20/05/2017

To: the NSW Department of Planning and Environment This is a submission to the Narrabri Gas EIS.

Protect our Water, Environment and Rights (POWER) objects to this project. The EIS asks more questions than it answers.

Significant concerns about the Santos EIS.

a) the general level of uncertainty associated with this eis, and the inability of Santos to accurately quantify their impacts over the life of their projects (approximately 30 years);
b) the DoP can not make decisions based on unsubstantiated modelling that is totally inconsistent in finding from both the Queensland and overseas experience; No-one can make decisions on an EIS that consists of future management plans that do not exist yet.
c) the potential for significant impacts on Stygofauna;
d) the volume of groundwater to be co-produced with CSG, particularly:
    i. impacts on groundwater systems and their structural integrity,
    ii. pressure and volume impacts on GAB aquifers;
    iii. changes to the water chemistry of GAB aquifers;
    iv. the very significant recovery times for groundwater systems to return to pre-CSG conditions once extractive operations cease,
    v. the volume of salts and heavy metals associated with CSG co-produced water, and the uncertainty around their disposal, and
    vi. impacts on surface water hydrology from the discharge of CSG co-produced water into Bohena Creek and the Namoi River;
    vii. future reinjection of CSG water.
e) land subsidence;
f) impacts on highly productive agricultural land;
g) impacts on Indigenous cultural and spiritual values;
h) the detrimental effects and division of the community.

- The media release regarding the submission of Santos EIS raises the first questions regarding the EIS. Santos is very good at 'wordsmithing' and providing reassuring statements without actually providing any information. Examples are highlighted:

"1 February 2017 Narrabri Gas Project Environmental Impact Statement submitted.
Santos today submitted the State Significant Development Application and associated Environmental Impact Statement (EIS) for its Narrabri Gas Project to the NSW Department of Planning and Environment. The proposed Narrabri Gas Project, located in North West NSW, could supply up to 50% of NSW gas needs and provide significant benefits to the region and the state more broadly. Santos will make the gas (how much?) available to NSW and the east coast domestic market via a pipeline linking into the existing Moomba to Sydney Pipeline. The pipeline will be constructed by APA Group and will be subject to a separate approval. Santos' Managing Director and Chief Executive Officer, Kevin Gallagher, said Santos has spent time producing a comprehensive EIS so the local Narrabri community and stakeholders can be confident the environment and water will be protected as the Project is developed. "The EIS has concluded the Project can proceed safely with minimal and manageable risk to the environment," Mr Gallagher said. "The Narrabri Gas Project has the potential to play a significant role in the domestic energy space. Natural gas has a vital role to play in delivering energy security, whilst having the additional benefit of being 50% cleaner than coal resulting in a significant reduction in carbon emissions. The development of new natural gas resources is crucial in assisting Australia's move towards a clean energy future. "In NSW alone, more than one million homes and 33,000 businesses rely on natural gas as a source of energy." The NSW Government estimates the top 500 industrial gas users provide more than 300,000 jobs which rely on an affordable, secure supply of natural gas and has recognised the project's significance, declaring it a Strategic Energy Project. The Project could create about 1300 jobs during the initial construction phase and around 200 ongoing jobs, many of which will be locally based.

This just asks more questions than the EIS supplies.

- The government can't afford to cap less than 250 bores still uncapped in NSW alone. Who will ever be able to cap thousands of bores when Santos has long gone and they all need recapping. 7% of bores fail initially, 30% within 20 years and 100% within 100 years. Bores do not last 'forever' as stated by Santos. Concrete and metal do not have a perpetual lifespan. This damage is permanent. Over time it will be like a pincushion with rusting pins. Who is liable for maintenance in perpetuity? Will it be the landowner? Farmers around the NGP have been told that once they accept payment from Santos they are liable for any problems into the future. Estimated costs of replacement and current values of water used per dependent sector are contained in the report “Economic output of groundwater dependent sectors in the Great Artesian Basin.” (appendix 1)

- “The EIS found the project will have minimal risk of impact on agricultural and domestic water sources”. Queensland has shown this is not the case. Broadacre Farming and agriculture can not co-exist. Does Santos still stand by this claim when they extend into their neighbouring PEL’s and find a different type of landuse such as broadacre, intensive and irrigated farming. Currently Santos have 3 petroleum title applications that have been pending since 2014. All Santos single and joint venture current petroleum licenses have been expired between 22/10/2011 until now. If they don’t plan to expand into the surrounding PEL’s they currently hold why have they not released the expired licenses. Why has the government not cancelled these licenses? (appendix 2)

- All the Chief Scientist recommendations have not all been met.

- The report “The Economic Contest Between Coal Seam Gas Mining and Agriculture on Prime Farmland: It May be closer than We Thought’ shows that ”the long term economic net benefits from agriculture-only exceed those from CSG-only and CSG-agriculture-agriculture coexistence.” Please read this report as part of this submission. (appendix 3)

- “Due to the geology of the deep coal seams, hydraulic fracturing will not be needed to extract the gas and Santos is not seeking approval to use this technology.” Why did Eastern Star Gas need to frack when they owned the licence? Does the fact ‘Santos is not seeking approval to use this technology’ mean they will never frack no matter what? A change of management or shareholder pressure will never mean fracking is on the table? Will it be written into any sale contract that the purchaser can’t frack? What legal stipulation will ensure they don’t change their mind?

- Artesian Bore Water Users Association Of NSW Inc. has commissioned a report into the Stygofauna population in the Pilliga. Due to the time consuming task of data collection and analysis this report is not yet completed. We will forward a copy of the report as an annexure to this submission when we receive it.

Dr Peter Serov has previously completed a report for a private individual which I can not include but details are as follows:

ABC

Ancient stygofauna could halt Santos' Pilliga coal seam gas project

By Catherine Clifford and ABC Online staff

Updated 12 Jul 2013, 11:42pm

PHOTO: Stygofauna are blind, colourless and they've been around for millions of years. (Supplied)

A microscopic collection of worms and mites could play havoc with Santos' biggest coal seam gas project in the New South Wales Pilliga State Forest.

The ancient, subterranean creatures that live deep in an underground aquifer are only one millimetre long and thinner than a human hair.

They are known as stygofauna and they play an important role in filtering and determining the quality of groundwater.

The new evidence about the stygofauna is contained in one of 1,800 submissions to the Federal Government opposing Santos' plans to drill 18 gas wells in the Pilliga State Forest near Narrabri.

Santos had estimated the project could supply 25 per cent of New South Wales' gas needs.

The Government will now use its recently-passed "water trigger" laws to determine if Santos can go ahead with the drilling.

Hydro-biologist Dr Peter Serov, who found the two new species of stygofauna, says the creatures could be at risk because they are extremely sensitive to changes in water quality.

"There needs to be a lot more rigorous sampling and monitoring of both water chemistry and biodiversity across the region to determine what the ultimate ranges of these species are and what their environmental requirements are at this point in time," he said.

Blind, clear, subterranean creatures

PHOTO: There are calls for more research to be done on the stygofauna. (Supplied)

Dr Serov says stygofauna are highly specialised organisms that have been around for hundreds of millions of years.

"They are a group that have adapted over millions of years to occupy a very, very specialised niche," he said.

"Initially all of them would have been surface invertebrates, but due to the vast changes that the environment of Australia has gone through... they have colonised the subterranean environment and over time they've developed their own body forms to actually live exclusively in this situation."

"They have no colouration, they're usually totally clear or white, they have no eyes, they have specialised sensory organs that enable them to determine whether they're going up or down," Dr Serov said.

But Santos groundwater expert, Dr Peter Hancock, says he wants to know just where the tiny animals were found.

He says they may not exist in the deep aquifers that coal seam gas wells drill down to.

"The deeper coal seam aquifers are unlikely to have stygofauna in them. It's the shallow alluvial aquifers that are most likely to have them," he said.

But retiring New England Independent MP, Tony Windsor, who introduced the water trigger laws, says the scientific process must go ahead before the coal seam gas company moves in.

"We don't fully understand the scientific nature of some of these groundwater systems and until we do at a scientific level, I think the political process should step back and the industry process should step back until we get the science right and then make the decision," he said.

http://www.abc.net.au/news/2013-07-12/4815736

- Re-injection of CSG Water – will this rear it's head when one of the management plans mentioned in the EIS are made up?

Research into re-injection of CSG water.

Release Date: MARCH 1, 2017

New USGS maps identify potential ground-shaking hazards in 2017 from both human-induced and natural earthquakes in the central and eastern U.S.

Damage to buildings in Cushing, Oklahoma from the magnitude 5.0 earthquake on November 6, 2016. Unreinforced brick and stone masonry buildings and facades are vulnerable to strong shaking. Photograph credit: Dolan Paris, USGS

New USGS maps identify potential ground-shaking hazards in 2017 from both human-induced and natural earthquakes in the central and eastern U.S., known as the CEUS. This is the second consecutive year both types of hazards are forecasted, as previous USGS maps only identified hazards from natural earthquakes. This research was published today in Seismological Research Letters.

Approximately 3.5 million people live and work in areas of the CEUS with significant potential for damaging shaking from induced seismicity in 2017. The majority of this population is in Oklahoma and southern Kansas.

Research also shows that an additional half million people in the CEUS face a significant chance of damage from natural earthquakes in 2017, which brings the total number of people at high risk from both natural and human-induced earthquakes to about 4 million.

“The good news is that the overall seismic hazard for this year is lower than in the 2016 forecast, but despite this decrease, there is still a significant likelihood for damaging ground shaking in the CEUS in the year ahead,” said Mark Petersen, chief of the USGS National Seismic Hazard Mapping Project.

The 2017 forecast decreased compared to last year because fewer felt earthquakes occurred in 2016 than in 2015. This may be due to a decrease in wastewater injection resulting from regulatory actions and/or from a decrease in oil and gas production due to lower prices.

Despite the decrease in the overall number of earthquakes in 2016, Oklahoma experienced the largest earthquake ever recorded in the state as well as the greatest number of large earthquakes compared to any prior year. Furthermore, the chance of damage from induced earthquakes will continue to fluctuate depending on policy and industry decisions, Petersen noted.

“The forecast for induced and natural earthquakes in 2017 is hundreds of times higher than before induced seismicity rates rapidly increased around 2008,” said Petersen. “Millions still face a significant chance of experiencing damaging earthquakes, and this could increase or decrease with industry practices, which are difficult to anticipate.”

Important Note: In the west, USGS scientists have focused on the hazard from natural earthquakes. Induced earthquakes have been observed in California as well, but they don’t significantly change the regional hazard level, which is already high due to frequent natural earthquakes.

What are Induced Earthquakes?

Induced earthquakes are triggered by human activities, with wastewater disposal being the primary cause in many areas of the CEUS. Wastewater from oil and gas operations can be disposed of by injecting it into deep underground wells. Injected fluids cause pressure changes that can weaken a fault and therefore bring it closer to failure. Most injection wells do not trigger felt earthquakes, suggesting that a combination of many factors contribute to such events.

“By understanding the relationship between earthquakes and wastewater injection, informed decisions can be made on processes such as controlling the volumes and rates of wastewater injected and determining which wells are most susceptible to inducing earthquakes,” said Petersen.

Many questions have been raised about hydraulic fracturing—commonly referred to as “fracking”—and more information can be found by reading common questions.

States with High Hazard

The maps indicate an especially high ground-shaking hazard in five areas of the CEUS in 2017. These same areas were identified in the 2016 forecast.

Induced seismicity poses the highest hazard in two areas, which are Oklahoma/southern Kansas and the Colorado/New Mexico area known as the Raton Basin. In those areas, there is a significant chance that damaging levels of ground motion will occur in 2017.

Enhanced hazard from induced seismicity was also found in Texas and north Arkansas, but the levels are significantly lower in these regions than that forecasted for 2016. While earthquakes are still a concern, scientists did not observe significant activity in the past year, so the forecasted hazard is lower in 2017.

There is also a high hazard for natural earthquakes in the New Madrid Seismic Zone. The NMSZ is the only one of the five identified areas that has not experienced induced earthquake activity. The NMSZ had a higher rate of natural earthquakes in the past three years, leading to a slightly higher hazard potential compared to previous years in portions of Arkansas, Missouri, Illinois, Kentucky and Tennessee.

“The 2016 forecast was quite accurate in assessing hazardous areas, especially in Oklahoma,” said Petersen. “Significant damage was experienced in Oklahoma during the past year as was forecasted in the 2016 model. However, the significantly decreased number of earthquakes in north Texas and Arkansas was not expected, and this was likely due to a decline in injection activity.”

“There is specific concern in parts of the central U.S. since the forecasted hazard levels are higher than what is considered in current building codes, which only incorporate natural earthquakes,” said Petersen.

People living in areas of higher earthquake hazard should learn how to be prepared for earthquakes. Guidance can be found through FEMA’s Ready Campaign.

USGS charts showing the number of earthquakes greater than or equal to magnitude 2.7 since 1980 in the five focus areas identified as having especially high ground-shaking hazard in the central and eastern U.S. in 2017.

Spotlight on Oklahoma

Between 1980 and 2000, Oklahoma averaged about two earthquakes greater than or equal to magnitude 2.7 per year. However, this number jumped to about 2,500 in 2014, 4,000 in 2015 and 2,500 in 2016. The decline in 2016 may be due in part to injection restrictions implemented by the state officials. Of the earthquakes last year, 21 were greater than magnitude 4.0 and three were greater than magnitude 5.0.

USGS research considers a magnitude 2.7 earthquake to be the level at which ground shaking can be felt. An earthquake of magnitude 4.0 or greater can cause minor or more significant damage.

The forecasted chance of damaging ground shaking in central Oklahoma is similar to that of natural earthquakes in high-hazard areas of California.

“Most of the damage we forecast will be cracking of plaster or unreinforced masonry. However, stronger ground shaking could also occur in some areas, which could cause more significant damage," said Petersen.

Protecting Communities

The new report is valuable for making informed decisions to reduce the nation’s vulnerability and providing safety information to those who may be at risk from strong shaking. For example, the 2016 forecast has been used by engineers to evaluate earthquake safety of buildings, bridges, pipelines and other important structures. Risk modelers have used data in developing new risk assessments, which can be used to better understand potential impacts on insurance premiums. The U.S. Army Corps of Engineers has used the information to provide guidance on updating their safety assessments of selected facilities.

Continuing collaborations between regulators, industry, and scientists will be important toward reducing hazard, improving future forecasts, and enhancing preparedness.

Central versus Western U.S.

In recent years, the CEUS has experienced a significant increase in induced earthquakes. Therefore, in the 2017 and 2016 forecasts, scientists distinguish between human-induced and natural seismicity only for the CEUS. Scientists also used a historical catalog of seismic events dating back to the 1700s, putting a strong emphasis on earthquakes that occurred during the last 2 years.

Future research, noted Petersen, could take a more detailed look at induced seismicity in the west, including in California at The Geysers, Brawley and small areas of the Los Angeles Basin.

Distinguishing Between Induced and Natural Earthquakes

To determine whether particular clusters of earthquakes were natural or induced, the USGS relied on published literature and discussions with state officials and the scientific and earthquake engineering community. Scientists looked at factors such as whether an earthquake occurred near a wastewater disposal well and whether the well was active during the time the earthquakes occurred. If so, it was classified as an induced event.

One-Year Outlook

The one-year outlook is chosen because induced earthquake activity can increase or decrease with time and is subject to commercial and policy decisions that could change rapidly. The 2016 and 2017 forecasts employ identical methodologies; the only difference is that the 2017 forecast includes an updated earthquake catalog with 2016 events. This allows for a direct comparison from one year to the next.

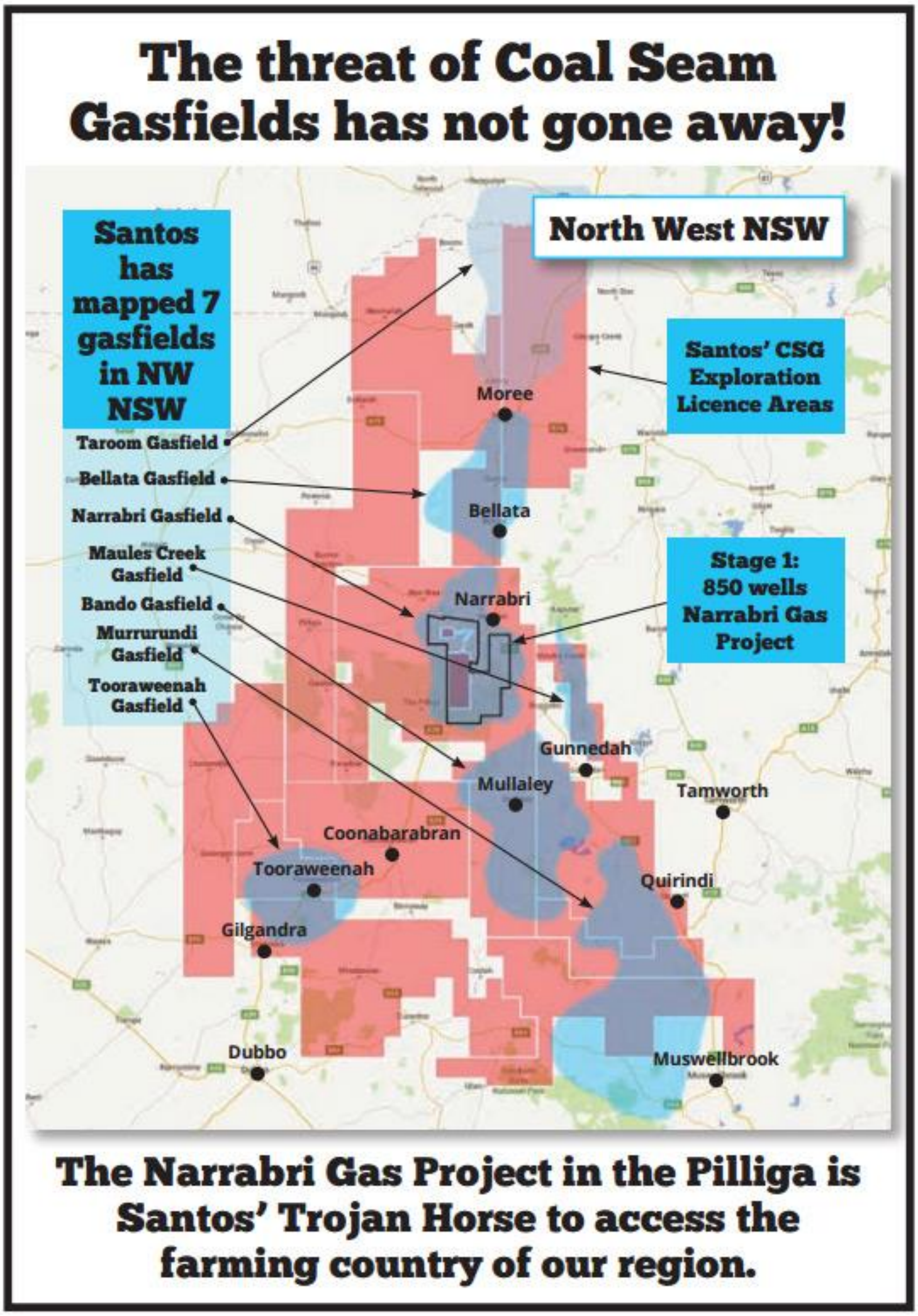
In contrast, the USGS National Seismic Hazard Map assesses natural earthquake hazards and uses a 50-year forecast. That timeframe was chosen because that is the average lifetime of a building, and such information is essential to engineering design and the development of building codes.

USGS Science

The USGS is the only federal agency with responsibility for recording and reporting earthquake activity nationwide and assessing seismic hazard. These maps are part of USGS contributions to the National Earthquake Hazards Reduction Program, which is a congressionally established partnership of four federal agencies with the purpose of reducing risks to life and property in the United States that result from earthquakes.

https://www.usgs.gov/news/new-usgs-maps-identify-potential-ground-shaking-hazards-2017

- How can an EIS be submitted with whole sections that are incomplete? With approximately 16 Management Plans mentioned in the EIS Santos obviously do not have a comprehensive plan for what they propose to do in the NGP. How can the public comment on something that is developed AFTER approval? Will this include re-injection, change to the no-fracking 'plan'?



It should be a statutory requirement that Santos explain the extent of their future plans and these should be treated cumulatively. The future effects will be cumulative.

- Well integrity
  No-one can claim, as Santos has, well integrity in perpetuity. Concrete and casing do not last forever. The following photos prove this.

Eastern Star Gas Bohena #2 – disused, not rehabilitated and badly deteriorating due to salt and/or leaking methane.
Less than 15 years old. July 2011

Corrosion on a fitting just over 12 months old. Kenya gasfield Qld

There is not enough known about this industry and the effects it has on the environment. If the gas isn't going anywhere why the rush. Ensure it is safe and not going to permanently damage the GAB.

Clean water is our constitutional right

POWER

Protect our Water, Environment and Rights.

Economic output of groundwater dependent sectors in the Great Artesian Basin

A REPORT COMMISSIONED BY THE AUSTRALIAN GOVERNMENT AND GREAT ARTESIAN BASIN JURISDICTIONS BASED ON ADVICE FROM THE GREAT ARTESIAN BASIN COORDINATING COMMITTEE

August 2016

Economic output of groundwater dependent sectors in the Great Artesian Basin

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Executive summary

The Great Artesian Basin (GAB) is a highly valuable water resource which provides locationally diverse benefits and opportunities. The waters of the GAB have:

- been an intrinsic part of social lifestyle and cultural values developed and maintained by Indigenous Australians in arid landscapes
- provided opportunities for the development of low-rainfall areas of Australia through secure access to water
- created economic value through a range of uses including livestock and domestic consumption, irrigation and industrial/mining.
- supported the quality of life and development of more than 120 towns and settlements and economic activity
- sustained infrastructure, lifestyles and local cultures in sparsely populated outback regions
- played host to unique groundwater dependent ecosystems at naturally occurring springs.

Arguably, most of the economic activity in GAB regions is dependent on access to GAB water resources. Without GAB water, economic development in many areas would not have been able to occur. It is also hard to imagine much of the town/urban water use and domestic water use in GAB regions being possible without access to GAB water. In many localities, alternative water supplies are prohibitively costly and total reliance on surface water would significantly reduce liveability. In other areas, such as eastern regions and the far north, other water sources are available and we are unable to differentiate the contributions of GAB water and these other sources of water to regional economic activity.

We estimate that the consumptive use of GAB water is integral to at least $12.8 billion of production annually (Table 1). The provision of drinking water through domestic bores and town water supply has been essential to the development of GAB regions. The non-consumptive benefits of GAB water resources include groundwater dependent ecosystems.

