jurassic Walloon Coal Measures and the Early Cretaceous Bungil Formation of the Blythesdale Group. The Walloon Coal Measures in the Gwydir subregion are much thinner than further north in southern Queensland and commercial CSG production does not appear viable. The Bungil Formation was found to have undersaturated coals with mean gas contents of approximately 4 m³/t (methane content greater than 93%), net seam thickness of up to 10 m, and low reservoir permeability. The low reservoir permeability indicates that these coals are not likely to produce CSG at economic rates without hydraulic stimulation of vertical wells or drilling of horizontal wells with multiple fractures placed along the well, a technology that is yet to be proven in Australia.

1.2.1.1 Coal

Very little coal exploration has been undertaken in the Gwydir subregion. Two confirmed coal exploration boreholes (Figure 3) were listed by 'MinView' (NSW DTI, 2014a) in the subregion (22 July 2014). These boreholes were drilled in 1975 by the NSW Government Department of

Mineral Resources. No exploration reports are available at present and no coal mining is presently taking place and therefore, information on coal resources in this subregion is sparse.

1.2.1.1.1 Bowen Basin

Sedimentary deposits of the southern Taroom Trough (refer to Figure 18 of companion product 1.1.3 for the Gwydir subregion (Welsh et al., 2014)) are the only Bowen Basin strata within the Gwydir subregion. Coals of the Bowen Basin in northern NSW are hosted within the Kianga Formation (Othman and Ward, 2002, p. 147), formally referred to by the same name as its equivalent, the Late Permian Baralaba Coal Measures of the Blackwater Group (refer to Figure 19 of companion product 1.1.3 for the Gwydir subregion (Welsh et al., 2014)) in southern Queensland (Geoscience Australia, 2014). However, only limited published information is available on the distribution and properties of coal resources in the Bowen Basin in northern NSW.

1.2.1.1.2 Gunnedah Basin

The area of the Gunnedah Basin within the Gwydir subregion includes the northernmost extent of the Mullaley sub-basin, in particular, the Bellata Trough which is situated in the south of the subregion against the western flank of the Boggabri Ridge (refer to Figure 17 of companion product 1.1.3 for the Gwydir subregion (Welsh et al., 2014)). The major coal deposits of the Gunnedah Basin (which occur south of the Gwydir subregion) are hosted within the Maules Creek Formation and the Black Jack Group (Tadros, 1993, 1995) (refer to Figure 19 of companion product 1.1.3 for the Gwydir subregion (Welsh et al., 2014)). However, as little exploration has been carried out in this area, little is known about coal distribution in these formations within the Bellata Trough. Although coal occurs in the Maules Creek Formation and the Hoskissons Coal of the Black Jack Group within the Gunnedah Basin, around Narrabri, south of the Gwydir subregion (Tadros et al., 1986, p. 1–6), it is not clear whether the Hoskissons Coal is present in the two Gwydir coal boreholes drilled as coal seams intersected are not specified in reports available (NSW DTI, 2014b).

Gurba et al. (2009, p. 96) reported that the Bellata Trough is largely unexplored with only two wells drilled, and most of the Black Jack Group and Watermark and Porcupine formations have been eroded from the sequence in this area (Othman and Ward, 2002, p. 155; Othman, 2003). Vitrinite reflectance (which is a measure of thermal maturity and capacity to produce oil or gas) data from one of these wells show a steady increase with increasing depth (Othman and Ward, 2002, p. 155; Othman, 2003), with coals of high volatile bituminous rank and reflectance values between 0.55 and 0.69% (Gurba et al., 2009, p. 96). The production of thermogenic coal seam gas begins to evolve at a coal rank of 0.5 to 0.6% vitrinite reflectance (Clayton, 1998). However, biogenic gas, derived from microbes, may be present below this rank and mixtures of biogenic and thermogenic gas will exist during the transition from one gas type to the other (Moore, 2012). In the area north and north-east of the Bellata Trough a number of petroleum wells have been drilled. Studies by Sherwood et al. (1995) and Othman and Ward (2002) using data from these wells show that the vitrinite reflectance values for the Surat-Bowen sequence in northern NSW range from 0.3 to 5.5%. The coals with values above 0.85% are reported to represent rocks affected by igneous intrusions, which has elevated their thermal maturity and increased their potential for producing gas. Information on the distribution and properties of coal resources is very limited.