The consumptive water uses by stock (pastoral and intensive), irrigation, and mining, electricity and gas industries are all of high economic value (Table 1). The use of the GAB water resource provides economic value-add to regional resources (land and minerals), and underpins much of the economic activity and employment across the GAB region. For example:

- *Stock:* There are over 14 million beef cattle for meat production and over 11 million sheep and lambs in GAB regions. Annually the gross value of beef production alone is in excess of $4 billion and sheep contribute a further $600 million.

- *Irrigation:* While high levels of sodium render untreated GAB water unsuitable for irrigation in many locations, it provides a valuable supplement to surface water for irrigated fodder and horticultural production in some areas. It is estimated that irrigated production using GAB water is valued in excess of $60 million annually.
- *Energy and Earth resources:* Mining, gas and other opportunities are dispersed across the GAB regions and are valuable economic uses of GAB water. The total value of mining output dependent on GAB water is estimated to exceed $6 billion annually. In addition, coal seam gas (CSG) which is produced by pumping groundwater to release gas from coal seams in the Surat Basin (a sub-basin of the GAB) has grown quickly to $1.7 billion in 2014-15 and could increase further.

The distribution of this production between the GAB jurisdictions (NSW, Queensland, South Australia and the Northern Territory) depends on the location of the companion inputs to production such as grazing land and mineral deposits. Table 1 below sets out the estimated distribution.

Table 1: Values dependent on GAB water resources ($ million per year)

Sector	NSW	Qld	SA	NT	Total
Estimated annual value of output that is dependent on GAB water resources					
Stock	1094.5	3004.4	105.1	463.7	4667.7
Mining	568.3	2980.7	2801.7	0	6350.7
CSG	7.7	1693.4	0	0	1701.1
Electricity	0	0.1	0	0	0.1
Irrigated Agriculture	30.4	27.7	0	0	58.1
Urban water	7.4	34.0	1.8	0.1	43.3
Total Value of output	1708.3	7740.3	2908.6	463.8	12821.0
Other values related to GAB water resources (noting environmental values could not be monetised)					
Tourism expenditure	100.5	311.0	150.0	163.0	724.5 (per year)
GABSI Infrastructure expenditure	118.9	148.0	13.8	0.0	280.7 (asset total)
Private Infrastructure investment					5000-15000 (asset total)

Source: Frontier Economics analysis

This report examines the direct economic activity of those sectors dependent on GAB water resources. There are also second- and third-round economic effects related to these sectors. For example, up and down-stream industries that provide inputs and process outputs of the sectors (i.e. farm supplies, mechanics, processors), and the local economy servicing the people working in all these industries. Hence, it could be argued that all of the economic activity in GAB regions is dependent on access to GAB water resources where other water sources are not available.

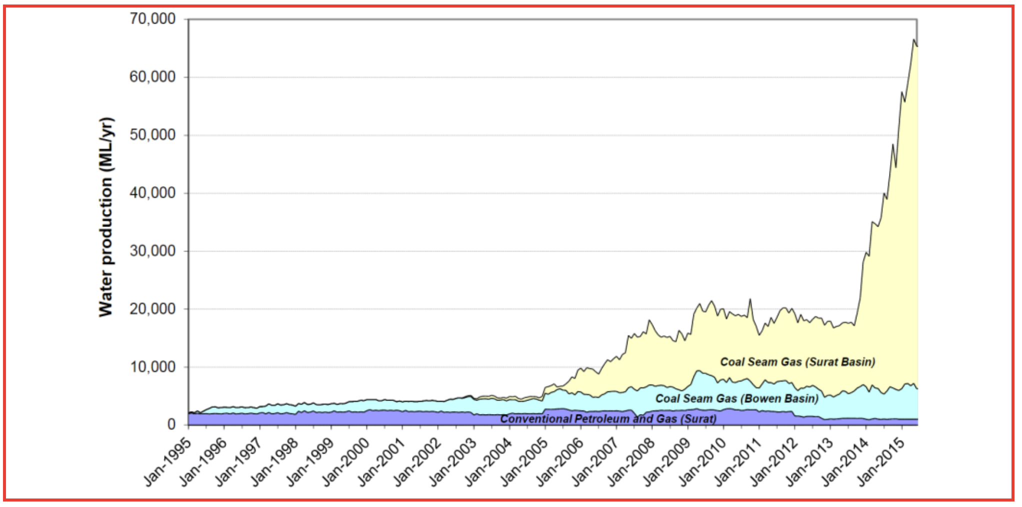
Significant public and private funds have been dedicated to develop and protect this resource to support its economic, social and environmental values. On-farm investment has been significant with 34,951 bores across the GAB. The vast majority of these bores are less than 200 metres deep, however some bores are deeper than 1200 metres.

The Great Artesian Basin Sustainability Initiative (GABSI) and related state and Territory water planning initiatives have entailed significant effort to manage the GAB water resource to reduce water extractions and maintain or increase pressure. Government funding for GABSI has exceeded $280 million in total (in 2016 dollars). These initiatives have achieved significant reductions in stock and domestic water usage by the pastoral sector, while maintaining or increasing the economic output of the sector. This has been possible because investments have targeted water savings, thereby reducing inefficient usage (uncontrolled bores and open drains).

Looking forward, GAB management will be challenged by new or increased water demand from new or expanding industries:

- The information available on GAB water resource use is limited, with much of the stock and domestic use estimated.
- There are limited opportunities to reallocate water use between existing uses and from existing to new uses. Water trading is hampered due to the challenges associated with hydrologically complex groundwater resources.
- Producing gas resources necessarily involves taking water as a by-product [associated water] which can be significant. The volumes taken tend to diminish over time. There is thus a high degree of uncertainty associated with volumes and reliability over time. In recent years, growth in GAB water volumes extracted by CSG in Queensland's section of the Surat Basin (Figure 1) has increased significantly.

Figure 1: GAB water use from coal seam gas production in Queensland (ML/yr)



Source:.DNRM 2016, p. 62.

Executive summary

1 Introduction

1.1 Purpose and scope of this report

This report provides an overview of the economic output of groundwater dependent sectors in the Great Artesian Basin (GAB).

The report intent is to provide clarity around current and future water use and users in the GAB and the value of the industries or sectors dependent on GAB water. It is anticipated that the analysis will inform the work of identifying future policy, funding options and incentives for the continued renewal and replacement of the GAB water infrastructure. It will also help inform the development of a new Strategic Management Plan for the GAB.

The report will be a useful resource for GAB stakeholders, particularly the Great Artesian Basin Coordinating Committee (GABCC). The economic value of GAB water was identified by the GABCC as a significant gap in the knowledge of the Basin to inform planning and management decisions within the GAB. The report will help the GABCC achieve an improved understanding of the economic activity within the GAB and allow the committee to provide more informed advice to GAB governments.

It is important to note that this project encountered significant data challenges, which meant that it was not possible to fully isolate the economic value derived directly from GAB groundwater from the other water resources available in the geographic basin.

1.2 The GAB

The GAB is one of the largest underground freshwater reservoirs in the world. It underlies approximately 22% of Australia – occupying an area of over 1.7 million square kilometres beneath arid and semi-arid parts of Queensland, New South Wales, South Australia and the Northern Territory. Approximately 70% of the GAB lies within Queensland.

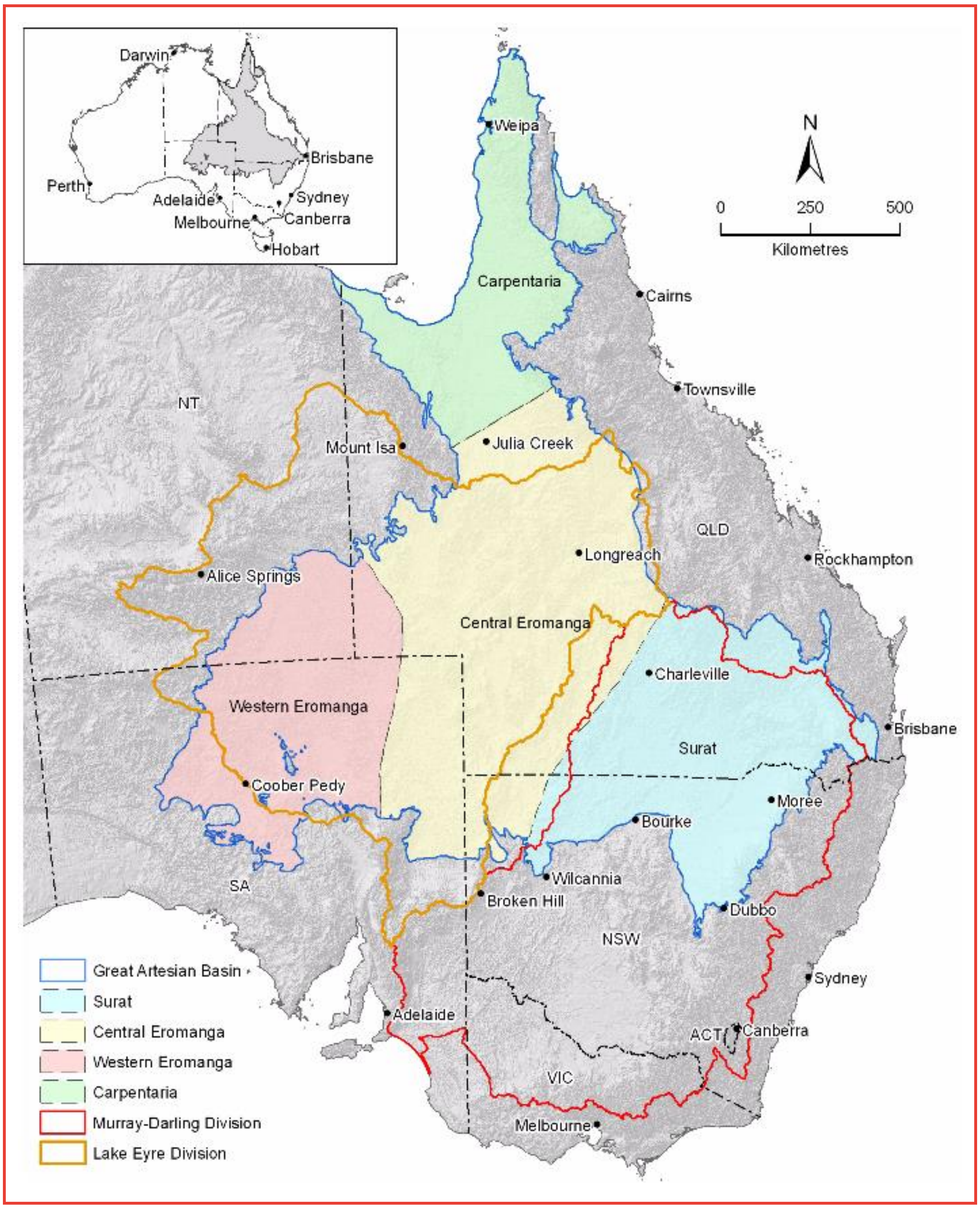
The GAB has been divided into four assessment regions (Figure 2):

- Surat — The Surat region is bounded by the Great Dividing Range to the east and the Eulo and Nebine ridges to the west.
- Central Eromanga — The Central Eromanga region is bounded by major geological structures including: the Birdsville Track Ridge and Toomba Fault to the west, the Euroka Arch to the north, and the Great Dividing Range and the Eulo and Nebine ridges to the east.
- Western Eromanga — The Western Eromanga region is bounded by major geological structures including: the Birdsville Track Ridge and Toomba Fault

to the east, the Northern Flinders and Willoran ranges to the south, and several older geological basins to the west and north-west (e.g. the Arckaringa, Pedirka, Warburton and Amadeus basins).

- Carpentaria — The Carpentaria region is bounded by major geological structures including: the Euroka Arch to the south, and the Great Dividing Range to the east of the Carpentaria Basin and to the west of the Laura Basin.

Figure 2: Regions of the GAB



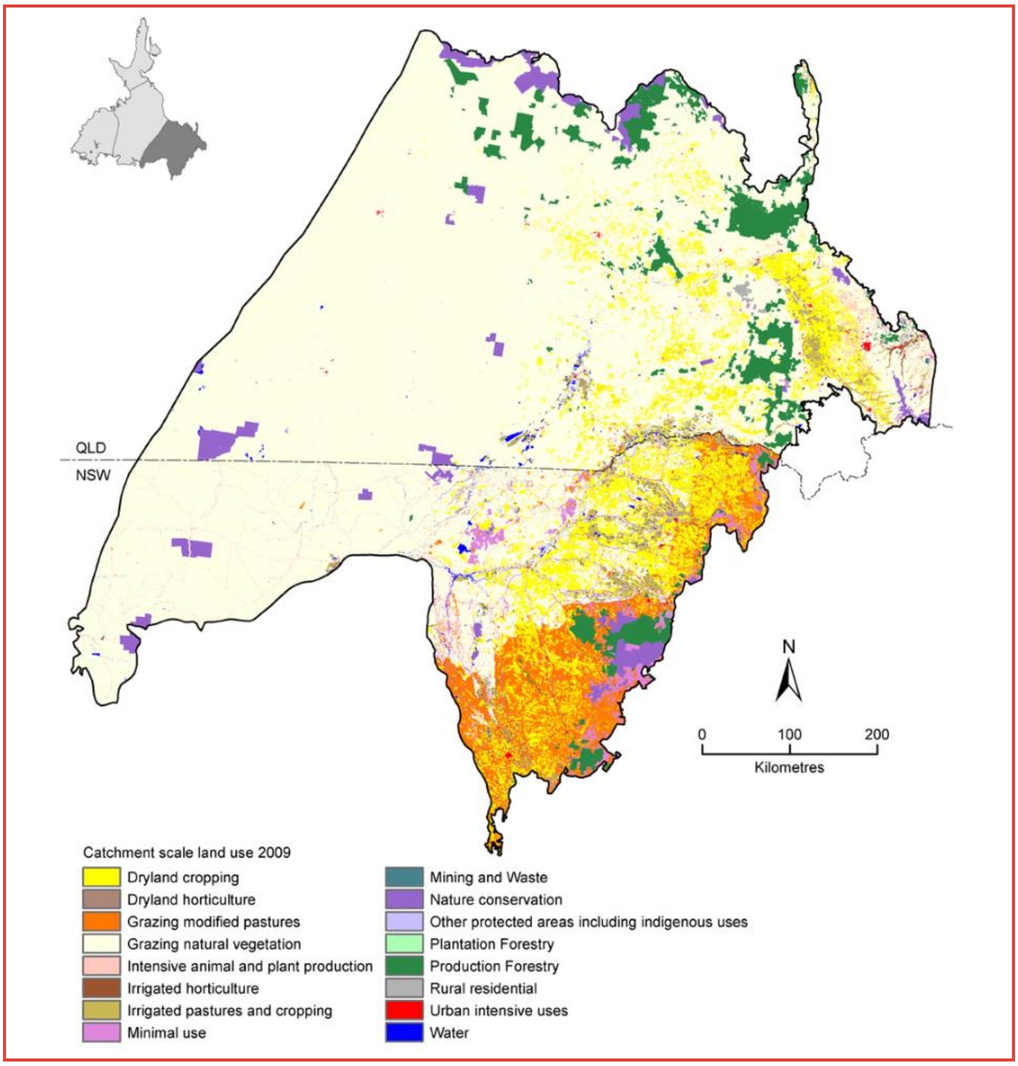
Source: Smerdon et al 2012.

Surat region

The Surat region occupies an area of 440,000 km^2 of south-eastern Queensland and north-central New South Wales. The Surat Basin in southern Queensland encompasses the Maranoa, Toowoomba and Western Downs regional council areas. Across the border in NSW, the basin extends south as far as Dubbo. As noted in the Surat Basin Regional Planning Framework (2011):

> The Surat Basin is renowned for agriculture and quality food production, and energy resources for both domestic and international consumption. These sectors represent the foundations of both population and economic growth, and are vital in securing the quality of life within local and regional communities such as those found in the Surat Basin…While the Surat Basin has, and will retain, a strong and traditional agricultural foundation, it also contains more than six billion tonnes of proven thermal coal reserves which are largely undeveloped and suitable for power generation, both domestically and abroad. The area also has significant reserves of coal seam gas (CSG). CSG is predominantly methane gas, which is also suitable for domestic power generation and export to international markets as liquefied natural gas (LNG).

Figure 3: Land use across the Surat region

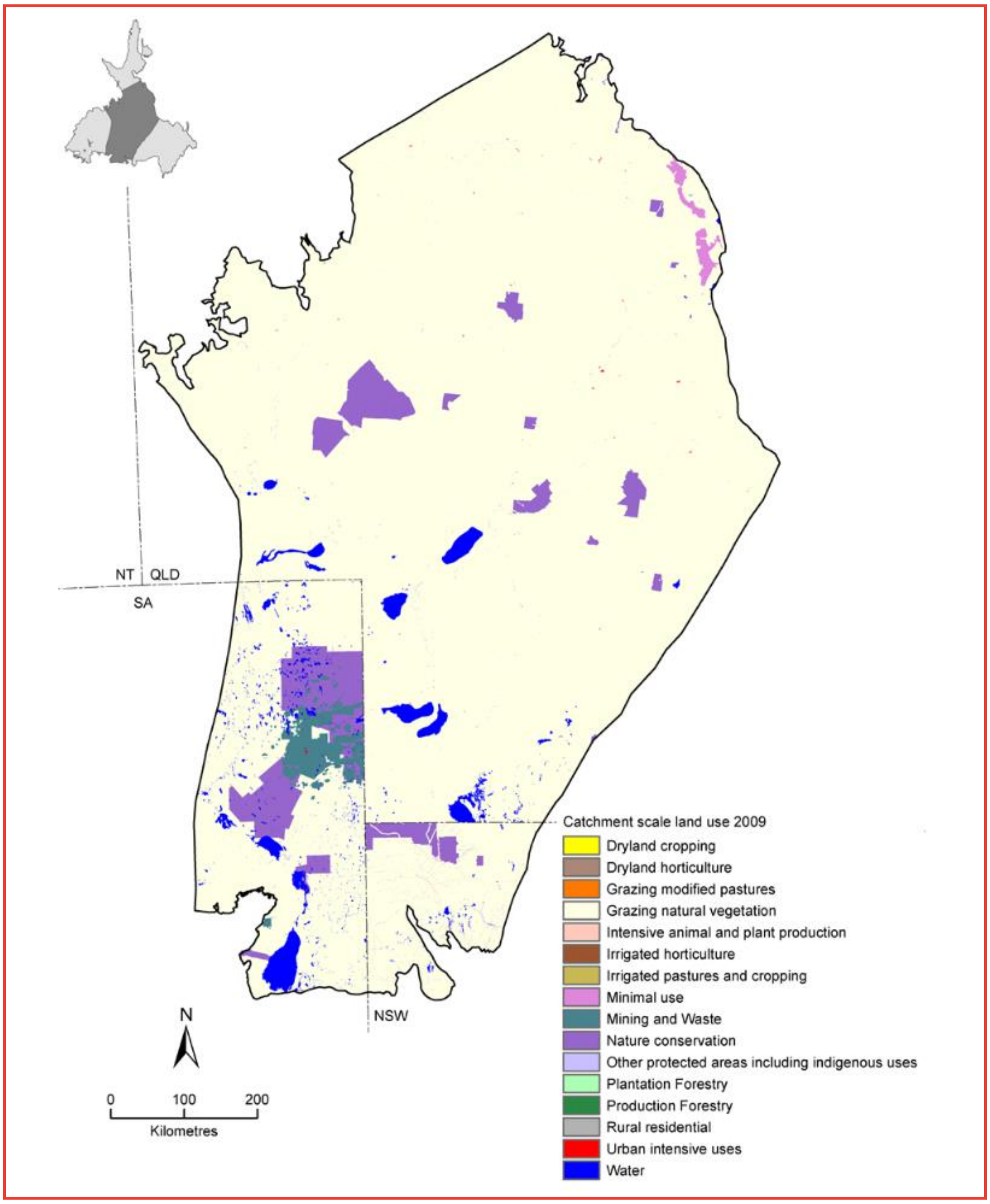


Source: Smerdon and Ransley 2012a.

Central Eromanga region

The Central Eromanga region occupies an area of around 690,000 km^2 roughly covering the central part of the GAB. It covers parts of Queensland, the Northern Territory, South Australia, and New South Wales. In Queensland and South Australia, the Eromanga Basin has been explored and developed for petroleum production.

Figure 4: Land use across the Central Eromanga region



Source: Smerdon and Ransley 2012b.

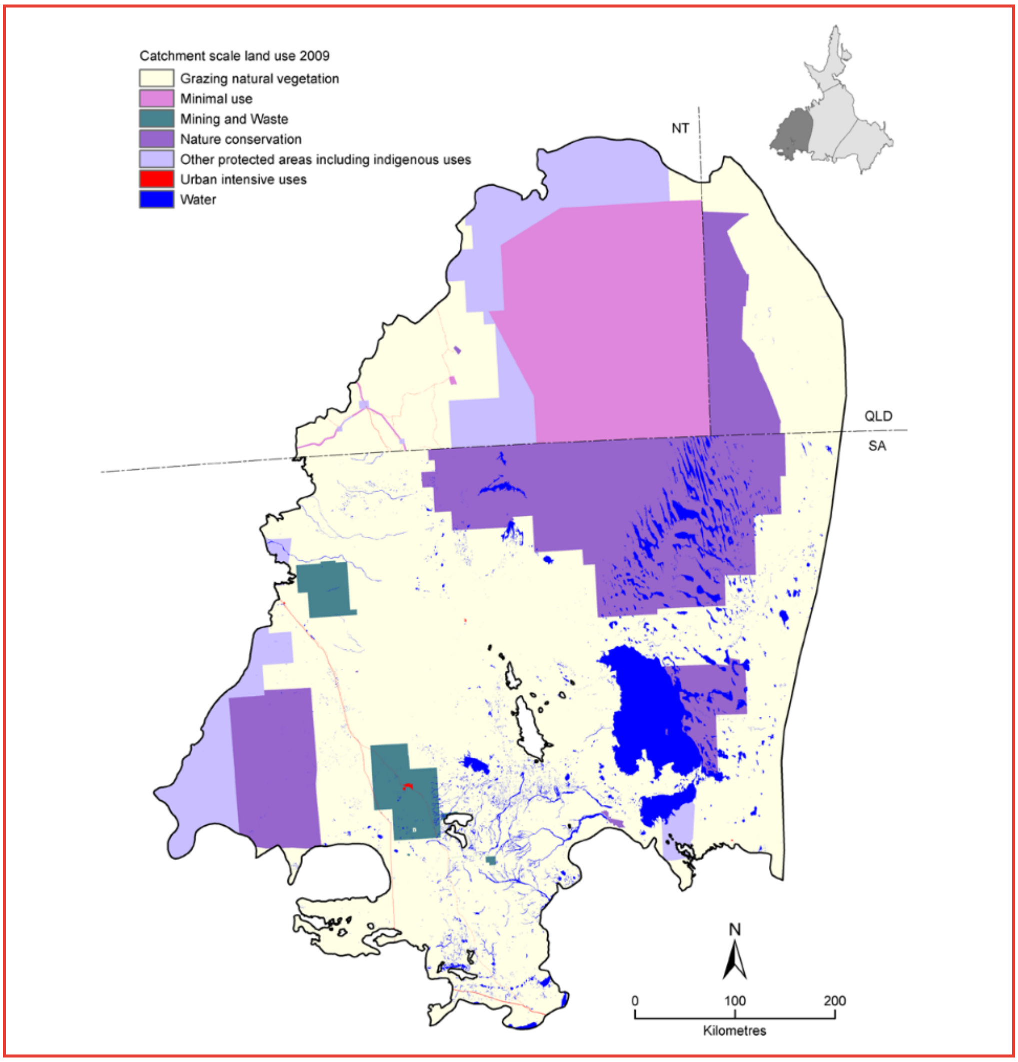
Western Eromanga region

The Western Eromanga region occupies an area of approximately 370,000 km^2 and includes the western margin of the GAB.

The Western Eromanga region is centred on the sparsely populated areas of far north-east South Australia, the south-west corner of Queensland and the south-east corner of the Northern Territory. The South Australian portion of the Western Eromanga region includes the Local Government Area of Coober Pedy, while the Queensland portion falls within the Shire of Diamantina. Parts of the western margin of the region also fall within Aboriginal freehold lands of the Maralinga Tjarutja and the Anangu Pitjantjatjara peoples.

Pastoralism is the predominant land use in the region, primarily being beef cattle with some sheep.

Figure 5: Land use across the Western Eromanga region



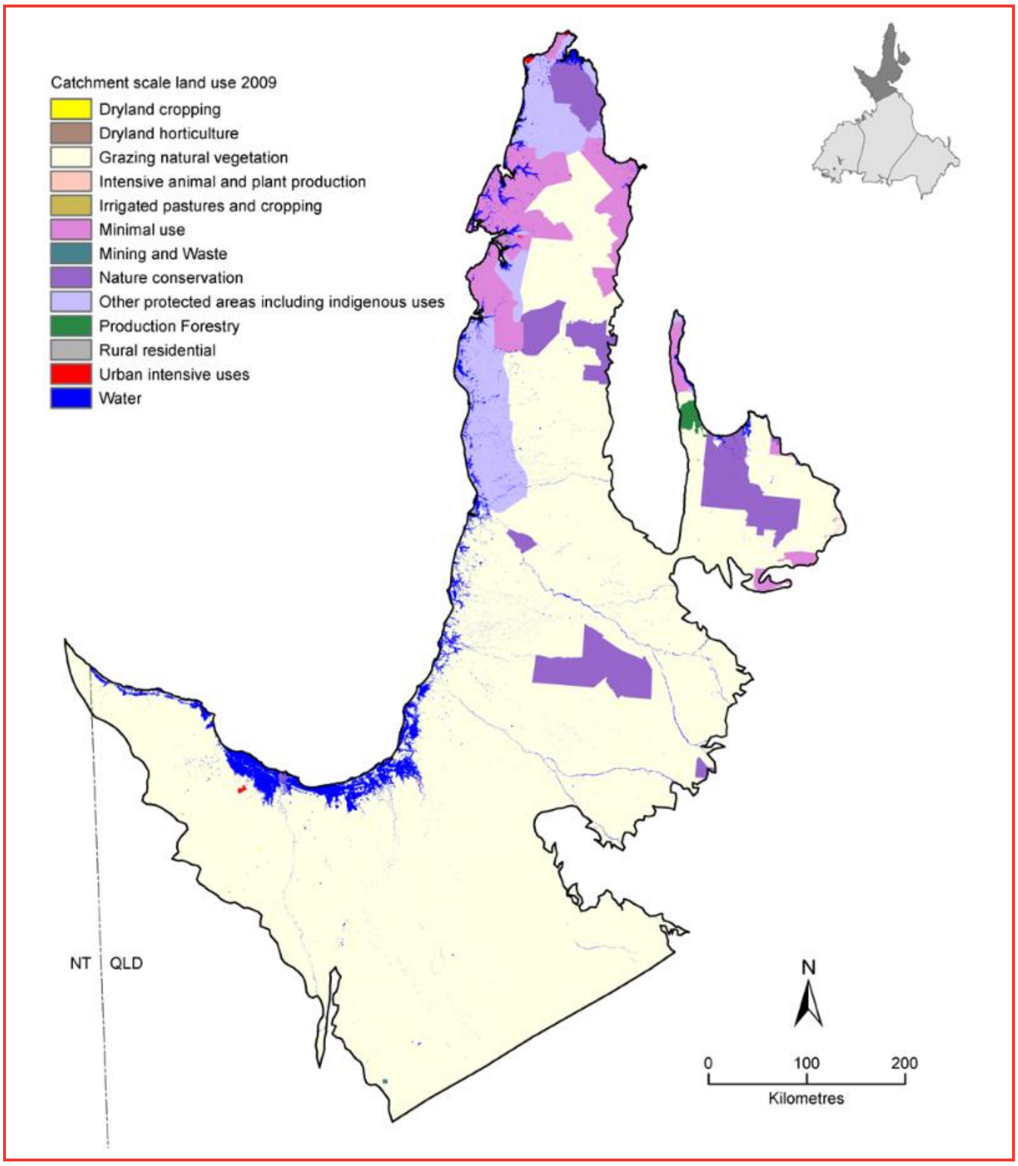
Source: Smerdon, Welsh and Ransley 2012a.

Currently, the main users of water in the GAB in the Western Eromanga region are spring discharge and associated wetlands, pastoralism, the mining and petroleum industries, wetlands, and town and other domestic water supplies. As a collective, the pastoral industry is currently the largest non-environmental user of groundwater in the Western Eromanga region, with bores mainly located in areas south and west of Lake Eyre. However, the biggest single entity extractor of groundwater in the Western Eromanga region is the Olympic Dam mining operation, located just outside the southern extent region. Groundwater for this operation is extracted from two borefield areas within the region located near Lake Eyre South, permitted through a special licensing agreement under the Roxby Downs (Indenture Ratification) Act 1982 (SAALNRMB, 2009).

Carpentaria region

The Carpentaria region occupies an area of 250,000 km^2 almost entirely within northern Queensland and a small portion of the Northern Territory where the region meets the Gulf of Carpentaria. It includes the Laura Basin (just north of Cooktown), the Carpentaria Basin and the Karumba Basin.

Figure 6: Land use across the Carpentaria region



Source: Smerdon, Welsh and Ransley 2012b.

1.3 Structure of this report

The remainder of this report is structured as follows:

- Section 2 provides information on the historical role of GAB groundwater.
- Section 3 examines the economic value of key GAB water using sectors.
- Section 4 considers investment in water infrastructure in the GAB.
- Section 5 provides concluding comments and observations.

2 Historical role of GAB groundwater

2.1 Introduction

In order to contextualise the role of the GAB in groundwater dependent sectors today, it is first helpful to understand how the role of the GAB has evolved historically in contributing to the economic, social/cultural and environmental values of the GAB region.

2.2 Role in Indigenous life and culture

The first people to make use of GAB water were Indigenous tribes for whom it was critical to survival. Indeed, there is evidence that the GAB sustained Aboriginal people for thousands of years prior to European settlement.

The natural springs of the GAB provided a critical source of fresh water, and supported valuable food sources including birds, mammals, reptiles, crustaceans and insects, creating an abundant hunting ground for local tribes. The plants and trees around the artesian springs were used for food, medicine, materials and shelter. The springs provided semi-permanent oases in the desert and supported trade and travel routes which evolved around them.

The springs also played a key part in the spiritual and cultural beliefs of Aboriginal people. Ceremonies and other events were held at spring wetland areas which remain precious cultural and sacred sites. Numerous Creation stories feature a connection to groundwater.

2.3 Early development of the GAB

The springs also sustained life for drovers along the stock routes before the first bores were drilled.

European discovery of GAB groundwater occurred in 1878, when a shallow bore near Bourke in New South Wales produced flowing water. Further discoveries followed quickly—in 1886, at Back Creek east of Barcaldine, and near Cunnamulla, the following year. By 1899 some 524 bores had been sunk. Most bores were allowed to flow freely onto the ground, running into open drains to water stock because the infrastructure to control this flow was not developed.

The discovery and use of water held underground in the GAB opened up thousands of square miles of country away from rivers in inland New South Wales, Queensland, and South Australia, previously unavailable for pastoral activities.

This heralded the arrival of the so-called 'Artesian age' where the GAB became an important water supply for cattle stations, irrigation, and livestock and domestic usage. Thousands of kilometres of bore drains from the GAB underpinned the development of many rural communities, providing water for a host of activities. The early settlers used bore water to run steam trains, finally making it possible to travel through the desert in relative speed and safety. Farmers sunk bores on their properties to provide a reliable water source for life on the stock routes. (GABCC 2008).

Bore water was used to clean wool before it was sold overseas. This boosted the value of fleece, and saved money on transport since farmers were no longer paying to ship dirt. (GABCC 2008).

Many inland towns relied on bore water for their everyday needs. Since the 1960's, bore water has been used for the mining of copper, gold, lead, zinc, uranium and silver, as well as oil and gas, and tourists travel from all over the world to explore the incredible landscapes of the GAB region. (GABCC 2008)

The role that GAB water resources have played in the development of areas of inland Australia has also made it culturally significant to non-indigenous Australians as embodied in Banjo Paterson's Song of the Artesian Water (December 1896).

2.4 Maintaining the GAB

Ongoing concerns about groundwater extraction and in particular falling artesian pressures due to inefficient water use and the related natural resource problems, such as erosion around bores and weed invasion, drove the development of a Strategic Management Plan (SMP) for the GAB in the late 1990s. The SMP was agreed to in 2000 and is the first whole-of-basin management plan adopted by GAB jurisdictions. In 1999, the Great Artesian Basin Sustainability Initiative (GABSI), a joint programme between the Australian government and state GAB jurisdictions (New South Wales, Queensland, South Australia and the Northern Territory), was introduced to provide for capping of uncontrolled bores and piping of open bore drains. The GABSI aims to better manage the water by controlling its use, and most importantly, by minimising wastage. The program is now in its fourth phase (GABSI 4) and is due to end in 2016-17 unless further extended.

2.5 Challenges

Water has historically been extracted from the GAB at a greater rate than recharge. Many bores were unregulated or abandoned, and a large proportion of the water drawn from the Basin was lost to seepage, and evaporation from bore drains. Even though technologies, practices and regulations have improved, these problems persisted for many decades.

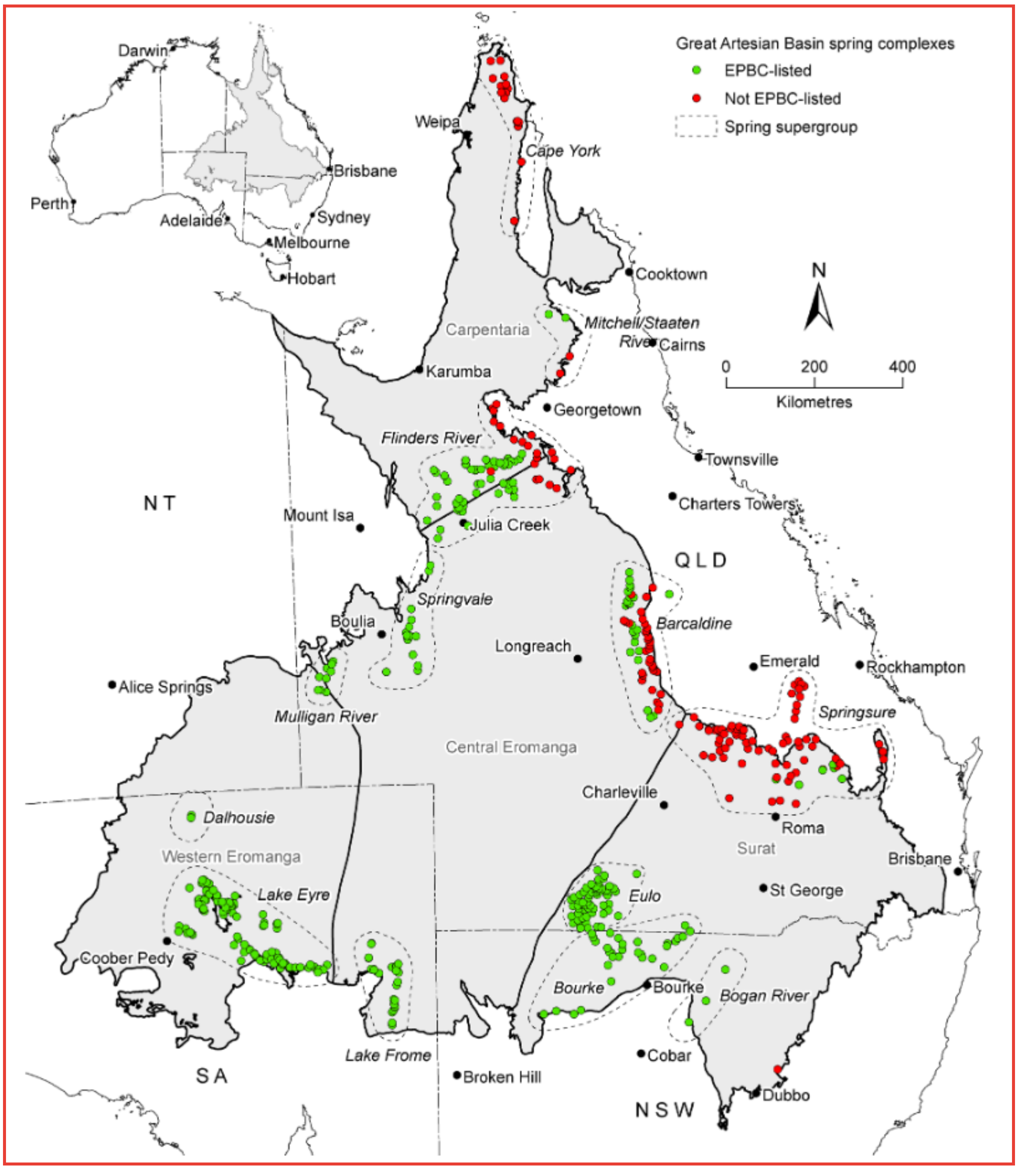
Infrastructure investment, to address this issue of losses and to maintain aquifer pressure, has also brought the challenge of funding that infrastructure maintenance which, if not done, risks the loss of the benefits from investment to date.

There are further challenges posed by newer industries of CSG and shale gas production and also climate change.

While this study focuses on the economic uses of groundwater in the GAB (see section 3), it is important to also recognise other significant values which need to be protected. The Aboriginal cultural values of groundwater-dependent sites remain poorly understood by many non-Aboriginal people. Planning for the future use of GAB water needs to recognise these cultural values. For example, the Water Sharing Plan for the NSW GAB Groundwater Sources acknowledges that access to traditional sources of GAB water may be necessary for continuing Indigenous cultural practices. South Australian and Queensland water management also identifies and protects Aboriginal cultural values. The urgency of these tasks is elevated by the current development pressures placed on the GAB.

The GAB is also important environmentally and its unique ecosystems are home to a host of native plant and animal species, many of which are not found anywhere else in the world (GABCC 2008). As many of the mound springs have dried up, the communities of native species which depend on the natural discharge of groundwater have been declared as endangered ecological communities under the *Commonwealth Environment Protection and Biodiversity Act 1999* (GABCC 2014). Figure 7 maps environmentally valuable sites in the GAB.

Figure 7: Environmentally valuable sites in the GAB



Source: Smerdon et al 2012.

3 Economic value of GAB water using activities

GAB water resources sustain the lives of more than 180 000 people and 7600 enterprises. Basin water is used in households in more than 120 towns and settlements and on hundreds of properties (GABCC nd).

This report brings together information on the range of economic activities that rely on GAB water resources. The focus of the assessment is on the value of output that is dependent on access to GAB water, and the distribution of this across the GAB jurisdictions.

Arguably most of the output of these areas is due to access to GAB water resources. Without it there might be no towns or industry, except where other water resources are available. The report focuses on primary outputs and their location to inform the future planning for the management and development of the GAB.

The activities undertaken across the GAB regions vary in the nature and extent of their use of groundwater. It is difficult to determine the volume and the use to which all GAB water is applied. In NSW, licences are not granted with particular approved purposes. In Queensland and South Australia, multiple purposes may be listed. In the Northern Territory, stock and domestic water use predominates. Further, the volume of stock and domestic water access across the GAB is generally estimated (not metered) based on regional characteristics (such as stocking rates).

Table 2 below sets out estimated GAB water use / water licence information for the GAB jurisdictions. Further detail is presented in Appendix 2.

Table 2: GAB Water licences and estimated use

Jurisdiction	GAB Estimated Use / Access Licence Volume (ML/yr)
New South Wales	
Stock and Domestic	56,270
Local Water Utility	7,028
Irrigation	76,758
Other uses	11,641
Queensland	
Stock and Domestic	121,759
Local Water Utility	32,057
Irrigation	32,341
Mining, Industrial and Commercial	30,909
Stock intensive (feedlots)	16,098
Gas extraction	65,000

South Australia	
Stock and Domestic[1] Local Water Utility [2] Irrigation [3] Mining [4] Industrial and Commercial Co-Produced water Bore Fed Wetland	10,438 1,579 115 24,200 934 21,900 2,025
Northern Territory	
Stock and Domestic Local Water Utility Environmental discharge	3,150 70 250

Notes: [1] Based on the licensed allocation which assumes delivery through a water tight delivery system (ie tank and trough). Under current licence conditions, the water tight delivery system will become mandatory in 2019. [2] Includes water supply for mining camps. [3] A single licence lists irrigation as a listed use, and other listed uses include Commercial, Bore Fed Wetland and Domestic. [4] Includes Olympic Dam.
Source: Appendix 2.

The relative use of GAB water in different activities has informed the following categorisation of GAB water using industries:

- Stock water use (which support pastoral activities), including stock intensive water use
- Irrigation
- Energy and Earth Resources (including Mining, Electricity and Gas)
- Urban Water and Domestic Use
- Other industries (including tourism).

The following discussion looks at each of these activities. For each activity we examine current patterns of water use, the economic value of the activity, and potential future water use taking into account prospects for the sector.

3.1 Stock use

Stock and domestic[1] water use and licences for intensive stock water use (such as feedlots) support stock industries reliant on GAB water resources. Stock and domestic includes the pastoral beef and sheep industries that rely on GAB water to keep stock watered.

The availability of GAB water is crucial to this sector, as low and unreliable rainfall makes a sole reliance on surface water risky and impractical for the volumes of water required. A key resource management challenge arises because stock and domestic usage of water is generally unmetered.

Intensive lot feeding of stock has become an important use of GAB water in recent years. While lot feeding to finish cattle and other stock is a distinct activity from the pastoral industry, its economic value is incorporated in Australian Bureau of Statistics (ABS) data on livestock industries and so is included in the discussion.

3.1.1 Patterns of water use

The pastoral industry has long been the largest user of GAB water, although much stock and domestic water use is not metered (volume is estimated) (Table 3).

Table 3: Estimated GAB stock water use

Jurisdiction	GAB Estimated Use / Access Licence Volume (ML/yr)
New South Wales — Stock and Domestic	56,270
Queensland — Stock and Domestic Stock intensive (feedlots)	121,759 16,098
South Australia — Stock and Domestic	11,846
Northern Territory — Stock and Domestic	3,150

Source: Appendix 2.

GAB regions are home to vast numbers of beef cattle and sheep. The most recent ABS data indicates that there are more than 14 million beef cattle for meat production and over 11 million sheep and lambs. Stock numbers fluctuate considerably during drought periods.

The majority of cattle grazing on GAB regions are in northern zones (Queensland, NT and northern areas of NSW), while sheep are more prevalent in the southern zones of SA and NSW (Table 4).

1 A stock and domestic right is a water right held by rural landowners for domestic, on-farm purposes. Stock and domestic means uses such as household purposes, watering of animals kept as pets, watering of cattle or other stock and irrigation of a kitchen garden.

Table 4: Livestock in GAB regions, 2013-14

Jurisdiction (GAB region)	Livestock - Meat cattle - Total (no.)	Livestock - Sheep and lambs - Total (no.)	Total beef and sheep in region (no.)
NSW	2,292,216	8,449,233	10,741,449
Qld	9,447,571	2,328,966	11,776,537
SA	252,365	260,000*	512,365
NT	2,158,388	-	2,158,388
Total	14,150,540	11,038,199	25,188,739

*Note: * This figure was provided by SA DEWNR given the ABS figure of 2,807,084 includes sheep outside of the GAB.*
Source: ABS 7121.0

3.1.2 Economic value of the sector

The challenges of accessing agricultural data that is relevant to GAB regions is discussed in Appendix 1 to this report. In this section we attempt to value the sector by using data based on the Australia Bureau of Statistics' SA4 regions that overlay the GAB.

Production

As shown in Table 5, the value of production from these livestock is in excess of $4 billion annually for beef cattle and $800 million for sheep (meat and wool). In order to confirm these estimates of economic value of production, the ABS data for NRM regions was also analysed and this found a similar total (Appendix 1).