1.2.1.1.3 Surat Basin

Etheridge and McLinn (1986, p. 20) stated that the Purlawaugh Formation identified in well DM Bellata DDH 1, in the Gwydir subregion, is time equivalent to the Hutton Sandstone and Walloon Coal Measures (refer to Figure 19 of companion product 1.1.3 for the Gwydir subregion (Welsh et al., 2014)). The interval is 38 m thick comprising of a fluvial channel point-bar sequence overlain by a floodplain sequence of clay and sandstone. In coal boreholes DM Moema DDH 1 and 1A the same formation was identified although the report states that no coal company was interested in either hole (Bourke, 1977, p. 2). Deposits within this area represent an extension to the Hutton Sandstone and the Walloon Coal Measures which have been identified as 'unit[s] that [are] considered to be a potential oil/gas reservoir' (Etheridge and McLinn, 1986, p. 20).

In northern NSW coals occur within the Bungil and Orallo formations, some of which are minor and unlikely to be economic targets; coal also occurs in the Walloon Coal Measures of the Surat Basin (Stewart and Alder, 1995, p. 158). Coal exploration has not been conducted for the Bungil and Orallo formations, and although the Walloon Coal Measures occur over a large area, their thickness, depth and lateral extent is not precisely known. The coals are considered to be high volatile bituminous rank and rich in vitrinite (Stewart and Alder, 1995, p. 158).

1.2.1.2 Coal seam gas

In the Gwydir subregion the Surat Basin overlies the Gunnedah-Bowen Basin (see Figure 16 in companion product 1.1 for the Gwydir subregion (Welsh et al., 2014)) which have both been targets for CSG exploration and production outside the subregion. In the Gunnedah-Bowen Basin initial exploration for CSG investigated the potential of the Late Permian Black Jack Group (ESG, 2009a), the Early Permian Maules Creek Formation of the Bellata Group (ESG, 2009a), and the Middle Triassic Moolayember Formation (ESG, 2010a, 2010b, 2009c). For Gunnedah and Bowen Basin stratigraphies see Figure 19 in the companion product 1.1 for the Gwydir subregion (Welsh et al., 2014) which also presents the stratigraphy of the Surat Basin. In the Surat Basin some CSG exploration has occurred in the Middle Jurassic Walloon Coal Measures, as well as in the Early Cretaceous Bungil Formation of the Blythesdale Group (ESG, 2009a, 2009b).

The Walloon Coal Measures are the primary target for CSG production further north in southern Queensland (in the Maranoa-Balonne-Condamine subregion, see product 1.2 for the Maranoa-Balonne-Condamine subregion (Sander et al., 2014)). However, in the Gwydir subregion the Walloon Coal Measures are less prospective for CSG. The total thickness of the Walloon Coal Measures in the northern part of the Gwydir subregion is 200 m and the net coal thickness is less than 2 m with thin coal seams occurring in some of the thick shales in the upper half of the coal measures (Pangaea, 2010a). In comparison, about 200 km to the north of the subregion, the Walloon Coal Measures are more than 500 m in thickness and net coal thickness is greater than 30 m (Pangaea, 2010a). Exploration of the Walloon Coal Measures in the north-east of the Gwydir subregion did not show potential for commercial CSG recovery. The exploration results indicated very low net coal seam thickness (ranging from 0.6 m to 3.05 m), permeability (not quantified), and gas content (ranging from an average gas content of 0.5 m³/t to 0.8 m³/t on an air dried basis) in this area (Pangaea 2010a, 2010b, 2010c, 2010d). Depth to coal ranged from 460 to 665 m (Pangaea 2010a, 2010b, 2010c, 2010d).