Table 5: Gross value of livestock industries in GAB regions ($ million), 2013-14

Jurisdiction (GAB region)	Gross value from livestock slaughtered and other disposals - Cattle and calves ($m)	Gross value from livestock slaughtered and other disposals - Sheep and lambs ($m)	Gross value from Wool ($m)	Total ($m)
NSW	629.2	207.2	258.1	1094.5
Qld	2864.1	60.4	79.9	3004.4
SA	84.3	11.8*	9.0*	105.1
NT	463.7	0	0	463.7
Grand Total	4041.1	279.4	347.0	4667.7

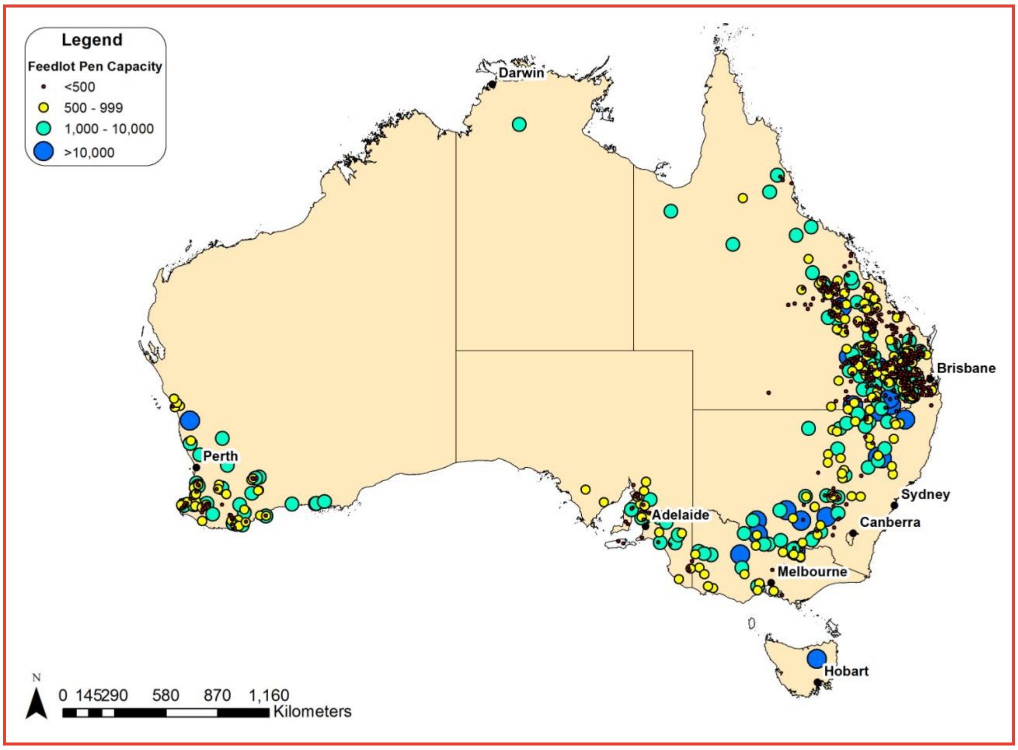
*Note: *Prorated based on the adjustment to the estimated number of SA sheep.*
Source: ABS 7503.0

Feedlots

While not reported separately, the gross value of production of feedlots across Australia is significant ($2.5 billion).

Most of the feedlots in Queensland are in the shires overlaying the GAB (Figure 8). NSW commercial feedlots are predominantly in the Eastern Recharge Groundwater Source.

Figure 8: The location, number and size of feedlots throughout Australia



Source: ALFA 2016

Water is used by feedlots for cattle drinking, effluent management, cooling cattle and dust abatement. (ACIL Tasman 2005). ACIL Tasman (2005) report that other intensive stock industries are important GAB water users too, and use piggeries as an example. Deloitte (2015) notes that where a feedlot relies on GAB water, the water is a crucial element in its function and location.

We understand from the ABS data the value of feedlot output is included in the Queensland total value for cattle slaughtered of $2.86 billion.

3.1.3 Potential future water use

The future water use for stock purposes is expected to increase in efficiency as free-flowing bores are progressively capped and bore drains are replaced with pipes and troughs.

Efficient water consumption (inclusive of losses) does not mean reduced industry output. In fact, production could be maintained or increased since the improved infrastructure reduces losses and provides water in a more controlled way that aids farm management (Moore (1992) notes the value of water quality to livestock productivity and the ability to more effectively control undesirable animal pests and weeds). This more efficient management of GAB water will still support the economic outcomes of stock and domestic water use while using less of the GAB resource.

The increasing use of metering should contribute to improved resource use information. For example, in Queensland, mandated meter installation was completed in the Mulgildie and Eastern Downs management areas in 2007 and in the Gatton-Esk Road Implementation Area in 2010. In addition to the mandated metered entitlements, a number of licences in areas such as the Surat, Flinders, Gulf East, Barcaldine West and Barcaldine North management areas have a condition that requires them to meter their take of water (DNRM 2015).

3.2 Irrigation use

The use of GAB water for irrigation is localised due to water quality issues. Some GAB groundwater has high levels of sodium or other salts, which renders the water unusable for irrigation in some places, while soil condition may also reduce the viability of irrigation. Water quality and sodicity issues can build up over time with regular irrigation. There are also challenges due to isolation from other farmers, agronomic advice and farm technology providers and the distance to potential markets.[2]

Despite this, a number of different irrigated crop types have been reported using GAB water, including sorghum, lucerne and cotton. GAB water is also used to irrigated limited horticultural crops (such as avocados, mandarins and grapes) though often GAB water is a backup source given both the water quality issues and the higher relative pumping cost compared to using surface water.

3.2.1 Patterns of water use

The table below sets out the volumes of water access licences associated with irrigation water use.

Table 6: GAB irrigation water access licences

Jurisdiction	GAB Access Licence Volume (ML/yr)
New South Wales	76,758
Queensland	32,341

2 Pers. comm., Mr Ed Fessey, 14 May 2016.

South Australia	115
Northern Territory	-

Source: Appendix 2.

Queensland

The areas overlying and neighbouring the GAB are important contributors to Queensland's irrigated agricultural area. However, a minimal proportion of this area would use GAB water as the irrigation water source (ACIL 2005).

A current search of the Water Management Database of the Department of Natural Resources and Mines identified total entitlements with irrigation as an approved purpose are 32,341ML per annum spread over 578 licences. In addition to this, there are 154 area-based licences (predominantly in Mulgildie and Clarence Moreton management areas), with irrigable area totalling approximately 5,850 hectares.

Industry contacts suggest that irrigation using GAB water occurs around Goondiwindi.

ACIL (2005) identified that:

- Most irrigation using GAB water is for small areas of fodder production for supplementary feeding of sheep and cattle during dry seasons or to boost fodder quality for particular classes of stock, such as weaner cattle, lambs or dairy cattle.
- Some producers are using GAB water to irrigate lucerne or other crops for sale such as hay, but there are relatively few producers involved. Higher transport costs for fodder from other areas have encouraged the development of these enterprises to supply local markets, especially in western areas of the state.
- There is some limited application for horticulture (tree crops and grapes) in Queensland and typically GAB water is mixed with surface storage water given the high mineral content and high temperatures of GAB water.

Often the GAB entitlement is a backup source given both the water quality issues and the higher relative pumping cost compared to using surface water sources. These other sources could include water captured from overflow and stored on farm dams or publicly owned dams on watercourses (where a water supply charge may apply as well as pumping costs).

NSW

In the past two decades an irrigation industry reliant on GAB water has developed in the Eastern and Southern Recharge Groundwater Sources, where water quality is suitable (NSW Office of Water 2009).

Parts of these areas have been developed for high volume irrigation extraction at two main locations: North Star – Croppa Creek at the northern end of the Eastern Recharge; and near Narromine at the southern end of the Southern Recharge Groundwater Source. Industry contacts suggested that irrigation occurs around Walgett, Moree, Narrabri, and Coonamble, and that GAB water may be blended with surface water for irrigation.

The NSW Department of Primary Industries identified that irrigation would be the primary use for virtually all of the aquifer access licences in Eastern Recharge, Southern Recharge and the 3 Lower Macquarie zones. The Department suggested that there was no significant irrigation in the other water sources.

Therefore, from the licence data presented in Appendix 2, the volume of GAB access licence entitlement associated with irrigation use is estimated to be 76,758 unit shares (if each unit share is utilised to provide 1ML, this would correspond to irrigation use of 76,758 ML).

SA

A single licence lists irrigation as a listed use to the volume of 115 ML per year.

NT

No irrigation using GAB water is reported in the Northern Territory.

3.2.2 Economic value of the sector

Irrigated production (surface and groundwater)

The gross values of crops that may be irrigated with groundwater are difficult to estimate since ABS data does not differentiate between crops irrigated with groundwater and crops irrigated with surface water. There is also the challenge of aligning ABS data regions to focus on the GAB resource. As discussed in Appendix 1, neither ABS SA4 regions nor NRM regions used by the ABS concord very closely with the geographical boundaries of the GAB. When data from NRM regions is considered, the estimates of production from broadacre crops (such as cereal for grain and seed and others) are much lower (as compared to estimates for meat cattle and sheep which were similar between SA4 and NRM approaches). This suggests that the SA4 estimate for broadacre crops above (in excess of $4 billion) is not attributable to production reliant on the GAB.

For this reason, an alternative approach is used to estimate irrigated output dependent on GAB water resources (see below).

Estimated irrigated output (groundwater only)

In light of the difficulties using ABS data that aggregates surface and groundwater irrigated production, we have estimated the value of irrigated agricultural production by considering the volumes of groundwater available that could be applied to different potential crops.

The farm budget (DPI 2012a) for NSW Northern Zone irrigated sorghum (surface irrigation using diesel pump from bore) uses an irrigation rate of 3.8 ML per hectare and suggests a central estimate of yield is 8 tonnes per hectare. An estimate of the on farm value of sorghum can be obtained from daily contract prices, which were around $180 per tonne in March-April 2016 (Broadbent Grain 2016).

The sorghum farm budget (central estimate) suggest that the NSW irrigation volume licences of 76,758 ML (assuming 1ML per unit share) could produce an irrigated crop valued at approximately $29.1 million.

If the northern NSW sorghum farm budget (central estimate) is applied to Queensland, it suggest that the Queensland irrigation volume licences of 32,341 ML could produce an irrigated crop valued at approximately $12.3 million. Using the same farm budget assumptions, the additional area-based licences for 5850 hectares could produce an irrigated crop valued at approximately $8.4 million. This provides a total potential Queensland sorghum crop valued at $20.7 million.

The farm budget (DPI 2012b) for NSW Northern Zone irrigated lucerne (surface irrigation of an established stand) uses an irrigation rate of 8.75 ML to achieve 7 cuts of 1.9 tonne per hectare (giving a central estimate for total yield of 13.3 tonnes per hectare).[3]

The lucerne farm budget (central estimate) suggests that the Queensland irrigation volume licences of 76,758 ML (assuming 1ML per unit share) could produce an irrigated crop valued at approximately $31.8 million.

If the northern NSW lucerne farm budget (central estimate) is applied to Queensland, it suggests that the Queensland irrigation volume licences of 32,341 ML could produce an irrigated crop valued at approximately $13.4 million. Using the same farm budget assumptions, the additional area licences for 5850 hectares could produce an irrigated crop valued at approximately $21.2 million. This leads to a total potential Queensland lucerne farm crop valued at $34.6 million.

No information on irrigated agriculture in SA and NT that relies on GAB water was identified. Therefore it is assumed that the output of GAB-reliant irrigated agriculture in SA and NT is negligible.

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3 The farm budget translates this yield to 320 bales/ha of AFIA Grade A1 (valued at approximately $8/bale), 106 bales/ha of AFIA Grade B2 (valued at approximately $6/bale) and 106 bales/ha of AFIA Grade C3 (valued at approximately $4/bale).

Table 7: Value of GAB irrigated agricultural output

GAB Jurisdiction	Value	Central estimate
NSW	$29.1-31.8 million	$30.4 million
Queensland	$20.7-34.6 million	$27.7 million
South Australia	-	0
Northern Territory	-	0
Total GAB	**$49.8-66.4 million**	**$58.1 million**

Source: Frontier analysis

Given that GAB water is known to also be used for higher value crops such as horticulture, the above estimates based on sorghum/lucerne represents a lower bound estimate.

3.2.3 Potential future water use

The Queensland Department of Agriculture, Fisheries and Forestry identifies potential for further significant agricultural development across Queensland (DAFF 2014). In its 2014 Agricultural Land Audit report, it identified that, based on the biophysical conditions, there is potential for future broadacre cropping particularly in the Surat and Surat East management areas, as well as annual and perennial horticulture opportunities in many areas across the state including the Cape and Surat management areas. There is also potential to increase pasture production in many areas across the state, including the south eastern part of the plan area. License applications for additional water indicate demand from the intensive livestock sector.

Research has recently been undertaken on the potential for intensive, irrigated cropping and livestock production along the alluvial floodplains of the Flinders and Gilbert rivers as part of the North Queensland Irrigated Agriculture Strategy where limited shallow groundwater is available.

3.3 Energy and Earth Resources

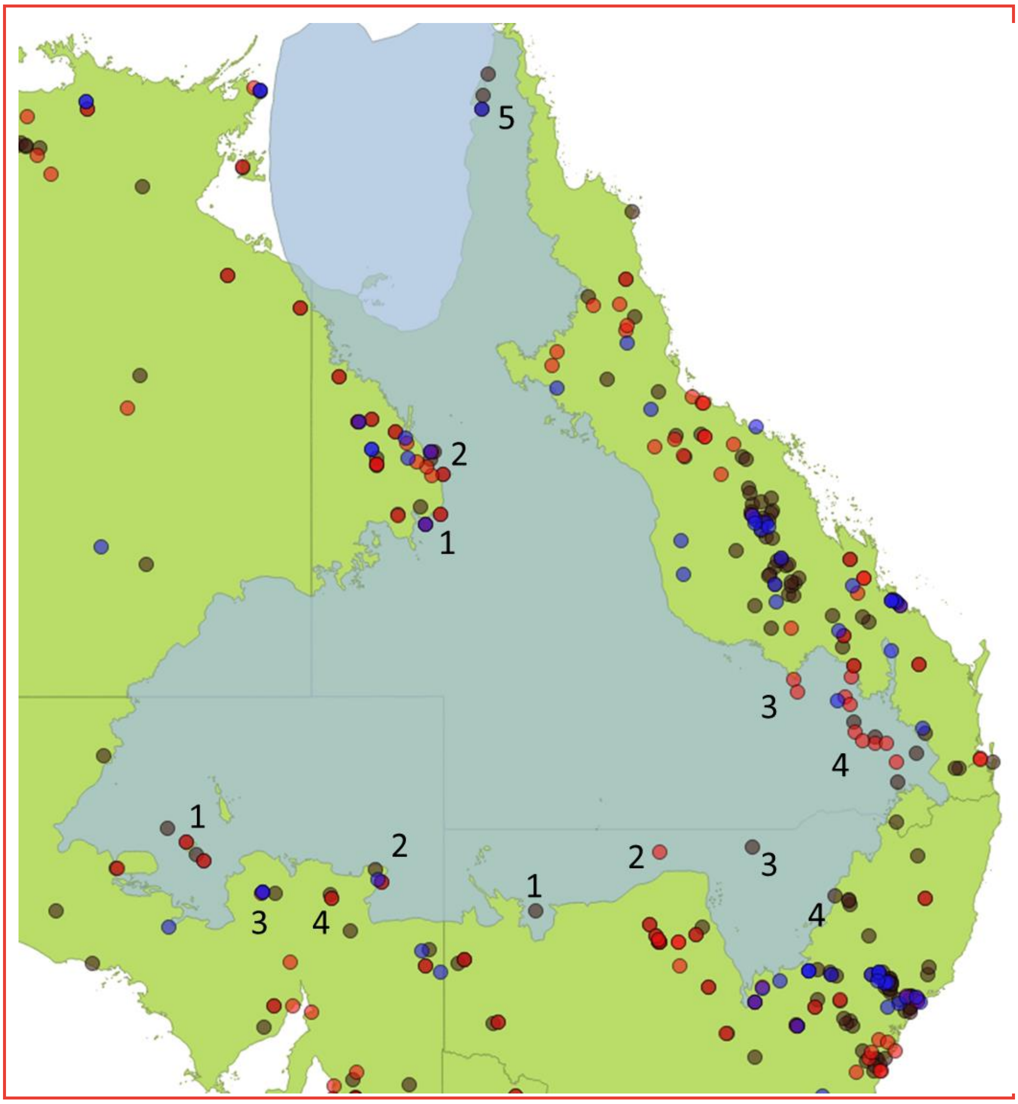
GAB water resources can be used to directly generate electricity by geothermal generation. Earth resources include mineral and ores, as well as coal, oil and gas, the extraction and processing of which involve GAB water resources.

Mining for copper, uranium, bauxite and opals depend on a reliable supply of GAB water. The extraction of oil and gas from the GAB results in the simultaneous extraction of substantial amounts of water as a waste product. Coal seam gas (CSG) is a rapidly expanding industry, and uses large amounts of water for the life of those projects. Opportunities are being explored for using associated water for economic uses.

3.3.1 Patterns of water use

Mining activity is relatively limited in GAB regions as compared to other parts of Australia. The figure below shows the significant exclusion of mining activity over the blue-shaded area of the map which corresponds to the GAB. The figure presents the operating mines (as at February 2015), mineral processing centres (as at February 2014) and new mining infrastructure (as at November 2013). The numbered sites are discussed in the subsection associated with each Basin jurisdiction.

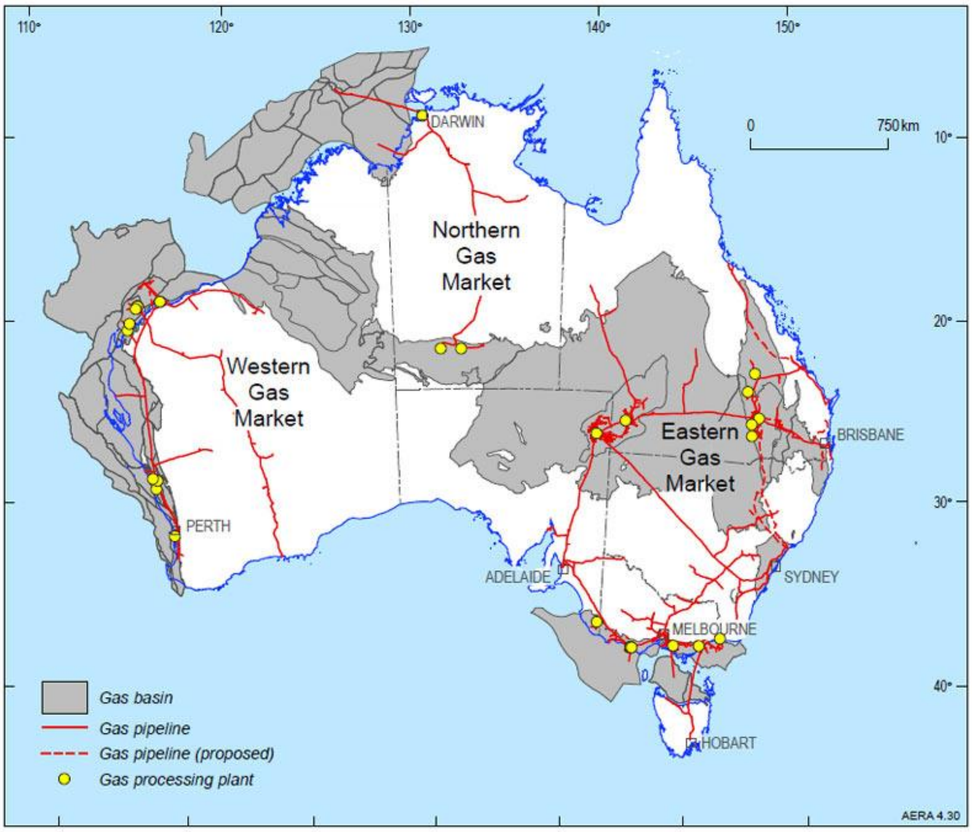
Figure 9: Operating mines, new mining infrastructure and mineral processing centres



Legend: Brown markers represent operation mines, red markers represent processing plants, and blue markers represent planned developments.
Source: Australian Mines Atlas 2015; Geoscience Australia 2016.

The distribution of CSG projects is concentrated on the eastern parts of the GAB, in Queensland and New South Wales. The GAB underlies much of the Eastern Gas Market and gas basin (Figure 10).

Figure 10: Australia's gas facilities



Source: Geoscience Australia nd.

NSW

Mine sites that are overlaying the GAB water resource (Figure 9) include:

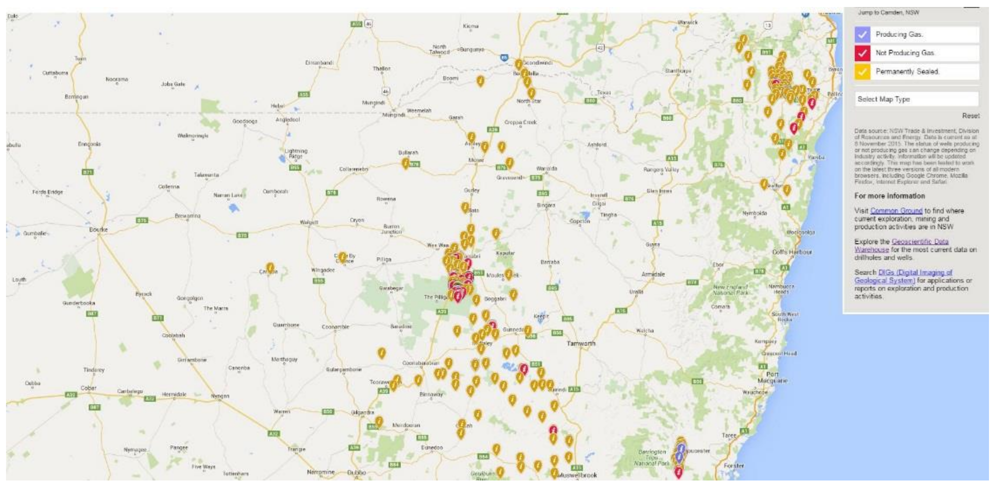
- NSW 1 — overlaying GAB: White Cliffs (Opal) operating mine.
- NSW 3 — overlaying GAB: Lightning Ridge (Opal) operating mine.
- NSW 4 — overlaying GAB: Narrabri (Coal – black)
- (The Australia Mine Atlas entry for NSW 2 is actually an error in the database for Three Springs (WA))

Mining is a modest user of artesian water in NSW and this is primarily associated with the opal mining in the Lightning Ridge and White Cliffs areas (NSW WSP 2009). Water use for Lightning Ridge varies from year to year, but is in part related to the number of agitators operating and the rainfall, and was 25-173ML per year in the period 1997-2002 (the only time series identified) (NSW DPI 2004).

Production of coal at Narrabri was reported to be 7.2Mt in 2015 (Whitehaven Coal 2016).

According to the NSW Government data mapped in Figure 11, there are no producing CSG wells in the NSW areas of the GAB. However, there is still some reported CSG produced as part of exploration activities around Narrabri, of 0.2PJ in 2014 and 1.6PJ in 2015 (pers. comm., APPEA, 6 May 2016).

Figure 11: NSW CSG wells



Source: NSW DIRE 2015; NSW Government 2016.

Queensland

Mining industries in Queensland use GAB water for both mineral extraction (mining) and mineral processing. Water use is concentrated in the shires of Cook, Monto, Chinchilla and Jondaryan. Mine sites that overlie the GAB water resource (Figure 9) include:

- QLD 1 — overlaying GAB: Cannington (Lead, Silver, Zinc, Bismuth, Antimony) operating mine and processing plant; Osborne (Copper, Gold) operating mine, processing plant and proposed magnetite development.
- QLD 2 — parts of the Mt Isa region overlaying GAB: include Eloise (Copper, Gold, Silver) operating mine and processing plant; Mount Margaret (Copper Gold, Uranium, Uranium Oxide) operating; Ernest Henry (Copper, Gold, Magnetite, Iron ore, Iron) operating mine, processing plant and proposed underground copper mine.
- QLD 3 — overlaying GAB: Fairview (Coal Bed Methane) processing plant; Spring Gully (Coal Bed Methane) processing plant.
- QLD 4 — overlaying GAB: Commodore (Coal – black) operating mine; New Acland (Coal – black) operating mine; Kogan Creek (Coal – black)

operating mine; Cameby Downs (Coal – black) operating mine; eight Coal Bed Methane processing plants.

- QLD 5 — overlaying GAB: Skardon River (Kaolin) operating mine; Ely (Bauxite) operating mine; Weipa (Alumina, Bauxite) operating mine and proposed expansion.

These mines produce significant volumes of a range of outputs (Table 8).

Table 8: Queensland mining output that is GAB-dependent

Mining product	Unit	Output
Copper	t	102,680
Gold	kg	1,412
Silver	t	844
Coal	t	12,836,905
Zinc	t	69,611
Lead	t	196,293

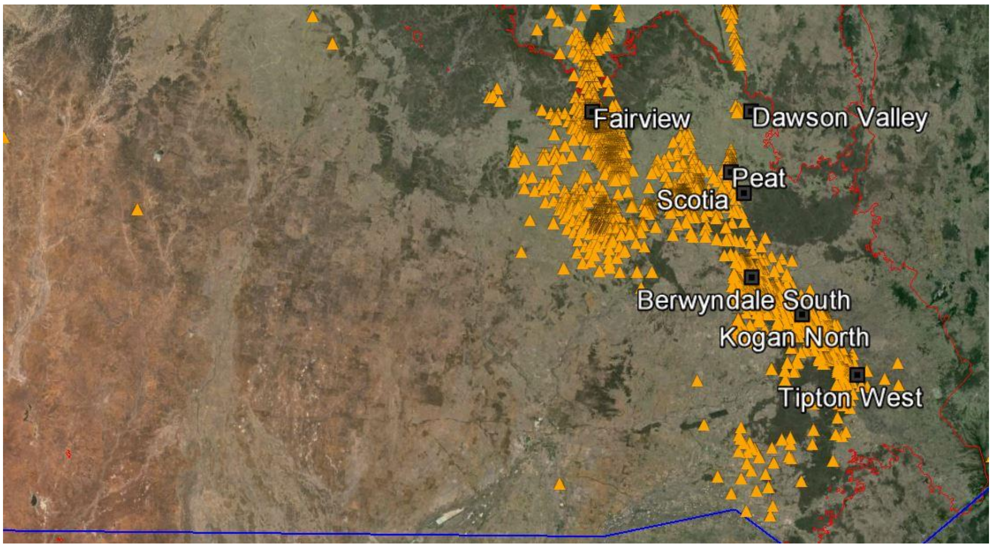
Note: This table aggregates production from the following mines: Cannington, Osbourne, Eloise, Mount Margaret, Ernest Henry, Commodore, New Acland, Kogan Creek, Cameby Downs.
Source: Queensland Government 2016a; Queensland Government 2016b.

Coal seam gas (CSG) is another prominent industry in Queensland that interacts with GAB water resources. The Queensland 5-year review of the GAB Water Resource Plan considered the impacts of the CSG industry on GAB groundwater (DNRM 2012).

The largest concentration of CSG wells in the GAB is in south-eastern Queensland (Figure 12), coincident with the coal methane bed processing plants identified in Figure 9. Each yellow marker represents an active CSG well using the most current available data from state websites (as at April 2016). There are also a number of CSG wells in central Queensland (Figure 13).

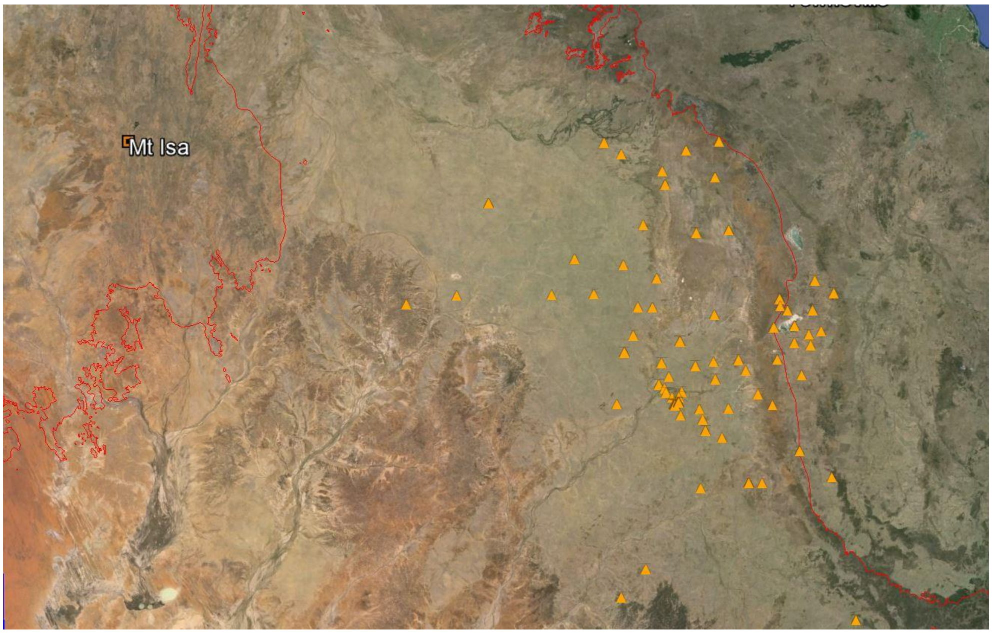
CSG extraction within the GAB area occurs in the Bowen and Surat Basins (although production from the Bowen Basin occurs from formations deeper than those dealt with in the plan). In the GAB, the CSG industry is most intensively developed in the Walloon Coal Measures (a series of volcanolithic sandstones, coal, mudstones and siltstones, extending over wide areas of the Surat Basin) (Kear and Hamilton-Bruce 2011).

Figure 12: CSG in SE Queensland



Source: Queensland Government 2015; Geoscience Australia 2016.

Figure 13: CSG in central Queensland

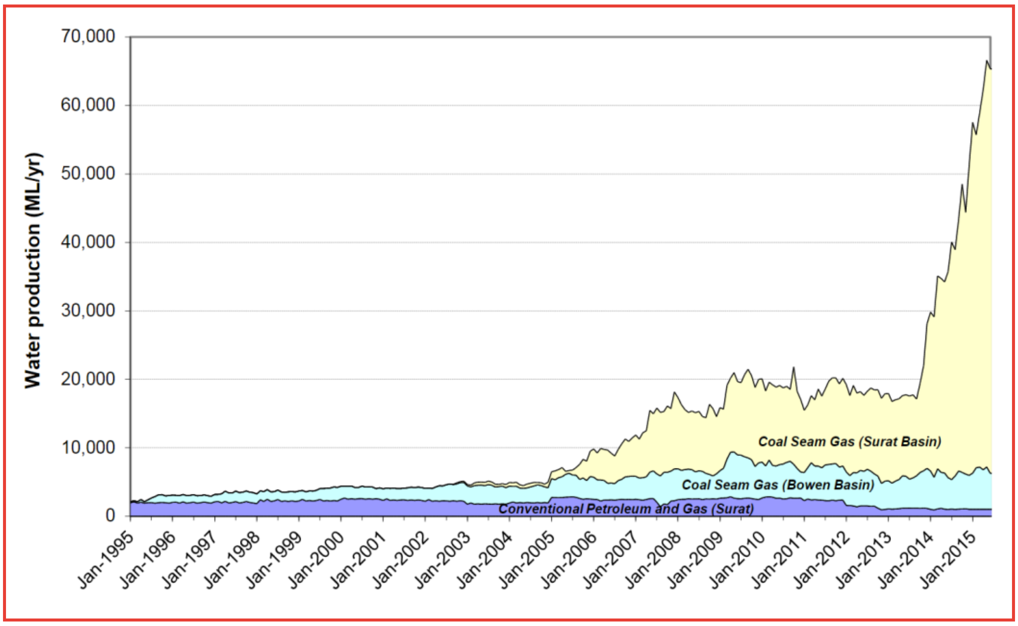


Source: Queensland Government 2015; Geoscience Australia 2016.

There has been an almost four-fold increase in the volume of associated water production from the Surat Basin from 2005 to 2013 (OGIA 2015). The number of producing CSG wells almost doubled in the first half of 2014 and this has increased associated water extraction significantly (DNRM 2015, p. 30).

This increasing trend has continued. The most recent estimate (July 2015) of water extraction from CSG in Queensland is 64,000ML per year (Figure 14). There is also an estimated 1,000 ML per year of water extracted for conventional petroleum and gas. This totals an estimated 65,000ML per year for groundwater extraction associated with Queensland's petroleum and gas developments. This is not managed under the water entitlement framework, rather through a comprehensive regulatory framework that aims to minimise and or mitigate the impacts of mining and gas development on primary producers and the environment. (pers. comm., DNRM, 11 May 2016).

Figure 14: Associated water from coal seam gas production in the Surat Basin



Source:.DNRM 2016, p. 62.

Conventional gas production (as opposed to CSG) also occurs in GAB regions. A significant resource for this gas is the Cooper Basin, which underlies the GAB. The Queensland Gas Fields Commission (2015) reports that relatively small volumes of groundwater are extracted as a by-product during conventional gas production. SA DEWNR (pers. comm., 28 July 2016)) noted that some Cooper Basin operations in SA currently access GAB water as well as using co-produced water (for example, Santos (2015) report that 1622ML of groundwater was extracted from their SA operations). SA DEWNR also noted that industry is now moving towards using the co-produced water to extract unconventional gas from the Cooper Basin, with this type of extraction is expected to increase in the future.

GAB water is also used for geothermal electricity generation in Birdsville. The plant specification is for water use at 27 litres per second (Ergon 2015), which is 850 ML per year if being continuously operated. The geothermal power station provides 80kW of electricity for customer use which is about 30% of the town's needs.

South Australia

Mines sites that are overlaying the GAB water resource (Figure 9) include:

- SA 1 — overlaying GAB: Cairn Hill[4] (Iron, Copper, Gold, Iron Ore) operating mine and processing plant; Coober Pedy (Opal) operating mine; Southern Iron- Peculiar Knob (Iron Ore, Iron) operating mine; Prominent Hill (Copper, Gold, Silver) operating mine and processing plant.
- SA 2 — overlaying GAB (or very close): Mount Fitton (Talc) operating mine; Beverly (Uranium, Uranium Oxide) operating mine and processing plant; Four Mile potential uranium mine.
- SA 3 — not overlaying GAB: Olympic Dam (Uranium, Gold) operating mine, processing plant and planned expansion; Andamooka (opal) operating mine
- SA 4 — not overlaying GAB: Leigh Creek (Coal – black) operating mine (now closed)[5]; Mountain of Light (Copper) operating mine and processing plant.

These mines produce significant volumes or a range of outputs (Table 8).

Table 9: South Australian mining output that is GAB-dependent

Mining product	Unit	Output
Copper	t	284905
Uranium Oxide	t	4901
Gold	oz	217555
Silver	oz	1487349
Iron ore	Mt	1.235

Note: This table aggregates production from Peculiar Knob, Prominent Hill, Beverly, Four Mile and Olympic Dam.
Source: SA DSD 2016.

The Olympic Dam underground copper and uranium mine is South Australia's largest mining water user. The primary water supply for the existing Olympic Dam operation is groundwater extracted from Wellfields A and B located in the GAB, about 120 and 200 km north of Olympic Dam, respectively.

4 Reported to not use GAB water (IMX Resources 2013).

5 Reported to not use GAB water (DEWNR 2013).

Economic value of GAB water using activities

3.3.2 Economic value of the sector

Mining

The value of GAB dependent mining outputs was estimated using production data from mines sites that are overlaying the GAB water resource in combination with representative prices for the output commodities. It is important to note that it was outside the scope of the project to confirm that every mine site overlaying the GAB water resource was dependent on GAB water. The Minerals Council of Australia were unable to assist with the provision of this information (MCA, pers. comm., 12 May 2016).

The total value is estimated to be in excess of $6 billion annually, with the bulk of this from Queensland and South Australian production (Table 10).

Table 10: Estimated value of GAB-dependent mining

Jurisdiction	Estimated value ($ million)
New South Wales	568.3
Queensland	2,980.7
South Australia	2,801.7
Northern Territory	-
Total	**6,350.8**

Source: Quantity data from tables above. Price data from Indexmundi 2016a-h, and NSW DIRE nd.

CSG

The Queensland area of the Surat Basin produced 352.8 PJ of CSG in 2014-15 (which was 77% of the state's CSG production) (DNRM 2016).[6]

The value of the Queensland CSG output may be inferred from the Brisbane wholesale gas market where the price was $4.80 per GJ at the Wallumbilla hub (at the end of March 2016) (AEMO 2016). This suggests that a market price of $1 693.4 million for the 352.8PJ.

The reported NSW production of 1.6PJ in 2015 would be valued at $7.7 million if valued on the same basis as above.

6 Although CSG production around Fairview and Spring Gully are in areas overlaying the GAB, the CSG extraction is technically Bowen Basin. For the combined Surat/Bowen Basin, CSG production 2014-15 was 408.8 PJ and CSG production for 12 months calendar year 2015 was 631.9 PJ (pers. comm. APPEA, 6 May 2016).

Electricity

The Birdsville geothermal plant provides 520,116kWh. Using a representative electricity tariff of 24.462 cents per kWh (Ergon 2016), this can be valued at a maximum of $127,000.

3.3.3 Potential future water use

Two instances of increased future water use have been identified for geothermal power generation in Queensland.

- Ergon Energy is expanding the 80 kW plant to completely meet Birdsville's electricity requirements (from 25%).
- Winton Shire Council resolved to design and construct two 150kW geothermal plants which uses GAB water at a temperature of 86°C, and at a flow rate of 72 litres per second (Reneweconomy 2015).

As the CSG industry continues to expand in Queensland, the amount of associated water taken for gas fields is expected to increase (DNRM 2015).

The Surat Basin Regional Planning Framework (2011) identified that:

> The Surat Basin will experience rapid growth over the next 30 years in the mining and gas sector due to increasing domestic and international demand for energy resources. However, it is difficult to accurately predict levels of resource demand. Consumption of thermal coal and CSG for power generation and material production will fluctuate with global economic conditions and the emergence of innovative and cleaner technology for energy production may also impact on demand.

The Minister's Performance Assessment Report (DNRM 2015, p.20) notes that the current GAB Water Resource Plan (WRP) does not currently consider the potential magnitude of water that may be taken by potential new industries such as the shale gas industry. Queensland is currently reviewing the WRP and water that may be potentially made available to new users will be re-evaluated using updated hydrogeological and environmental assessments.

In South Australia, GAB water use by gas operations may increase in the future due to the use of co-produced water to extract unconventional gas from the underlying Cooper Basin (SA DEWNR, pers. comm., 28 July 2016).

3.4 Urban Water use

3.4.1 Patterns of water use

Basin water is used in more than 120 towns and settlements across the GAB. Many of these towns rely on GAB water in combination with surface water supplies, while others are wholly dependent on GAB water for urban supplies. For example, although urban water supplies in Queensland represent only 5% of the total water use from the GAB, a large proportion of towns overlying the resource rely solely on this supply (Cox and McKay 2006).

GABCC (2012) reports total entitlements for urban use from the GAB was 40 341 ML per annum. Town water includes domestic uses as well as limited commercial and specified industrial uses. Domestic uses include drinking water, bathing, washing, watering gardens and other external uses.

Information provided to this report is broadly consistent with this, identifying 40847 ML of licenced annual use (Table 11). Overall, GABCC (nd) reports that GAB water sustains more than 180,000 people.

Table 11: GAB Urban water licences

Local Water Utility jurisdiction	GAB Estimated Use / Access Licence Volume (ML/yr)
New South Wales	7,028
Queensland	32,057
South Australia	1,692[1]
Northern Territory	70
Total	**40,847**

Note:[1] This is different to the local water utility licence volume of 630ML/yr since it includes town water use from mining camp licences. The majority of this entitlement was for Roxby Downs (876 ML p.a.), Coober Pedy (475 ML p.a.) and Oodnadatta (32.9 ML p.a.).
Source: Appendix 2.

New South Wales

NSW towns accounted for 7028 ML of entitlement per annum (Table 12). In NSW, at least 42 communities currently source GAB water for town water and domestic supplies.

Table 12: Licence Volumes for Local Water Utilities Access Licences in the NSW GAB

Local Water Utility	Entitlement (ML/yr)	Population
Bourke Shire Council	252	3095
Coonamble Shire Council	1541	4030
Gilgandra Shire Council	2020	4355
Moree Plains Shire Council	925	13429
Narrabri Shire Council	179	14000

Walgett Shire Council	707	7199
Warren Shire Council	740	2900
Warrumbungle Shire Council	264	9808
Brewarrina Shire Council	50	2193
Narromine Shire Council	350	6800
Total	7028	67809

Note: The entitlement (Access Licence Volume) is sourced from DPI Corporate database. The population information is sourced from the web sites of the relevant councils.
Source: Pers. comm., NSW DPI, 6 May 2016.

Queensland

Queensland is the largest user of GAB water for town supply. In Queensland, GAB aquifers supply water for more than 85 towns or settlements. Some 25 towns had an entitlement of less than 100 ML per year, 44 had an entitlement of between 100 and 500 ML per year and 16 had entitlements greater than 500 ML per year. These include Aramac, Barcaldine, Blackall, Charleville, Cunnamulla, Dalby, Longreach, Miles, Millmerran, Mitchell, Quilpie, Roma and St George (ACIL Tasman 2005).

Table 13: Populations Queensland towns relying on GAB water for urban supply

Town	Population
Aramac	299
Barcaldine	1655
Blackall	1588
Charleville	3728
Cunnamulla	1641
Dalby	12,299
Longreach	3356
Miles	1588
Millmerran	1566
Mitchell	1311
Quilpie	574
Roma	6906
St George	3292

Source: ABS Populations Census 2011.

Economic value of GAB water using activities

South Australia

Towns in South Australia accounted for some 1,692 ML of entitlements per annum in 2007. The majority of this entitlement was for Roxby Downs (876 ML p.a.), Coober Pedy (475 ML p.a.) and Oodnadatta (32.9 ML p.a.).

Northern Territory

In the Northern Territory, Power & Water Corp is licensed for 96 ML per year for supply to Finke, but generally extract approximately 60ML per year.[7] The population of Finke is 162 (ABS Population Census 2011).

3.4.2 Economic value of the sector

Clean, reliable and affordable water and wastewater services are fundamental to life, health outcomes and the economy in urban areas across Australia (WSAA 2015). Infrastructure Australia's recent audit estimated that the urban water sector makes a Direct Economic Contribution of some $10.6 billion across the economy (Infrastructure Australia, 2015).

Like all urban areas, access to water for regional centres and settlements across the GAB is vital to their continued existence and their quality of life. In this sense water is critical to the ability of these centres to service industries and economic activity in the surrounding regions.

In order to estimate the value of urban water provision dependent on GAB water resources, a representative water tariff can be applied to the volume of licenced urban use. Using a representative tariff of the Longreach region charge of $1.06 per kL[8], provides the results in Table 14.

Table 14: GAB Urban water licences and estimated value

Local Water Utility jurisdiction	Estimated Use / Access Licence Volume (ML/yr)	Estimated value ($ million)
New South Wales	7,028	7.4
Queensland	32,057	34.0
South Australia	1,692[1]	1.8
Northern Territory	70	0.1
Total	**40,847**	**43.3**

Note:[1] This is different to the local water utility licence volume of 630ML/yr since it includes town water use from mining camp licences and other sources. The majority of this entitlement was for Roxby Downs

7 Pers. comm., NT DLRM, 14 January 2016.

8 $1.06/kL is the charge for the first 300kL of excess consumption above the allowance in the Longreach, Ilfracombe, Isisford/Yaraka areas (Longreach Regional Council 2015).

(876 ML p.a.), Coober Pedy (475 ML p.a.) and Oodnadatta (32.9 ML p.a.).
Source: Appendix 2.

3.4.3 Potential future water use

Additional water supply may be required to support population growth, changes in population distribution, loss of access to surface water, or in response to reduced availability or quality of GAB water at particular sites.

As noted by Infrastructure Australia (2015), growth in the number of properties served by urban water suppliers will generally grow in line with regional population growth. This is likely to vary significantly across the GAB depending on the future growth or contraction of different economic activities (e.g. mining and gas exploration and development).

3.5 Other industries (including tourism)

3.5.1 Patterns of water use

GAB water is also a key input into other economic activities across the GAB.

In particular, many tourist attractions and developments across the Basin rely on artesian water. In some areas, artesian water is used in mineral spas and tourists are attracted by the cultural and natural history of springs that are developed as visitor sites. The tourism industry, includes baths, camel treks, Indigenous heritage sites and the Ghan railway. (GABCC 2008). In NSW and Queensland, flowing and non-flowing artesian bores are used for spa-bath tourist facilities in places such as Moree, Lightning Ridge, Boomi, Mitchell, Bedourie and Burren Junction. (Moree Plains Shire Council, 2001).

A list of the key regions and specific tourism and recreations sites partly supported by the GAB is provided in Table 15.

Table 15: Key tourism and recreation sites supported by the GAB

Jurisdiction	Key tourism and recreation sites
NSW	• Moree, various locations - a number of accommodation houses that have access to private artesian spas. • Bourke, Comeroo Camel Station - multi-faceted tourist retreat with camel riding, private artesian spas, and a working sheep station. • Pilliga Bore Baths • Burren Junction Bore Baths – also has accommodation and facilities. • Lightning Ridge Bore Baths – has several accommodation houses and Bore Baths.
QLD	• Blackall Aquatic Centre - aquatic centre with artesian spa. • Mitchell Great Artesian Spa Complex - Mitchell's major tourist attraction. • Cunnamulla, Charlotte Plains Farmstay - a working sheep and cattle property with bore baths.

	• Ilfracombe Artesian Spa • Bedourie Artesian Spa – 22 person Therapeutic Spa and provides for an aquatic centre (built in 2000) • Cunnamulla Fella Centre – Artesian Time Tunnel, Paroo Shire Council, Eromanga Basin
SA	• Wabma Kadarbu Mound Springs Conservation Park – Blanche Cup and The Bubbler mound springs • Witjira National Park – Dalhousie Springs

Source: SKM 2014.