The geology of the Bungil Formation is not well understood as it has not been well explored, because it is traditionally considered to be of no commercial interest for conventional petroleum production (ESG, 2009a). The formation consists of fine-grained sandstones and siltstones interbedded with numerous, thin, carbonaceous shales and coals, which are of lignite to sub-bituminous rank (ESG, 2009a). For coals of such low rank, any measurable volumes of gas are a result of biogenic gas production as they are not mature enough to have generated thermogenic gas (Moore, 2012). The gas content of biogenically derived resources is generally not above 4 to 6 m³/t (Moore, 2012). However, on the upside, often the composition of the gas present in low rank coals is predominantly methane (CH₄) (Moore, 2012). The Bungil Formation has been a target for CSG exploration in the western Gwydir subregion as well as in the Moree area in the centre of the subregion where a net coal thickness of up to 10 m from five to ten coal seams is typical and the coals are known to be gas-bearing (ESG, 2009a). Exploration indicated the coals were undersaturated with mean gas content of approximately 4 m³/t (dry ash free basis) (ESG, 2009a, 2009b). The gas composition is more than 93% CH₄. Drill stem tests and log scanner data indicated low reservoir permeability, although the coal was buried at a comparatively shallow depth (on average 350 m depth to coal) (ESG, 2009a, 2009b). A gas content of 4 m³/t can be economic if other reservoir properties are favourable (as seen for example in the Powder River Basin in the USA where the coals were reported to have gas contents of less than 3.5 m³/t (US DOE, 2002)). However, when coals are undersaturated with respect to gas, water has to be produced first to depressurise the reservoir until a pressure is reached at which gas starts to desorb from the coal and flows to the production well. Furthermore, the low reservoir permeability implies that these coals are not likely to produce CSG at economic rates without hydraulic fracture stimulation of vertical wells or drilling of horizontal wells with multiple fractures placed along the well, a technology that is yet to be proven in Australia (Jeffrey, 2012). Jeffrey (2012) stated that target coal seams for fracture stimulation of vertical wells generally have permeabilities between 1 and 20 mD. The production of gas from coals below 0.1 mD is not economic with a hydraulically fractured vertical well (Jeffrey, 2012). However, coal seams that have permeabilities below 1 mD may be produced at economic rates using horizontal wells with multiple fractures along the well (Jeffrey, 2012).

South of the Moree area in the central Gwydir subregion, the Moolayember Formation has been a CSG exploration target while the Bungil Formation does not occur (ESG, 2010a). The mean gas content is more than 4 m³/t on a dry ash free basis (ESG, 2010a, 2010b, 2009c) with no gas composition reported. Net coal seam thickness ranges from 3.3 to 8.5 m with maximum individual seam thickness ranging from 0.75 to 1 m (ESG, 2010b, 2009c). Depth to coal varies greatly, ranging from 310 m in the Moree High to 810 m. Drill stem tests indicated low permeability (ESG, 2010a, 2009c).

In the south of the subregion, in the Bellata Trough region, the Hoskissons Coal of the Black Jack Group and the Maules Creek Formation (ESG, 2009a) have been targeted to explore their potential for CSG extraction. The Hoskissons Coal is widespread across the Gunnedah Basin and typically up to 10 m thick (ESG, 2009a). The coals are sub-bituminous to bituminous rank. The coals of the Maules Creek Formation are bituminous and individual seams can be up to 8 m thick, with a total net thickness of more than 35 m (ESG, 2009a). Initial exploration in the subregion has found the Hoskissons seam, encountered at 683 m depth, to be 2.3 m thick with a gas content of 5.9 m³/t

(dry ash free basis, gas composition more than 90% CH₄) (ESG, 2010c). The Bohena Seam of the Maules Creek Formation at 953 m depth is thick (14.8 m) with a high gas content (14 m³/t), but of a very high carbon dioxide (CO₂) content (more than 80% CO₂) (ESG, 2010c). Drill stem tests indicated low reservoir permeability for both coal seams (ESG, 2010c).

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1.2.1 Available coal and coal seam gas resources

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1.2.2 Current activity and tenements

Summary

There are no coal mines in operation in the Gwydir subregion.

No commercial coal seam gas extraction has occurred, or is currently occurring, in the Gwydir subregion.

1.2.2.1 Coal

As at 8 October 2014, data available publicly through the NSW Government's Trade and Investment Resources and Energy data portal, 'MinView' (NSW DTI, 2014), shows that there are currently no coal mines operating in the Gwydir subregion.

1.2.2.2 Coal seam gas

As of 3 September 2014 no commercial coal seam gas extraction has occurred or is currently occurring in the Gwydir subregion.

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1.2.2 Current activity and tenements

1.2.3 Proposals and exploration

Summary

Coal exploration is not actively being pursued in the Gwydir subregion. Therefore no proposals or exploration for coal can be reported here.