While the tourism sector is not in itself a major consumptive user of GAB water, the ongoing health of the GAB springs is vital to the attraction of these sites as tourism destinations.

3.5.2 Economic value of the sector

It has not been possible to estimate the proportion of tourism that is dependent on GAB water resources directly.

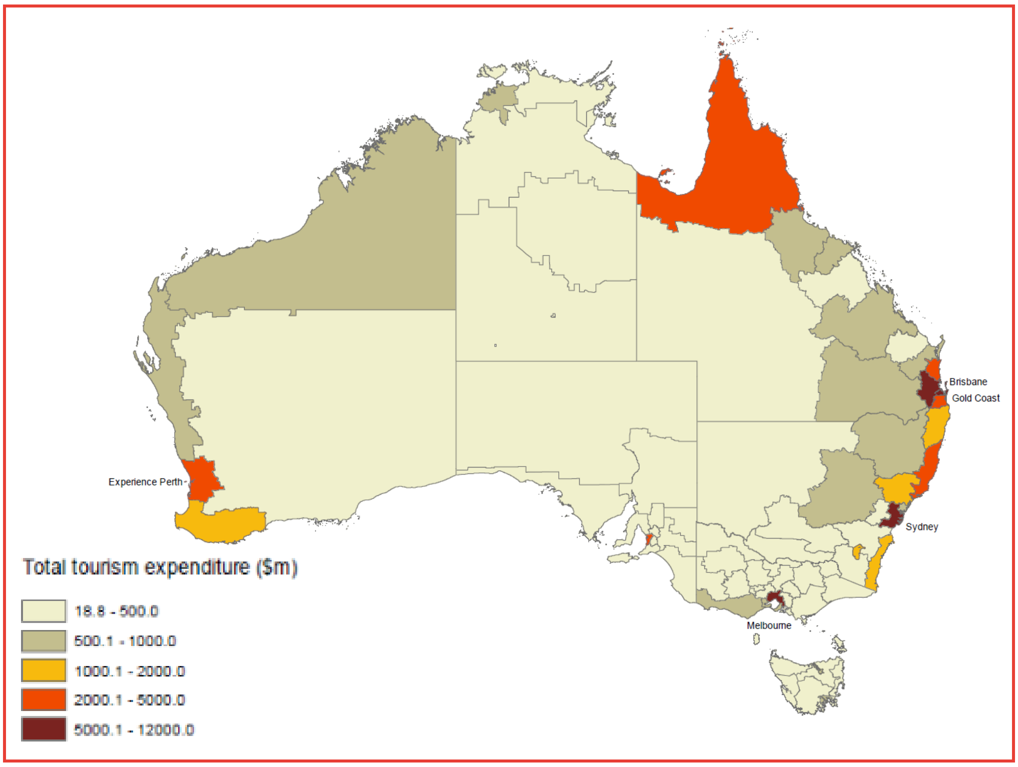
As discussed elsewhere in this report, arguably, most of the economic activity in GAB regions is reliant on access to the GAB water resource. Without the water access, economic development would not be viable where other reliable water sources are not available.

Tourism expenditure in GAB regions is significant, however, small compared to tourism in other regions. This is demonstrated in 2011 report by Tourism Research Australia estimates the economic importance of tourism in Australian regions (Figure 15).

The reporting regions for tourism data do not align well with GAB boundaries. This only region clearly relevant is the Queensland outback. Many other tourism indicator regions include GAB regions and also include significant areas of non-GAB areas (and often with greater population density). However, based on the data underlying the above map, an estimate of the tourism expenditure in areas dependent on the GAB is $725 million (Table 16).

In the GAB region of Outback Queensland the economic importance of tourism (as a proportion of the regional economy) was found to be 6.5% (TRA 2011).

Figure 15: Total tourism expenditure in 2007-08



Source: TRA 2011

Table 16: Tourism Indicators 2013-14

Region	Total overnight visitors ('000)	Tourism Businesses*	Tourism expenditure ($m)
Outback Queensland	**237**	**611**	**311**
Outback NSW	347	500	201
Darling Downs	1832	3057	1201
Tropical North Queensland	2317	3643	2752
SA Flinders Ranges and Outback	451	550	300
NT Lasseter	257	9	326
Estimate for GAB-type regions^	765	1141	725

*Notes: * 2012-13 since 2013-14 not reported. ^ A conservative estimate includes all of tourism activity in Outback Queensland, and half of tourism activity in Outback NSW, SA Flinders Ranges and Outback, and NT Lasseter. Tropical North Queensland and Darling Down are excluded due to the expectation that most activity tourism activity in these areas is outside of GAB overlaying regions and not reliant on GAB water access.*
Source: TRA 2016.

Economic value of GAB water using activities

3.5.3 Potential future water use

Natural springs and environmental tourism depend on GAB water pressure being maintained.

The overall size of the tourism industry is small in most of the GAB area. Although there may be a gradual increase in visitation and spend there is no information expecting a rapid change. At present there are few water-related attractions and water's key role is in sustaining tourism infrastructure.

4 Investment in water infrastructure in the GAB

This study also sought information on the asset value of capping and piping infrastructure in the GAB based on replacement value.

In doing so we have drawn on public information where available and input from jurisdictions.

4.1 Private On-farm investment

There are an estimated 34,591 bores across the GAB (Table 17). The vast majority of these bores are less than 200 metres deep, however some bores are deeper than 1200 metres.

Table 17: GAB bore depth and estimated replacement cost ($ million)

Bore depth (m)	Number of bores	Estimated replacement cost ($ million)*
0-200	23507	952.7
200-400	4879	684.7
400-600	1687	459.6
600-800	722	244.3
800-1000	441	198.8
1000-1200	385	201.4
>1200	1162	2011.9
No depth data	1808	73.3^
Total	**34591**	**4826.6**

*Note: *Estimated replacement cost is based on the GABCC estimate for SA, NT and NSW bores and extrapolated across Queensland bores. ^ Assuming bores with no depth data are 0-200m deep.*
Source: GABCC 2016; Queensland DNRM, pers. comm., 12 April 2016.

It is estimated, that 87% of bores in Queensland are landholder owned. Since 1954, all artesian bores have had to supply water via fully reticulated water systems. This means that the majority of bores which are for water supply would therefore have surface pipes, tanks and troughs.

The private benefits of capping and piping are wide ranging and significant. CIE (2003) identified potential benefits including:

- The elimination of all costs associated with bore drain maintenance and repairs, such as delving, repairing breakouts and bore drain inspections
- Reduced mustering times and much simplified mustering processes

- Better utilisation of all natural resources on the property through better water distribution
- more flexible and efficient property management — by controlling watering points, properties can be rotationally grazed, improving native vegetation and livestock performance
- having clean water for stock to drink
- having pressure and clean water at the homestead
- ability to better control vertebrate pests, thereby reducing control costs
- reduced costs of controlling weeds which can be spread along bore drains
- increased pumping costs avoided where artesian wells might otherwise turn subartesian
- increased security of water supplies, thereby reducing management anxiety
- improved scope to better manage in times of drought.

4.2 Public investment — GABSI

GABSI funding for phases 1–4 has totalled $230 million over fifteen years (Table 18). Between 1999-00 and 2012-13, 647 bores have been controlled, 19,178 kilometres of bore drains deleted, and 28,345 kilometres of piping installed. These works have resulted in estimated annual water savings of 204,527ML. These savings are distributed between the states as follows: New South Wales (64,971 ML per year); Queensland (119,217 ML per year) and South Australia (20,338 ML per year) (SKM 2014).

The GABSI has involved extensive funding and facilitation by governments (see Table 17 below), and landholder contributions (both cash and in-kind). For example, in Queensland, during Stage 3 of GABSI alone it is estimated that landholders contributed $12.8 million in cash and about $4.7 million through in-kind contributions, across 230 projects (DNRM 2014). Over the 15 years of this program a total of $53 million dollars and in-kind investment was provided by landholders. In New South Wales, landholder contributions are estimated to have been $87.1 million[9]. In South Australia, landholder contributions have been $3.7 million[10].

9 Pers. comm., NSW DPI, 31 May 2016.

10 Pers. comm., SA DEWNR, 9 May 2016.

Table 18: Government funding over the phases 1-3 of GABSI (nominal $ million)

Funding source	Phase 1 (1999/2000 – 2003/2004)	Phase 2 (2004/2005 – 2008/2009)	Phase 3 (2009/2010 – 2012/2013)	Remaining Phase 3 (2013/2014)	Total
Commonwealth	28.39	39.89	30.95	15.83	**115.06**
South Australia	1.75	0.20	2.25	1.60	**5.8**
New South Wales	12.34	15.79	13.00	7.40	**48.53**
Queensland	13.23	23.88	16.49	6.83	**60.43**
Total (government)	**55.71**	**79.76**	**62.69**	**31.66**	***229.82***

Source: SKM 2014

GABSI built on earlier initiatives that targeted uncontrolled bores, and inefficient bore drains. For example, in Queensland, the GAB Rehabilitation Program was active 1989 to 1998, and the Bore Drain Replacement Program was active 1994 to 2000. Table 18 sets out water savings from water efficiency investments outside of GABSI.

Table 19: Water efficiency investments outside of GABSI

	Flow Saved (ML/annum)
NSW	9,051
Queensland	69,141
South Australia	39,420

Source: SKM 2014; Data request responses from jurisdictions.

4.3 Value of investment

The value of this investment is significant. One approach to estimating this value is the cost of the infrastructure, where recent build cost would approximate replacement cost.

The GABSI investment in each Basin jurisdiction can be estimated by prorating the Commonwealth contributions to GABSI between the Basin jurisdictions in line with their contributions. Given these investments have occurred over an extended timeframe, the expenditure can be compared by inflating these estimates by CPI to obtain estimated funding in 2016 dollars (Table 20).

Table 20: Estimated government investment by Basin jurisdiction (real $ million 2016)

	Phase 1	Phase 2	Phase 3	Phase 4	Total
NSW	36.1	39.5	28.0	15.3	118.9
Queensland	38.7	59.7	35.5	14.1	148.0
South Australia	5.1	0.5	4.8	3.3	13.8
Northern Territory	0.0	0.0	0.0	0.0	0.0
Total					280.7

Source: Frontier Economics analysis

The total cost of surface water infrastructure in the Basin may be extrapolated across all GAB water supply bores using data from the GABSI program as it is likely that water distribution systems put in place are of similar scale, with or without rehabilitation funding.

If this approach is applied to the 34,591 bores across the GAB, rather than the 647 bores controlled under GABSI, then the expected replacement cost of all bores and associated water distribution systems is in the order of $15 billion dollars.

GABCC data suggests that the replacement cost of the 34,591 bores only is estimated to be nearly $5 billion (Table 17).

The value of private investment is therefore expected to lie in the range of $5-15 billion.

5 Concluding comments

The GAB is a highly valuable water resource which provides locationally diverse benefits and opportunities. Arguably, most of the economic activity in GAB regions is dependent on access to GAB water resources. Without GAB water, economic development in many areas would not have been able to occur. It is also hard to imagine much of the town/urban water use and domestic water use in GAB regions being possible without access to GAB water. In many localities, alternative water supplies are prohibitively costly and total reliance on surface water would significantly reduce liveability. In other areas, such as eastern regions and the far north, other water sources are available and we are unable to differentiate the contributions of GAB water and these other sources of water to regional economic activity.

We estimate that the consumptive use of GAB water is integral to at least $12.8 billion of production annually (Table 21). The provision of drinking water through domestic bores and town water supply has been essential to the development of GAB regions. The non-consumptive benefits of GAB water resources include groundwater dependent ecosystems.

Table 21: Values dependent on GAB water resources ($ million per year)

	NSW	Qld	SA	NT	Total
Estimated annual value of output that is dependent on GAB water resources					
Stock	1094.5	3004.4	105.1	463.7	4667.7
Mining	568.3	2980.7	2801.7	0	6350.7
CSG	7.7	1693.4	0	0	1701.1
Electricity	0	0.1	0	0	0.1
Irrigated Agriculture	30.4	27.7	0	0	58.1
Urban water	7.4	34.0	1.8	0.1	43.3
Total Value of output	1708.3	7740.3	2908.6	463.8	12821.0
Other values related to GAB water resources (noting environmental values could not be monetised)					
Tourism expenditure	100.5	311.0	150.0	163.0	724.5 (per year)
GABSI Infrastructure expenditure	118.9	148.0	13.8	0.0	280.7 (asset total)
Private Infrastructure investment					5000-15000 (asset total)

Source: Frontier Economics analysis

This report examines the direct economic activity of those sectors dependent on GAB water resources. There are also second- and third-round economic effects related to these sectors. For example, up and down-stream industries that provide inputs and process outputs of the sectors (i.e. farm supplies, mechanics, processors), and the local economy servicing the people working in all these industries. Hence, it could be argued that all of the economic activity in GAB regions is dependent on access to GAB water resources where other water sources are not available.

The GABSI and related state and territory water planning initiatives have entailed significant effort to manage the GAB water resource to reduce water extractions and maintain pressure.

These initiatives have achieved significant reductions in stock and domestic water usage of the pastoral sector, while maintaining or increasing the economic output of the sector. This has been possible because investments have targeted water savings, thereby reducing inefficient usage (uncontrolled bores and open drains).

Developments in the gas industry require additional access to GAB water, and these volumes can be substantial. In recent years, growth in water volumes extracted by CSG in Queensland has increased significantly. This finding is based on data up to July 2015, and no information was available for the following 11 months to establish if the trajectory of high growth had continued.

Appendix 1: Agricultural data issues and the alignment of GAB to ABS regions

The ABS report agricultural data down to the SA4 and NRM level. However, concordance of the boundaries of these regions with the hydrological boundaries of the GAB is poor.

Previous analysis has attributed economic activity in proportion to the overlapping area of the ABS region, however this assumes that the economic activity is evenly distributed across the ABS region. In fact, economic activity is unevenly distributed to the location of population, farms and businesses. The distribution can by more uneven when more specialised economic activities are considered — such as mining, with is highly localised at the mine site.

The most accurate measure would be to obtain customised ABS datasets which are matched to GAB regions. This is possible since ABS data is geocoded. It may be possible to obtain such data, however data will not be released if the number of relevant data point drops below the minimum that may jeopardise privacy. The use of customised boundary data would not aid in identification of output from irrigation with surface or groundwater since this much of the irrigation of land overlying the GAB uses surface water.

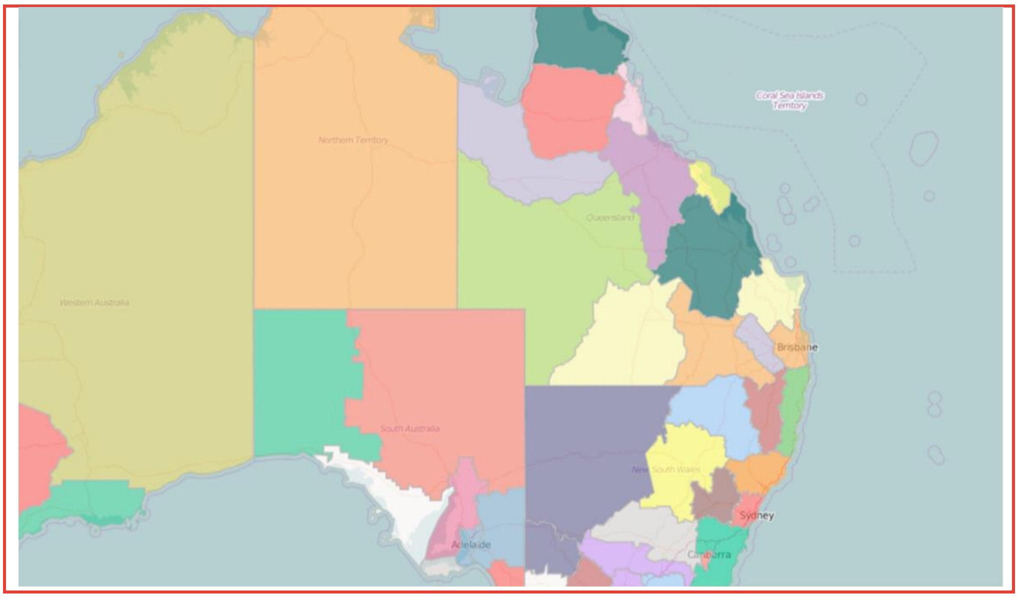
The NRM regions relevant to the GAB include:

- NSW
  - The GAB is contained within the North West, Central West and Western NRM regions. However, significant amounts of these NRM regions are also outside the area of the GAB.
  - Other NRM regions not associated with the GAB are Central Tablelands, Greater Sydney, Hunter, Murray, Northern Tablelands, Northern Coast, Riverina, South East.
- Queensland
  - The GAB underlies significant areas of the NRM regions South West Queensland, Border Rivers Maranoa–Balonne, Fitzroy, Desert Channels, Southern Gulf, Northern Gulf, and Cape York regions, as well as small areas of Condamine and Burnett Mary NRM regions.
  - Other NRM regions not associated with the GAB are Burdekin, Mackay Whitsunday, South East Queensland, Torres Strait, Wet Tropics.
- South Australia
  - South Australian Arid Lands

  - Other areas (Alinytjara Wilurara, Eyre Peninsula, Kangaroo Island, Adelaide and Mount Lofty Ranges ,South Australian Murray Darling Basin, Northern and Yorke, South East) are mostly/all outside the GAB

- NT
  - NT — the entire Northern Territory is a single NRM region. The GAB underlies only a small proportion of this region.

Figure 16: NRM regions



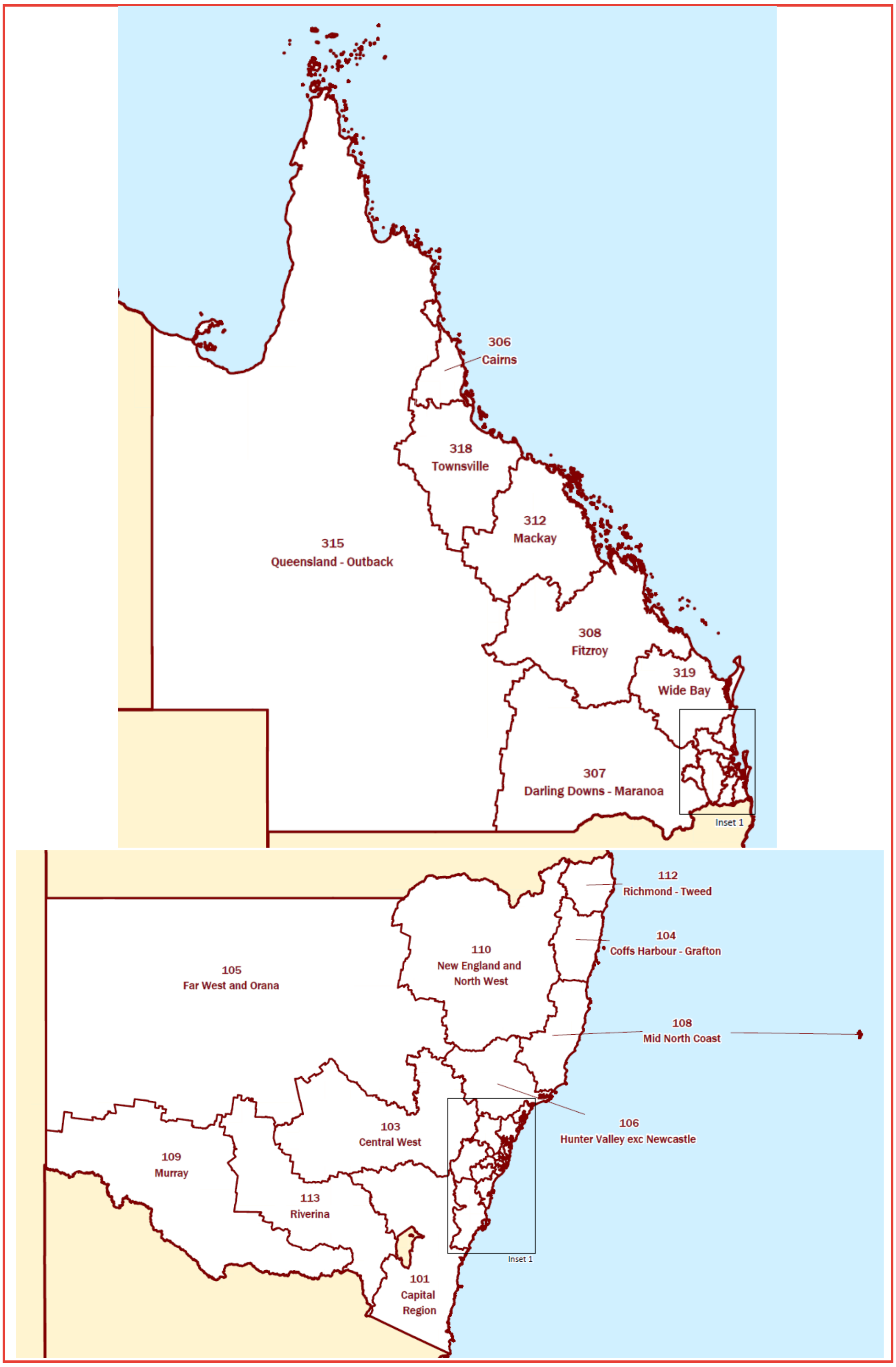
Source: http://nrmregionsaustralia.com.au/nrm-regions-map/

The ABS SA4 concordance is similarly problematic. The SA4 regions relevant to the GAB include:

- NSW
  - The GAB underlies significant areas of the SA4 regions Far West and Orana (105) and New England and North West (110).
- Queensland
  - The GAB underlies significant areas of the SA4 regions Queensland – Outback (315), Darling-Downs – Maranoa (307). It also underlies some of Fitzroy (308), and very small amounts of Townville (318), Wide Bay (319) and Mackay (312).
- South Australia
  - SA – Outback (406), although significant amounts of this region is also outside the area of the GAB.
- NT

- NT – Outback (702), although the vast majority of this region is also outside the area of the GAB.

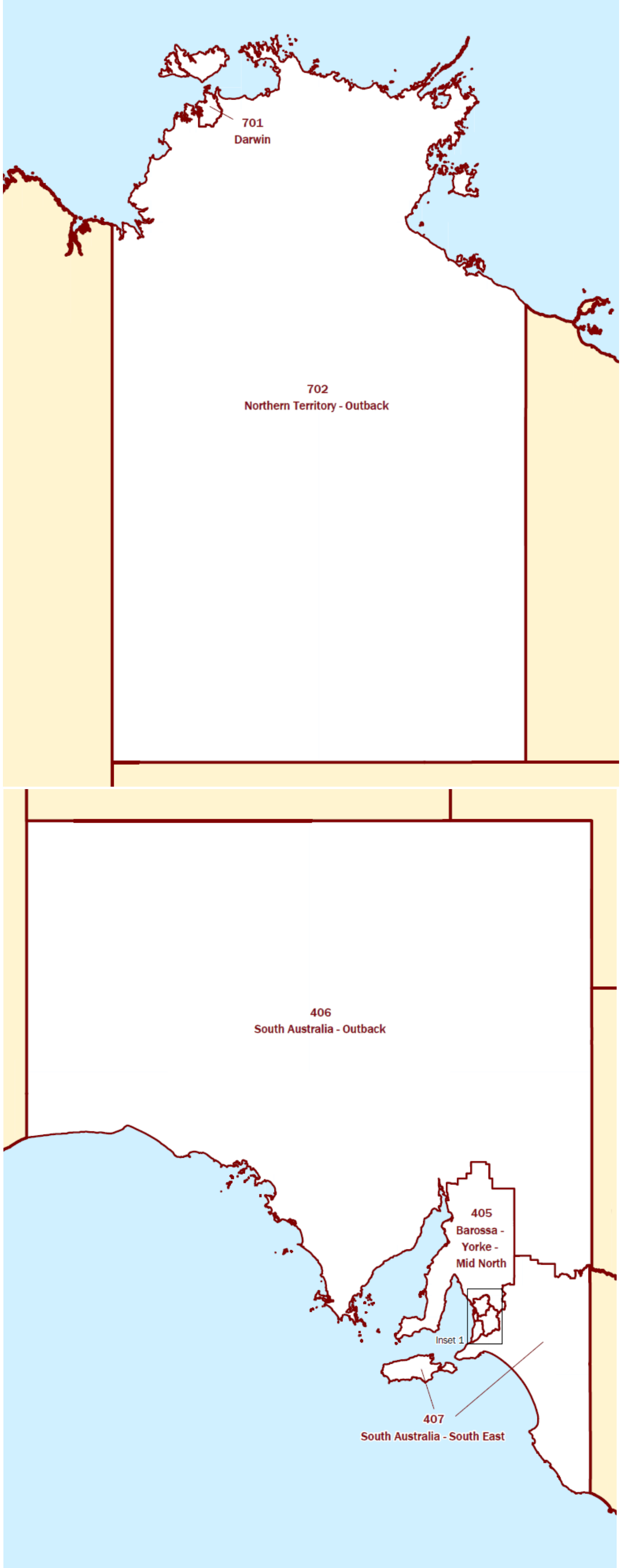
Figure 17: NSW and Queensland SA4 regions



Source: ABS 1270.0.55.001

Appendix 1: Agricultural data issues and the alignment of GAB to ABS regions

Figure 18: South Australian and Northern Territory SA4 regions



Source: ABS 1270.0.55.001

Data on livestock

For livestock industries, the value of production is broadly consistent using ABS SA4 or ABS data for NRM regions (Table 23 and Table 24).

Table 22: Livestock in GAB SA4 regions, 2013-14

GAB region (ABS SA4)	Livestock - Meat cattle - Total (no.)	Livestock - Sheep and lambs - Total (no.)	Total beef and sheep in region (no.)
Darling Downs - Maranoa	2,065,894	748,815	2,814,709
Far West and Orana	748,308	5,491,014	6,239,322
Fitzroy	2,738,238	423	2,738,661
New England and North West	1,543,908	2,958,219	4,502,127
Northern Territory - Outback	2,158,388		2,158,388
Queensland - Outback	4,643,439	1,579,728	6,223,167
South Australia - Outback	252,365	2,807,084	3,059,449
Grand Total	14,150,540	13,585,283	27,735,823

Notes: ABS 7121.0

Table 23: Gross value of livestock industries in GAB SA4 regions ($ million), 2013-14

GAB region (ABS SA4)	Gross value from livestock slaughtered and other disposals - Cattle and calves ($m)	Gross value from livestock slaughtered and other disposals - Sheep and lambs ($m)	Gross value from Wool ($m)
Qld - Darling Downs - Maranoa	630.5	18.7	25.7
NSW - Far West and Orana	203.7	138.8	167.7
Qld - Fitzroy	823.6	0.0	0.0
NSW - New England and North West	425.5	68.4	90.4
Northern Territory - Outback	463.7	0.0	0.0
Queensland - Outback	1410.0	41.7	54.2

Appendix 1: Agricultural data issues and the alignment of GAB to ABS regions

South Australia - Outback	84.3	127.3	97.2
Grand Total	4041.1	394.9	435.3

Source: ABS 7503.0

Table 24: Gross value of livestock industries in GAB NRM regions ($ million), 2013-14

GAB region (ABS NRM)	Production from meat cattle	Production from sheep and other livestock
Qld - Border Rivers Maranoa-Balonne	343.04	57.79
Qld - Cape York	25.46	0.06
NSW - Central West	236	300.49
Qld - Desert Channels	495.29	70.8
Qld - Fitzroy	1075.86	33.42
Qld - Northern Gulf	329.04	1.05
Northern Territory	929.7	46.32
South Australian Arid Lands	74.22	80.9
South West Queensland	172.9	28.63
Qld - Southern Gulf	362.38	3.54
NSW - Western	42.47	146.23
Grand Total	4086.36	769.23

Source: ABS 7503.0

Data on irrigated agriculture

The ABS estimates of gross value of crops that may be irrigated with groundwater in the GAB region is presented in Table 25. Caution is required, however, in interpreting this data because much of the production of broadacre crops and hay/silage would be expected to rely on rainfall, or where there is irrigation, from surface water resources. Similarly, it is difficult to ascertain what proportion of the fruit and nut production in reliant on GAB water resources.

Table 25: Gross value of crop industries in GAB regions ($ million), 2013-14

GAB region (ABS SA4)	Broadacre crops - Total	Fruit and nuts (excluding grapes) - Total	Hay and Silage - Total
Darling Downs - Maranoa	1,113.7	76.4	48.6
Far West and Orana	698.2	1.1	9.7
Fitzroy	277.9	19.9	12.5
New England and North West	1,433.1	11.9	37.8
Northern Territory - Outback	0.1	3.3	7.8
Queensland - Outback	18.3	60.6	5.5
South Australia - Outback	723.9	0.0	8.6
Grand Total	4,265.2	173.2	130.5

Notes: ABS 7503.0

There is also the challenge of aligning ABS data regions to focus on the GAB resource. As discussed above, neither ABS SA4 regions nor NRM regions used by the ABS concord very closely with the geographical boundaries of the GAB. When data from the NRM regions is considered (see Table 26), the data on production from broadacre crops (such as cereal for grain and seed and others) is much lower. This suggests that the high estimate for broadacre crops above (in excess of $4 billion) is not attributable to production reliant of the GAB.

Table 26: Gross value of Agricultural Production in GAB NRM regions ($ million), 2013-14

GAB region (ABS NRM)	Cereals for grain and seed (a)	Cotton (b)	Dairy production (d)	Fruit and nuts (excluding grapes)	Grapes	Hay	Nurseries, cut flowers and cultivated turf	Other broadacre crops
Border Rivers Maranoa-Balonne	208.79	475.61	1.89	48.52	7.26	20.82	20.99	44.23
Cape York	0.22			9.15		0.21		0.21
Central West	319.67	188.48	2.18	58.61	2.63	20.46	7.49	50.81
Desert Channels	0.57		0.06			1.68		0.09
Fitzroy	192.17	95.32	9.02	19.32	33.03	13.1	7.41	51.77
Northern Gulf	0.01			44.86	1.1	0.48		0.05
Northern Territory				47.94	8	16.62	0	0.04
South Australian Arid Lands	0.98					0.27		0.16
South West Queensland	0.91				2.15	0.08		
Southern Gulf						3		
Western	10.3	91.06		0.86	0.52	0.15		2.58
Grand Total	733.62	850.47	13.15	229.26	54.69	76.87	35.89	149.94

Source: ABS 7503.0

Appendix 1: Agricultural data issues and the alignment of GAB to ABS regions

Appendix 2: Water licence information

Table 27: Access Licences and water requirement, GAB NSW

Groundwater Source	Domestic & Stock Water requirement (ML/yr)	Local Water Utility Access Licences	Aquifer Access Licences (Share Units)
Eastern Recharge	2,000	0	35,006
Southern Recharge	3,000	3,058	25,908
Surat	28,100	3,318	5,527
Warrego	14,300	252	406
Central	4,900	0	39
GAB Surat Shallow	978	50	5,662
GAB Warrego Shallow	650	0	0
GAB Central Shallow	1,162	0	7
Lower Macquarie Zone 3	520	350	8,264
Lower Macquarie Zone 4	215	0	5,103
Lower Macquarie Zone 5	445	0	2,477
Total	***56,270***	***7,028***	***88,399***
Estimated total irrigation*			76,758
Estimated other uses			11,641

*Note: *The NSW Department of Primary Industries identified that irrigation would be the primary use for virtually all of the aquifer access licences in Eastern Recharge, Southern Recharge and the 3 Lower Macquarie zones. The Department suggested that there was no significant irrigation in the other water sources*

Source: NSW DPI

Table 28: Water licences and entitlement volumes, GAB Queensland

Main approved purpose	Number of licences/ allocations/ entitlements!	Estimated total GAB water use (ML/yr)
Commercial	31	617
Irrigation/ agriculture	578	32,341
Stock and domestic	5,476	121,759
Stock intensive	248	16,098
Urban (town water supply)	105	32,057
Industrial and Mining	83	30,292
P&G / CSG	(not currently licensed)	65,000
Total licences	**6,521**	
Total GAB water extracted		**298,164**

Source: DNRM provided data from Water Management Database.

Table 29: Water usage volumes, GAB South Australia

Use type	ML/yr
Bore Fed Wetland	2,025
Camp Water	948
Commercial	79
Co-Produced Water	21,900
Domestic	915
Industrial	850
Irrigation	115
Mining	24,200
Recreation	6
Stock	9,524
Town Water Supply	630
Total	61,191

Source: DEWNR provided data WILMA Records for the Far North Prescribed Water Resource Area; pers. comm. DEWNR, 6 June 2016.

Table 30: Estimated NT GAB extraction volumes

Use	Volume (ML/yr)
Stock and Domestic	3150
Environmental discharge	250
Local water supply (Apatula Community)	70

Source: Fulton 2012.

Appendix 2: Water licence information

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OPLL	Offshore Petroleum Pipeline Licence	PEL	Petroleum Exploration Licence
OPPL	Offshore Petroleum Production Licence	PEP	Petroleum Exploration Permit
OPRL	Offshore Petroleum Retention Lease	PPL	Petroleum Production Lease
PAL	Petroleum Assessment Lease	PSPAUTH	Petroleum Special Prospecting Authority

CURRENT PETROLEUM TITLE APPLICATIONS

Application	App Date	Area	Location	Applicant
PPLA 13 (1991)	01-May-2014	266 SQ KMS	About 31 km SW of NARRABRI	SANTOS NSW PTY LTD
PPLA 14 (1991)	01-May-2014	153 SQ KMS	About 20 km S of NARRABRI	SANTOS NSW PTY LTD
PPLA 15 (1991)	01-May-2014	263 SQ KMS	About 21 km WSW of NARRABRI	SANTOS NSW PTY LTD
PPLA 16 (1991)	01-May-2014	240 SQ KMS	About 32 km W of BOGGABRI	SANTOS NSW PTY LTD

CURRENT PETROLEUM TITLES

Title	Grant Date	Due Expiry	Area	Location	Holder
PAL 2 (1991)	30-Oct-2007	30-Oct-2013	265 SQ KMS	About 31 km SW of NARRABRI	SANTOS NSW PTY LTD
PEL 1 (1991)	11-Feb-1993	10-Feb-2015	72 BLOCKS	About 27 km SSE of GUNNEDAH	AUSTRALIAN COALBED METHANE PTY LIMITED
PEL 6 (1991)	09-Dec-1993	08-Dec-2011	72 BLOCKS	About 39 km SSE of MOREE	COMET RIDGE GUNNEDAH PTY LTD
PEL 12 (1991)	27-Sep-1995	26-Sep-2016	31 BLOCKS	About 53 km E of COONABARABRAN	AUSTRALIAN COALBED METHANE PTY LIMITED
PEL 238 (1955)	01-Sep-1980	02-Aug-2016	109 BLOCKS	About 36 km SW of NARRABRI	SANTOS NSW PTY LTD
PEL 285 (1955)	16-Apr-1992	04-Aug-2020	13 BLOCKS	About 19 km S of GLOUCESTER	AGL UPSTREAM INVESTMENTS PTY LIMITED
PEL 427 (1991)	21-May-1998	20-May-2016	77 BLOCKS	About 37 km WNW of MOREE	COMET RIDGE LTD
PEL 428 (1991)	15-Sep-1998	14-Sep-2012	81 BLOCKS	About 76 km WNW of NARRABRI	COMET RIDGE LTD
PEL 433 (1991)	14-Feb-2001	13-Feb-2015	79 BLOCKS	About 56 km ESE of GILGANDRA	SANTOS NSW PTY LTD
PEL 434 (1991)	14-Feb-2001	13-Feb-2016	59 BLOCKS	About 22 km SSE of COONAMBLE	SANTOS NSW PTY LTD

CURRENT PETROLEUM TITLES

Title	Grant Date	Due Expiry	Area	Location	Holder
PEL 450 (1991)	16-Jun-2006	15-Jun-2012	59 BLOCKS	About 7 km WNW of COONABARABRAN	SANTOS QNT PTY.LTD.
PEL 452 (1991)	10-Jan-2007	09-Jan-2013	19 BLOCKS	About 31 km WSW of QUIRINDI	SANTOS QNT PTY.LTD.
PEL 456 (1991)	05-Mar-2008	05-Mar-2018	69 BLOCKS		HUNTER GAS PTY LTD
PEL 456 (1991)	05-Mar-2008	05-Mar-2018	0 BLOCKS	About 50 km NW of DENMAN	HUNTER GAS PTY LTD
PEL 461 (1991)	04-Sep-2008	04-Sep-2012	2 BLOCKS	About 14 km ENE of WYEE	OUR ENERGY GROUP PTY LTD
PEL 462 (1991)	22-Oct-2008	22-Oct-2011	23 BLOCKS	About 44 km W of COONABARABRAN	SANTOS QNT PTY.LTD.
PEP 11 (1967)	24-Jun-1999	03-Jan-2012	129 BLOCKS	About 42 km E of GOSFORD	BOUNTY OIL & GAS NL
PPL 1 (1991)	02-Sep-2002	01-Sep-2023	48 SQ KMS	About 6 km SSW of CAMDEN	AGL UPSTREAM INVESTMENTS PTY LIMITED
PPL 2 (1991)	10-Oct-2002	09-Oct-2023	93 HA	About 8 km NE of PICTON	AGL UPSTREAM INVESTMENTS PTY LIMITED
PPL 3 (1991)	15-Dec-2003	14-Dec-2024	2638 HA	About 21 km W of NARRABRI	SANTOS NSW (HILLGROVE) PTY LTD
PPL 4 (1991)	06-Oct-2004	05-Oct-2025	5530 HA	About 8 km SE of CAMDEN	AGL UPSTREAM INVESTMENTS PTY LIMITED
PPL 5 (1991)	28-Feb-2007	27-Feb-2028	102 SQ KMS	About 7 km E of CAMDEN	AGL UPSTREAM INVESTMENTS PTY LIMITED
PPL 6 (1991)	29-May-2008	29-May-2029	725 HA	About 7 km NE of PICTON	AGL UPSTREAM INVESTMENTS PTY LIMITED

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The Economic Contest Between Coal Seam Gas Mining and Agriculture on Prime Farmland: It May Be Closer than We Thought

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The Economic Contest Between Coal Seam Gas Mining and Agriculture on Prime Farmland: It May Be Closer than We Thought

Abstract
There is substantial market impetus behind the expansion of coal seam gas (CSG) in Australia, driven by buoyant international demand for liquefied natural gas. The benefits of CSG development come in the first few decades, followed by a potentially long period in which the agricultural and environmental costs dominate. We identify the key drivers influencing the economic contest of CSG versus agriculture on prime farmland, and undertake a Darling Downs case study using evidence from primary and secondary sources. Despite the momentum driving CSG development, under some plausible scenarios, the long-term economic net benefits from agriculture-only exceed those from CSG-only and CSG-agriculture coexistence.

Keywords
Agriculture, coal seam gas, Darling Downs, rents, net benefits, environmental costs, external costs, co-existence

Cover Page Footnote
This article benefited from the data contributed by Cotton Australia and Friends of Felton.

Introduction

Coal seam gas (CSG) mining in Australia has grown rapidly since 1995, responding to buoyant international demand for liquefied natural gas (LNG), and encouraged by Australia's minerals exploration and extraction laws, which provide big rewards to those who find and extract these exhaustible resources. In several regions, notably the Liverpool Plains in New South Wales and the Darling Downs in Queensland, CSG comes into direct contact with agriculture. Our purpose in this article is to explore in economic terms, the relationship between CSG and agriculture on prime farmland.

In this introductory section we aim to provide a general sense of the trajectory of the industry and its impact on the Australian economy, and examine the nature and extent of its environmental impacts, insofar as they can be known and/or anticipated on the basis of reasoning and available evidence. In this context, to indicate that an impact might be present, or might be substantial, implies only that reasoning and/or evidence suggest such possibilities. At this stage in the industry's development, a definitive account of CSG's future economic and environmental impacts in Australia is impossible. Instead, our objective is to frame the potential and the uncertainties that attend this industry. In subsequent sections, our economic analysis confronts these uncertainties directly, by using best estimates of the essential quantities and relationships, and by conducting transparent sensitivity analyses for those quantities and relationships that entail the major uncertainties.

Demand, especially export demand

From a trivially small baseline in 1995, CSG is projected to provide about one-half of Australia's total gas output by the mid-2020s. Queensland is the state that led the way in terms of projects operating and committed, CSG production, and CSG reserves remaining (Figure 1). In 2010, Queensland was projected to have about 40,000 wells producing CSG by 2030 (Carlisle, 2012). Ongoing exploration may add to that number, but a modest contraction in export projections reflecting increased supply from competing exporters may have the opposite effect. Even at a relatively high rate of development, Australia is thought to have about 100 years of CSG reserves (Carlisle, 2012). Much of the output will be exported in several forms, perhaps the most prominent being LNG, with projected exports of 16 million tonnes by 2015 (Carlisle, 2012).

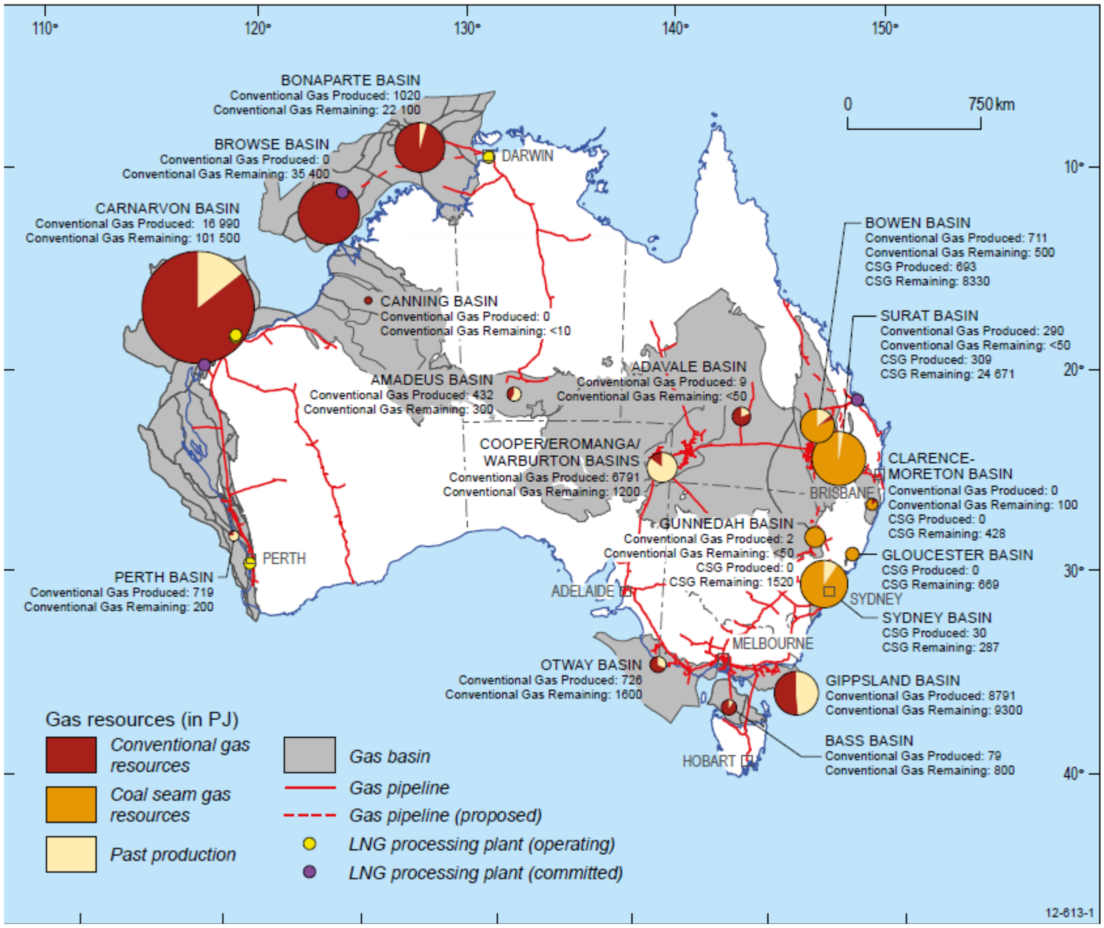

Figure 1: Location of Australia's gas resources and infrastructure

Source: Australian Gas Resources Assessment (BREE, 2012a).

Australian minerals rights and resource taxation policies encourage extraction

It is well known that minerals rights and taxation regimens influence the rates of extraction and the distribution of rewards therefrom (Schulze, 1974; Dasgupta, Heal and Stiglitz, 1980). Furthermore, minerals are exhaustible resources; once extracted they are gone, (as opposed to renewable resources such as timber, which is capable of regeneration if managed appropriately) and extraction is inherently unsustainable. However, an economy that extracts exhaustible resources may be able to sustain its standard of living so long as the economic rents (net economic value) of extracted minerals are reinvested in productive capital (Solow, 1974; Hartwick, 1977). In addition to generating revenue for government and providing an instrument for managing the rate of extraction, it can be argued that minerals taxes should generate capital reserves for reinvestment in the national interest. Thus minerals rights and taxation policies are important considerations in any discussion of CSG mining and the national interest.