There are currently no proposals for coal seam gas (CSG) development in the Gwydir subregion and no reserves have been booked (as of September 2014). However, some initial exploration for CSG has occurred, which has resulted in combined contingency resources (quantities of petroleum that are estimated to be potentially recoverable from known accumulations, but which are not currently considered to be commercially recoverable) of 991 PJ in the subregion.

In the north-eastern part of the subregion exploration for CSG has occurred in the Middle Jurassic Walloon Coal Measures, which were not found to have potential for commercial CSG production.

In the central and central-western Gwydir subregion coals of the Early Cretaceous Bungil Formation have been explored. The coals were undersaturated with mean gas contents of approximately 4 m³/t (dry ash free basis, methane content greater than 93%), a net coal thickness of up to 4.6 m, and low reservoir permeability.

The Middle Triassic Moolayember Formation has been a CSG target in the central-eastern subregion. Results from three exploration wells indicated a mean gas content of more than 4 m³/t (dry ash free basis, no gas composition reported) and a net coal thickness of 3.3 to 8.5 m. Drill stem tests indicated low permeability of the Moolayember Formation.

Further south, in the Bellata Trough region, the CSG potential of the Moolayember and the Bungil formations as well as the Late Permian Black Jack Group and the Early Permian Maules Creek Formation have been assessed. Here the Moolayember and Bungil formations were not found to contain gas volumes of commercial significance. Results from an exploration well targeting the Hoskissons Coal of the Black Jack Group and the Bohena Seam of the Maules Creek Formation were reported as having a net thickness of 2.3 m and a gas content of 5.6 m³/t for the Hoskissons Coal (more than 90% methane) and a net thickness of 14.8 m and a high gas content of 14.2 m³/t for the Bohena Seam. However, the gas consists of more than 80% carbon dioxide. Reservoir permeability was indicated to be low for both coal seams.

CSG exploration and commercialisation in the Gwydir subregion must be consistent with the CSG regulations and exclusion zones that apply in NSW. These zones prohibit new CSG exploration and development within a 2 km buffer of existing and future residential areas.

1.2.3.1 Coal

As at 8 October 2014, data available publicly through NSW Government's Trade and Investment Resources and Energy data portal, 'MinView' (NSW DTI, 2014a), shows that there are currently no large coal mining applications (mining lease applications) proposed for the Gwydir subregion.

There are currently no coal exploration tenements that either partly or wholly occur in the Gwydir subregion. Therefore, no proposals or exploration are reported here.

1.2.3.2 Coal seam gas

There are currently no proposals for CSG development in the Gwydir subregion and no reserves have been booked (as of September 2014). However, some initial exploration for CSG has occurred, which has resulted in bookings of a combined recoverable contingent resource of 991 PJ. As per the Society of Petroleum Engineers' (SPE) Resource Classification System and Definitions, contingent resources are those quantities of petroleum which have been estimated to be potentially recoverable from known accumulations, but are not currently considered to be commercially recoverable (SPE, 2000). Contingent resources may include accumulations for which there is currently no viable market, or where commercial recovery is dependent on the development of new technology, or where evaluation of the accumulation is still at an early stage (SPE, 2000). In the Gwydir subregion the Surat Basin overlies the Gunnedah-Bowen Basin and both basins have been subject to CSG exploration. So far, exploration has targeted the Early Permian Maules Creek Formation, the Late Permian Black Jack Group, the Middle Triassic Moolayember Formation and the Middle Jurassic Walloon Coal Measures, as well as the Early Cretaceous Bungil Formation (ESG, 2009a). For Gunnedah Basin, Bowen Basin, and Surat Basin stratigraphies showing the above mentioned formations see Figure 19 in companion product 1.1 for the Gwydir subregion (Welsh et al., 2014). Findings of the exploration activities are detailed below.

Current petroleum permits fully or partially in the Gwydir subregion are shown in Figure 3 and their details are summarised in Table 2. For the permits that are only partially in the subregion, only exploration within the boundary of the Gwydir subregion is presented here. Types of petroleum permits in the subregion, as shown in Figure 3, are petroleum exploration licences (PELs) (which give holders the exclusive right to prospect for petroleum on the land comprised in the licence (NSW Government, 2014)), petroleum exploration licence applications (PELAs) and petroleum special prospecting authority applications (PSPAPPs). The holder of a special prospecting authority has the exclusive right to conduct speculative geological, geophysical or geochemical surveys or scientific investigations on and in respect of the land comprised in the authority (NSW Government, 2014). To produce petroleum and construct and maintain the necessary infrastructure, a petroleum production lease (PPL) is required, which needs to be obtained via a petroleum production lease application (PPLA) (NSW Government, 2014).

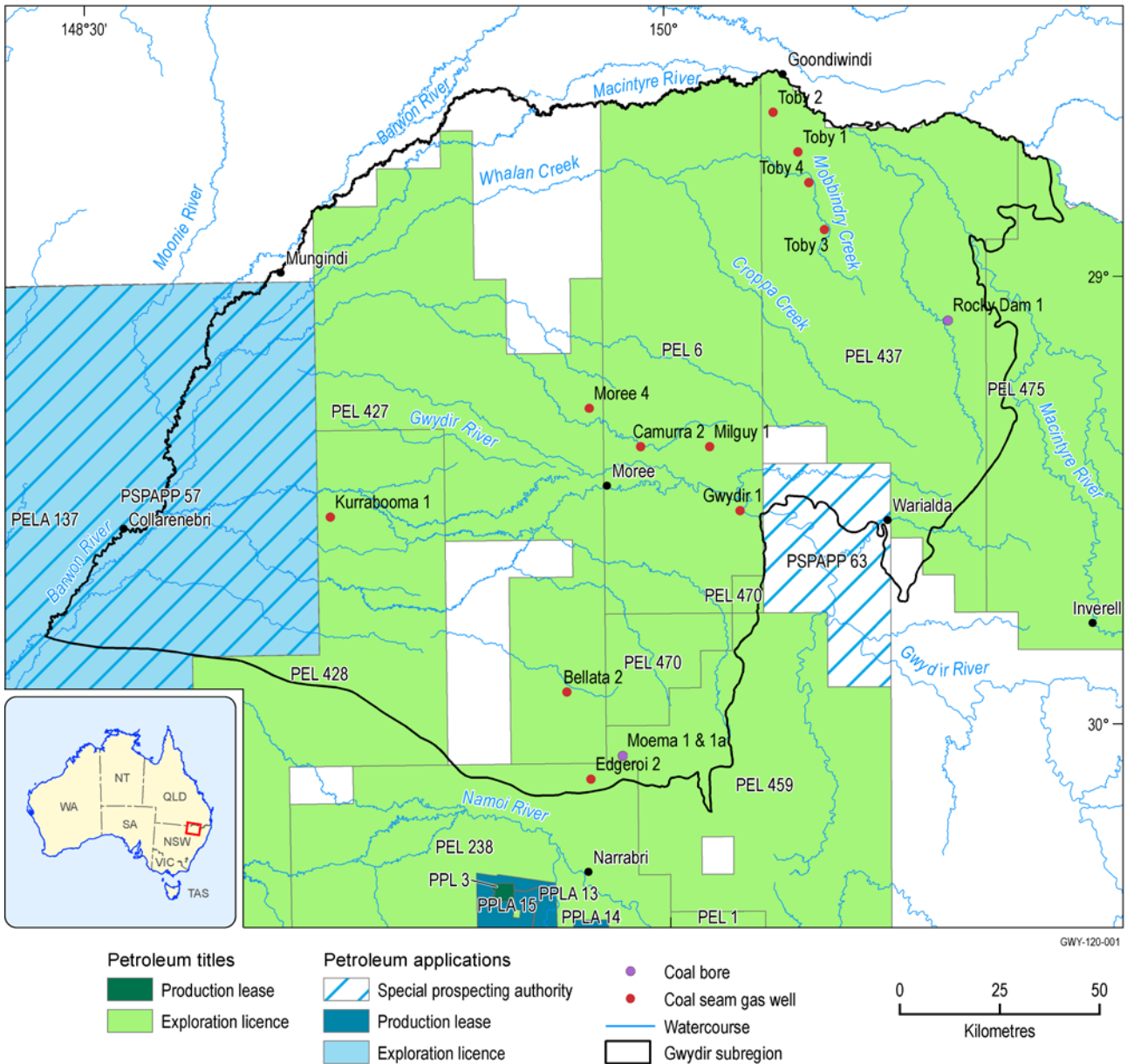


Figure 3 Petroleum permits, coal seam gas exploration wells and coal bores in the Gwydir subregion

Source: NSW Department of Trade and Investment (NSW DTI, 2014b), viewed 22 August 2014

PEL = petroleum exploration licence; PELA = petroleum exploration licence application; PPL = petroleum production lease; PPLA = petroleum production lease application; PSPAPP = petroleum special prospecting authority application

Table 3 Details of petroleum permits fully or partially in the Gwydir subregion

CSG Permits	Area (km ²)	Past CSG exploration targets	Major shareholders	Notes
PEL 6	5057	Moolayember Formation	Santos Ltd, EnergyAustralia, Comet Ridge Limited	
PEL 6 E	109	NA	Santos Ltd, EnergyAustralia, Comet Ridge Limited	
PEL 238	7920	Maules Creek Formation, Black Jack Group	Santos Ltd, EnergyAustralia	Only northern fraction of permit in subregion
PEL 427	5768	Moolayember Formation, Bungil Formation	Santos Ltd, Comet Ridge Limited, EnergyAustralia	
PEL 428	6021	Bungil Formation	Santos Ltd, Comet Ridge Limited, Davidson Prospecting Pty Ltd, EnergyAustralia	Only northern part in subregion
PEL 437	5647	Walloon Coal Measures	Pangaea PEL 437 Pty Limited	
PEL 459	5564	NA	Macquarie Energy Pty Ltd	Only north-western fraction in subregion
PEL 470	745	NA	Leichhardt Resources	
PEL 475	5084	NA	Drequilin Pty Limited	Only north-western fraction in subregion
PELA 137	9118	NA	Comet Ridge Limited	Application outcome pending on outcome of PSPAPP 57 (NSW DTI, 2014c). Only eastern part of permit in subregion
PSPAPP 63	1494	NA	Trough Exploration Pty Ltd	Only northern part in subregion

Source: pbEncom (2014)

PEL = petroleum exploration licence; PELA = petroleum exploration licence application; PSPAPP = petroleum special prospecting authority application; NA means 'data not available'

The Walloon Coal Measures of the Surat Basin are viable CSG producers further north in southern Queensland (in the Maranoa-Balonne-Condamine subregion, see product 1.2 for the Maranoa-Balonne-Condamine subregion (Sander et al., 2014)). However, in the Gwydir subregion the formation is significantly thinner (approximately 200 m in thickness compared to 500 m thickness further north) as is the net coal (less than 2 m in the Gwydir subregion compared with more than 30 m in Queensland) (Pangaea, 2010a). Results of an exploration programme (exploration wells Toby 1–4 in Figure 3) carried out by Pangaea PEL 437 Pty Limited (Pangaea) in 2010 indicated very low net coal seam thickness (ranging from 0.6 m to 3.05 m), permeability (not quantified), and gas content (ranging from mean gas content of 0.5 m³/t to 0.8 m³/t on air dried basis) in this area (Pangaea, 2010a, 2010b, 2010c, 2010d). Depth to coal ranged from 460 to 665 m (Pangaea, 2010a, 2010b, 2010c, 2010d). Thus, the Walloon Coal Measures in the Gwydir subregion

are currently not considered prospective for commercial CSG production (Pangaea, 2010a, 2010b, 2010c, 2010d).

The lignite to sub-bituminous coals of the Bungil Formation have been a CSG exploration target in the western Gwydir subregion as well as in the Moree region in the subregion centre (see Figure 3). At Moree the coal seams appear reasonably well-developed and are known to be gas-bearing (ESG, 2009a). Five to ten seams are typically present over an approximate 100 m interval with aggregate net thickness of up to approximately 10 m (ESG, 2009a). At exploration well Moree 4 (Petroleum Exploration Licence (PEL) 427, see Figure 3) the Bungil Formation was at a depth of 380 m and the coals had a net thickness of 4.3 m and were undersaturated with a mean gas content of 4.2 m³/t (dry ash free basis, 93% methane (CH₄)). Reservoir permeability was indicated as very low in drill stem tests (ESG, 2009a). At the exploration well Kurrabooma 1 (PEL 428, see Figure 3), targeting the same formation at a depth of 320 m, net coal thickness was 4.6 m and the coal was gas undersaturated with a mean gas content of 3.4 m³/t (dry ash free basis, 99% CH₄). Log scanner data indicated that the coals are not highly fractured (ESG, 2009b), implying low reservoir permeability. There have been 751 PJ of recoverable contingent resources booked in PEL 427 and 107 PJ in PEL 428 (ESG, 2011). No further development plans are known for these licence areas as of September 2014.

In the central-eastern Gwydir subregion, coals of the Moolayember Formation have been explored for their CSG potential. Results from exploration well Camurra 2 in PEL 6, located several kilometres to the south-east of the Moree 4 exploration well (see Figure 3), showed that the Bungil Formation does not occur here. The Moolayember Formation occurred at 810 m depth and the net coal thickness was 6.8 m with gas contents between 2.1 and 4.9 m³/t (dry ash free basis) (ESG, 2010a). The gas composition was not reported. At exploration well Gwydir 1 (PEL 6, see Figure 3), targeting the Moolayember Formation coals in the Moree High of the southern Bowen Basin at a depth of 311 m, a net coal thickness of 3.3 m was intersected with the thickest seam being 0.75 m thick. Gas content was given as 4.7 m³/t (dry ash free basis, no gas composition reported) (ESG, 2009c). Exploration well Milguy 1 (PEL 6, see Figure 3) intersected 8.5 m of net coal in the Moolayember Formation (at 711 m depth), the thickest seam being 1 m. The mean gas content was provided as 4.4 m³/t (dry ash free basis) (ESG, 2010b). The gas composition was not reported. All three wells indicated low reservoir permeability of the Moolayember Formation (ESG, 2009c, 2010a, 2010b). There have been 153 PJ of recoverable contingent resources booked in PEL 6 (ESG, 2011). No further development proposals are known for this licence area as of September 2014.

In the Bellata Trough region in the south of the subregion (southern part of PEL 427 and northern part of PEL 238, see Figure 3), the CSG potential of the Moolayember and the Bungil formations, as well as the Late Permian Black Jack Group and the Early Permian Maules Creek Formation have been assessed. Results from exploration well Bellata 2 (PEL 427, see Figure 3), intersecting the Moolayember Formation at 638 m depth and the Bungil Formation at less than 165 m depth, did not indicate gas volumes of commercial significance in any of the formations (Comet Ridge, 2004). Further south exploration well Edgeroi 2 (PEL 238, see Figure 3) was drilled to evaluate the CSG potential of the Early Permian Maules Creek Formation (Bohena Seam) and the Late Permian Black Jack Group (Hoskissons Coal) (ESG, 2010c). The Hoskissons Coal was encountered at a depth of 683 m and had a net thickness of 2.3 m and a gas content of 5.9 m³/t (dry ash free basis, gas

composition more than 90% CH₄). Eastern Star Gas reports that the coals of the Bohena Seam, at a depth of 953 m, have a net thickness of 14.8 m and a high gas content of 14.2 m³/t (dry ash free basis). However, the composition of the gas is more than 80% CO₂ (ESG, 2010c). Drill stem tests indicated low reservoir permeability for both coal seams (ESG, 2010c).

To the west of the Bellata Trough, in PEL 470 (Leichhardt Resources' Mooki Project area), the combined net thickness of the coals of the Black Jack Group and Maules Creek Formation was reported by Leichhardt Resources to be about 40 m (Leichhardt Resources, 2013). However, to date no exploration wells have been drilled in this area, thus no further information is available.

CSG exploration and commercialisation in the Gwydir subregion must be consistent with the CSG regulations and the CSG exclusion zones that apply in NSW. The exclusion zones prohibit new CSG exploration and development within a 2 km buffer of existing and future residential areas (NSW DPI, 2013a, 2013b). See Figure 10 in companion product 1.1 for exclusion zones in the Gwydir subregion (Welsh et al., 2014).

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1.2.3 Proposals and exploration

1.2.4 Catalogue of potential resource developments

Summary

As at December 2012, the Geoscience Australia OZMIN database records no identified coal resources in the Gwydir subregion and as of October 2014 no further changes to this are presently known. Additionally, as of October 2014, there are no coal or coal seam gas (CSG) developments planned or proposed in the Gwydir subregion.

1.2.4.1 Potential coal developments

Geoscience Australia's OZMIN database (Geoscience Australia, 2006) reports that as of October 2014 there are no coal resources, coal mines or potential coal developments in the Gwydir subregion.

1.2.4.2 Potential coal seam gas developments

As of October 2014 there are no CSG developments planned or proposed in the Gwydir subregion.

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