In Australia, subsurface rights are separated from surface rights and retained by the Crown (MCMPR, n.d. a). Surface rights come in several forms, predominantly long-term leases from governments, and freehold title. Subsurface rights are dominant to surface rights in the sense that protections for surface rights-holders who may be impacted by subsurface extraction are limited to those provided explicitly by statute law and regulations.

Traditionally, federal, state and territory governments (the subsurface rights-holders in Australia), allocate exploration and production rights to private investors and collect a return for the public via a mix of arrangements, predominantly royalties and taxes (Hogan and McCallum, 2010). Commentators have described Australia's rights regime for minerals as effectively "finders keepers" (Bergstrom, 1984; Daintith, 2010). Exploration licenses are issued inexpensively and non-competitively, and license-holders are encouraged to explore actively. Licensed explorers who find potentially profitable deposits are awarded extraction leases, so that discoveries effectively belong to the finder. The states collect royalties, typically 10 percent *ad valorem* at the well-head for CSG (MCMPR n.d. b). Researchers have concluded that such regimes encourage extraction (Daintith, 2010; Taggart, 1998). Despite the dominant position of Australian governments as subsurface rights-holders, Hogan and McCallum (2010) argue that they have left a considerable proportion of the net benefits on the table, i.e. failed to collect a substantial portion of the economic value of the nation's mineral resources that have been depleted, a stance that is tilted toward excessively rewarding extraction.

Multinational operators and retention of resource net benefits in Australia

There are a number of obvious economic benefits from the robust expansion of CSG development, although some are more tenuous on closer examination. Projections call for 18,000 new jobs, directly and indirectly in Queensland, but the majority of those jobs will not continue beyond the construction phase (Carlisle, 2012). Billions of dollars in federal company taxes will be generated. For example, the Gladstone liquefied natural gas plant and associated gas fields will generate an estimated $40 billion in federal taxes over their productive life, according to the operators (Carlisle, 2012) and royalty returns of $850 million per annum to the Queensland government beginning in 2014 (Queensland Government, 2010). As well as providing jobs and taxes, exports benefit the balance of payments. It is a standard result in economics that, in an economy that was already close to full employment, expansion of a particular economic sector occurs mostly by reallocating resources otherwise employed elsewhere in the economy; and it is reasonable to apply that result to CSG extraction and processing. It follows that the net economic gains attributable to CSG expansion equate to the difference between employment, income and taxes collected with and without expansion of CSG operations.

The potential profits from the industry are substantial but, because the industry is predominantly foreign-owned – consensus estimates suggest at least 80 percent foreign ownership in the minerals sector – many of the profits will leave Australia (Reserve Bank of Australia, 2011). If those profits include a substantial portion of the rents from extracting exhaustible resources, as well as the rewards to extraction and processing effort, it becomes much more difficult to assure Australia's economic sustainability by reinvesting the rents from extraction of exhaustible resources as suggested by Solow (1974) and Hartwick (1977).[1] It is not easy to be precise about the portion of the resource rents lost to Australia. For example, (i) apportioning profits into rewards for effort and resource rents is not an exact science, and (ii) Australians hold a portion of the stock in these multinational firms and thereby retain some of the rents. So, in the case study reported below, we apply sensitivity analysis to the proportion of rents retained in Australia.

With much of the profit from extraction shifted off-shore, the instruments available to Australian governments for rent collection are limited to royalties, severance taxes and other direct taxes on mineral extraction, thus the magnitude of revenue collected matters crucially to the nation. While the industry will pay substantial royalties to state governments, it remains an open question whether royalties and taxes on the industry are high enough to compensate Australians for the eventual exhaustion of a valuable resource and the potentially long-lived

[1] Because our argument is directed explicitly at the issue of retention and reinvestment of the rents from extraction of exhaustible resources, certain potential counter-arguments are ineffective. For example, we do not need to debate the benefits in general of foreign investment in Australia or concern ourselves with the relatively modest foreign investment in Australian farmland, a renewable resource; and the fact that multinational minerals operators invest in Australian mines and peripherals does not invalidate our point – these investments will generate resource rents and retention of those rents will still be at issue.

damage to land and water resources that results from the extraction process (Hogan and MacCallum, 2010).

Environmental impacts of CSG

CSG mining on a large scale is a highly intrusive process entailing a considerable catalogue of potential environmental risks and land use conflicts – diminished water supply and quality, methane leakage into the atmosphere, disturbance of subsurface aquifers and geological structure, fragmentation of landscape, and disruption of agricultural production (Carlisle, 2012; Healy, 2012; Randall, 2012). The magnitudes of these threats are not merely uncertain in the statistical sense; in some cases they are driven by complex systems that work in ways we do not fully understand, even conceptually. In the face of these uncertainties and unknowns, the above-mentioned separation of surface and subsurface rights limits the protections for landowners. Their protection, like that of the general public, is limited by the willingness and capacity of governments to implement adequate regulatory regimes.

Water usage

Water is extracted from the coal seams to release the gas. At the site and project levels, farmers and settlements using artesian water worry that water pressures and levels will fall, and wells and bores will need to be drilled deeper and may dry up completely. The Queensland government has insisted on 'make good' provisions requiring operators to provide water to users facing reduced and more expensive groundwater supplies as a result of CSG activity (Swayne, 2012). 'Making good' is intended to compensate in-kind for any harm that may arise from extracting water to release the gas, but three kinds of operational difficulties are obvious: establishing the cause-and-effect relationship with CSG extraction; the increasing infeasibility of making good as the cumulative impacts of CSG extraction grow larger with the increasing number of wells across the landscape; and reconciling the long-term impacts on aquifers, which are likely to play out on a time-scale of many decades and perhaps centuries, with the much shorter time-scale of CSG extraction.

Because so much of the CSG action will be concentrated in the Great Artesian Basin (GAB), basin-level analysis is essential. According to the National Water Commission (2011), planned CSG development will, at full operation, withdraw more than 300 gigalitres of groundwater annually from the GAB, i.e. more than 60 percent of total allowable withdrawals. This 60 percent for CSG implies some combination of displacing existing uses and pushing total withdrawals well above sustainable levels. The National Water Commission estimate is thought to be relatively conservative; industry sources offer a somewhat lower projection, but the federal government's "Water Group" suggests, based on its case studies of the Surat and Bowen sub-basins, that GAB-wide withdrawals may considerably exceed the National Water Commission estimate (Department of Sustainability, Environment, Water, Population and Communities, 2010).

The theory of complex systems suggests that it is near-impossible to predict the cumulative impacts on groundwater over several centuries, because the GAB hydrological system is much too complex and the cumulative shock to the system from CSG development will be much too large to be characterised with standard groundwater models and modeling methods (Randall, 2011; Randall, 2012).

Waste water

The water co-produced in CSG extraction is briny to varying degrees and contains a range of chemicals naturally present in and around the coal seam. Depending on site conditions, toxic and radioactive substances may be present. The process of hydro-fracturing (fracking), where used, may add to the chemicals in waste water – while the industry insists it is not presently using them, BTEX (benzene and similar organic chemicals thought carcinogenic) chemicals have in the past been added to the water.[2]

Recycling the waste water represents the only conceivable way to compensate for the huge volume of groundwater to be extracted by the industry. Treatment and recycling are processes that separate the waste water into two components, a treated/recycled component that, depending on the level of treatment, is safe for certain uses, and a solid and/or liquid component (sludge) in which salt and chemical contaminants are concentrated. The simplest and cheapest treatment methods, evaporation ponds, contribute nothing to recycling, whereas reverse osmosis (basically desalination) is very expensive (GHD, 2003). In addition to the costs of recycling plants, recycling at scale requires an extensive network of pipes to bring waste water from spatially dispersed sites to a central recycling plant. If recycling waste water becomes the norm, recycled water will be produced in such volumes that the environmental impacts of returning it to the environment will raise issues: releasing recycled water into surface streams may produce sustained

[2] In Queensland, a conservative rule of thumb is that fracking can be expected to occur in about 10 percent of new wells (more in some locations), increasing to 40 percent as wells approach the end of their productive life (Queensland Government, http://www.ehp.qld.gov.au/factsheets/pdf/csg/csg8.pdf, viewed 20 March 2013).

flows where ecosystems demand episodic flows; and successfully re-injecting it into depressurised aquifers in order to recharge the groundwater may over-tax our technical capacity and our understanding of complex aquifer systems in the coalfields (National Water Commission, 2011).

The Australian Broadcasting Corporation reports cases where cognisant governments have permitted discharges into streams of co-produced water that, despite treatment, contains a variety of chemicals at concentrations above guidelines for aquatic ecosystems and in some cases at toxic levels (Carlisle, 2012).

Regardless of treatment method, by-products include salt in vast volumes and contaminated sludge in quantities and kinds that depend on local conditions and extraction and treatment practices. Until better solutions are discovered, most of the contaminated waste will be stored in brine ponds and salt pits on the gas fields (see for example the position of Santos, a major CSG operator; Santos, 2012).

The atmosphere

CSG burns much more cleanly than coal – typical carbon emissions per unit of electricity generated from burning coal range from 43 percent to 87 percent greater than from CSG-LNG (Clark et al., 2011) – and, if emissions were restricted to those from burning fuel, widespread substitution of CSG for coal would bring big reductions in Australia's carbon footprint. More comprehensive accounts suggest a more nuanced picture – when the energy used in extraction, the methane and carbon dioxide that will inevitably escape from CSG wells and gas fields, energy used and emissions in processing, etc., are counted, the greenhouse gas reduction benefit of CSG becomes more tenuous and specific to individual CSG operations (Department of Climate Change and Energy Efficiency, n.d.).

The cognisant federal agency has recognised the policy and regulatory problem posed by large quantities of methane and carbon gases likely to be released directly into the atmosphere from the gas fields and liquefaction plants (DIICCSRTE, 2013).

It has been estimated that approved CSG and LNG projects, including associated infrastructure, could generate 39 million tonnes of carbon dioxide equivalent each year (Carlisle, 2012). Modeling suggests that the CSG industry eventually could produce as much greenhouse gas as all the cars on the road in Australia (Carlisle, 2012).

Impacts on subsurface geology and hydrology

Subsurface geology and hydrology can be disturbed by CSG mining in two distinct ways: withdrawal of large quantities of water, which is endemic to CSG operations; and fracking, which fractures the coal seam and surrounding soil and rock layers to release the gas, and is used in some CSG operations. Gas extraction and the lowering of water tables create voids that may lead to land subsidence. Fracking may lead to disturbance and irreparable damage to aquifers, migration of methane and contaminants, and increased seismic activity (Healy, 2012).

Fragmentation of the landscape: ecosystems, agriculture, rural communities and society

CSG extraction is a spatially dispersed industry with a much greater footprint on landscape and environment than the fairly modest surface area devoted to well-heads would suggest. The networks of pipes for fracking water, gas, and waste water, along with the processing, waste storage, and treatment facilities, and the network of roads to tend the wells and transportation upgrades to get the CSG products to market all contribute to landscape fragmentation with negative impacts on agriculture and ecosystems.

Regarding ecosystem impacts, the Australian Broadcasting Corporation reports instances in which the federal government has granted major CSG operators permission to clear land containing species and ecosystems protected under federal threatened species legislation (Carlisle, 2012).

Landscape fragmentation associated with CSG development reduces agricultural productivity and increases farmers' costs. Despite the major operators' commitment to good neighbor policies, the dominance of subsurface rights disadvantages surface rights-holders by weakening their bargaining position. In regions with active or potential CSG operations, organisations have arisen to express concerns about the potential impacts of a weakened agriculture on rural and community ways of life (Lock the Gate Alliance, n.d.). Conflicts between agriculture and CSG strike with particular force in some of Australia's most productive farming areas, including the Darling Downs and the Liverpool Plains, where the national interest in prime farmland (quite scarce in Australia) comes into play, in addition to local concerns.

Some would argue that there is a national interest in preserving the very best farmland for agriculture, even if the economic argument for CSG development is strong (Dart, 2011). However, the possibility might be considered that, for the best land, the economic advantage of CSG is not so compelling. CSG offers the prospect of several decades of lucrative extraction but it is reasonable to expect environmental costs, some of them potentially substantial in cumulative effect, to continue perhaps for long after the gas is gone. Furthermore, the economic benefits of CSG are not assured: while current projections are for high and stable commodities prices for the life of the planned projects, the extractive industries historically have experienced cycles of boom and bust (Rosenau-Tornow, Buchholz, Riemann, and Wagner, 2009; Jacks, 2013). At best, CSG is a transition energy technology and we do not know how long its window of opportunity will be.

The remainder of this article frames the issues in the contest between CSG and agriculture on prime farmland, assembles and interprets economic evidence from primary and secondary sources, identifies the key economic drivers of the CSG versus agriculture decision and, for a specific case study region in the Darling Downs region of Queensland, shows how the possible future values of the various drivers influence the benefits and costs of CSG mining on agricultural land.

Economic assessment of CSG versus agriculture

A benefit-cost analysis (BCA) framework was used to assess the absolute and relative economic net benefits of CSG and agriculture. This involved computing and monetising the relevant benefits and costs to calculate the net benefits generated by either CSG mining, agriculture, or both on the same piece of land. Where the values of the variables are unknown or known but subject to uncertainty, sensitivity analysis has been conducted to identify the effects of a plausible range of values for these variables on the net benefits.

Scope and data description

We conducted a case study of Arrow Energy's Surat Gas Project, which covers an area of approximately 8600 km^2 in the Darling Downs, a region renowned for its agricultural productivity (Figure 2). Sixty percent of this area is considered productive agricultural land (Coffey Environments, 2012). Unpublished agricultural gross margin data was provided by local farmers in the Darling Downs. To establish that the reported productivity is indeed consistent with prime agricultural land, the gross margin values have been compared with other local farmers' gross margins and the publicly available farm budgets for a comparable region in New South Wales (NSW Department of Primary Industries, 2011). CSG production volume and prices, while difficult to predict, are sourced from publicly available information and projections. Further details of data and assumptions are provided in Table 1.

The stream of future benefits and costs is expressed first in annual net benefit terms, and ultimately in net present value in 2012 dollars. The time horizons that are common in BCA, typically in the range of 30 to 50 years, would be unsuitable for the present study because CSG benefits all accrue in the first several decades while the environmental costs and degradation of agriculture continue for long after the CSG has been depleted. While one could argue for even longer time horizons, we settled on 100 years.

Figure 2: Map of Arrow Energy's Surat Gas project in Darling Downs region
Source: Surat Gas Project Environmental Impact Statement, Coffey Environments (2012)

Net benefits calculation

The conceptual framework for net benefits calculation for various activities is presented here, and details of the values used in the calculations are explained further in Table 1. Agricultural net benefits are calculated as rents using the asset pricing model. The returns from the land or asset are capitalised into land rents using a budgeting approach (Randall and Castle, 1985).

Single period rent per hectare is calculated by capitalising the profit from producing commodities. Profit π_x is the difference between the total revenue from producing a vector of commodities x_i and its total costs in producing commodities x_i described by the cost function $C(x_i)$ that takes into account all direct costs involved in production, and agricultural land rent p_a(equation 1).

$$\pi_x = p_{xi}x_i - C(x_i) - p_a \quad (1)$$

At equilibrium, profits are driven to zero. Land rent is equal to the total revenue deducting total costs of the agricultural commodities (equation 2):

$$p_a = p_{xi}x_i - C(x_i) \quad (2)$$

Now the land rent per hectare is scaled-up to rents accruing to the total area of land by factor *h,* the number of hectare (equation 3):

$$P_A = hp_a \quad (3)$$

Assuming agricultural rent grows at annual rate of g where $0 < g < 1$, agricultural land rent at time $t + 1$ is given by equation (4):

$$P_A(t + 1) = P_A(t)(1 + g) \quad (4)$$

The net present value, NPV, of agricultural production is the sum of discounted annual rents calculated from period 0 to the end period T, where T is 100 years (equation 5):

$$NPV_A = \sum_{t=0}^{T} \frac{P_A(t)}{(1+r)^t} \quad (5)$$

The impact of CSG extraction and processing on agricultural rent, I_t , at time t can be written as the product of rent P_A and B_t, where B_t is the percentage of reduction on agricultural production if CSG mining is present (equation 6).

$$I_t = P_A(t)B_t \quad (6)$$

A budgeting approach similar to that used for calculating agricultural rents was applied for calculating CSG rents per hectare at time t. Where the net profits from domestic gas Z_1 and LNG Z_2 are the revenue from gas and LNG minus the costs of production $C(Z_1 + Z_Z)$, the environmental costs $C(E_t)$ and the CSG rents generated per hectare p_s(equation 7).

$$\pi_s = p_{z1}Z_1 + p_{z2}Z_2 - C(Z_1 + Z_Z) - C(E_t) - p_s \quad (7)$$

At equilibrium, profits are driven to zero, the CSG rents per hectare at time t are (equation 8):

$$p_s = p_{z1}Z_1 + p_{z2}Z_2 - C(Z_1 + Z_Z) - C(E_t) \quad (8)$$

To convert rents of CSG generated per hectare to rents for total area of land, rents per hectare can be scaled by factor w (equation 9):

$$P_S = wp_s \quad (9)$$

While agriculture-only and CSG-only are plausible options, so is the coexistence of CSG mining with agriculture. In the coexistence case, the rents include the net benefits of CSG rents P_S and the agricultural rents P_A diminished by the negative impacts of CSG operations I_t(equation 10).

$$P_C = P_S + (P_A - I_t) \quad (10)$$

The NPV of the coexistence case is the sum of discounted annual rents from period 1 to period T of coexistence rents, where T is 100 years (equation 11).

$$NPV_C = \sum_{t=0}^{T} \frac{P_C(t)}{(1+r)^t} \quad (11)$$

If CSG mining results in complete elimination of agricultural rents then the rents are limited to CSG rents. Complete lost agricultural rents as a result of CSG mining is represented by the impacts I_t where (equation 12):

$$I_t = P_A(t) \quad (12)$$

Substituting (12) into (10), the calculation for coexistence, we obtain CSG rents only as P_C is equal to P_S(equation 13):

$$P_C = P_S + (P_A - P_A) = P_S \quad (13)$$

The NPV for CSG rents is computed by equation (14):

$$NPV_S = \sum_{t=0}^{T} \frac{P_S(t)}{(1+r)^t} \quad (14)$$

The exact impact of CSG on agricultural productivity is specific to the location, farming practices, extraction methods, and safeguards implemented; therefore, the level of diminished agricultural productivity has been tested in sensitivity analysis.

The best estimates of key variables underlying the benefit and cost calculations are based on the assumptions and data sources summarised in Table 1. Variables subject to high levels of uncertainty and/or contention, such as the discount rate, environmental costs, diminution of agriculture in the coexistence case, and gas prices, are further discussed below in the context of sensitivity analysis.

Table 1: Key variables, assumptions and explanations, and data sources

Variables	Assumptions and explanations	Data sources
x_i	Agricultural commodity $i = 1,2,3, \dots n$ These commodities are mostly grain and cotton crops	(Primary data from local farms)
p_{xi}	Price of agricultural commodity i	
π_x	Profits of agricultural commodities	
$C(x_i)$	Cost function producing agricultural commodity i, inclusive of labour, capital and all input costs required in the production	
p_a	Agricultural rents accruing to a hectare of land	
h	Scaling factor from one hectare to total area of land. The total area of agriculture land is 5160 km^2,Arrow Energy EIS scope description estimated 60 percent of the total project area of 8600 km^2 is productive cropland	(Coffey Environments, 2012)
P_A	Agricultural rents accrued to total area of land	
g	Growth factor of agricultural value, $0 < g < 1$, $g = 0.013$ The real value growth rate estimated by ABARES from 2012 to 2050	(ABARES, 2012)
t	Time in years, $t = 0,1 \dots .100$	
T	The end time period, in this paper, T is 40 and 100 years	
NPV_A	Net present value of a stream of agricultural rents	
I_t	The reduced net benefits of agriculture due to CSG extraction. This is based on the mining firm's payments under access agreements and is used as a lower bound in the sensitivity analysis	Anecdotal evidence
B_t	Percentage of reduction on agricultural rents by CSG	
π_s	Profits of CSG production on a hectare of land	
Z_i	Quantity of gas in produced; $i = 1$(domestic gas), $i = 2$ (LNG, using Arrow Energy EIS chapter 5 projected production description)	(Coffey Environments, 2012)
p_{zi}	Gas prices	(BREE, 2011;

	$i = 1$ Domestic gas: table 6.4 Gas Market Report, $i = 2$ LNG; extrapolated from figure E Australian Energy Projections to 2034-35	BREE, 2012b)
$C(Z_i)$	Cost of producing 1 petajoule of domestic and LNG, inclusive of exploration, development and general gas production costs	(Core Energy Group, 2012)
$C(E_t)$	Environmental costs and decommissioning costs, which are approximated by the offshore gas decommissioning costs, onshore data are unavailable, offshore decommissioning costs are assumed to be higher	(Department of Resources Energy and Tourism, 2008)
K	The proportion of environmental costs that CSG firms have internalised; assuming the treatment of by-product water by CSG firms. Cost of treating for the by-product water produced using reverse osmosis costs are capital and operational costs	(GHD, 2003)
p_s	CSG rents accrued to a hectare of land	
w	The weighting factor of the gas production volume that would occur on the total area of land	(Coffey Environments, 2012)
P_S	CSG rents accrued to the total area of land	
P_C	Coexistence rents accrued to the total area of land	
NPV_C	Net present value of a stream of coexistence rents	
P_R	CSG rents accrued to Australians, inclusive of royalties and environmental costs	
P_{CR}	Coexistence rents accrued to Australians, inclusive of royalties, environmental costs of CSG and the leftover agricultural rents	
NPV_{CR}	Net present value of a stream of coexistence rents accrued to Australians	
NPV_S	Net present value of a stream of CSG rents or the case in which complete elimination of agriculture occurs	

Time paths of net benefits

While the obvious benefits of CSG development come in the first few decades, there follows a potentially long period of agricultural and environmental degradation. As shown in Figure 3, external costs continue long after the end of gas production in year 40. CSG rents and coexistence rents incur high capital costs in the beginning but realise the benefits of extraction from year 4 to year 40 from the demand for LNG. The environmental costs, however, continue after mining is completed but gradually decrease over time based on the assumptions that decommissioning of CSG infrastructure and recovery of agriculture occur. Agricultural rents grow steadily, driven by technological change and rising demand for food crops, at an annual growth rate estimated by ABARES (2012).

The most important impact of CSG on agriculture is diminished agricultural productivity, in the case of agriculture and CSG coexistence. After the CSG has been depleted, the coexistence net benefits will always stay below the agriculture line as diminished agricultural production continues long into the future. This indicates the possibility that the net benefits gap between CSG mining and agriculture-only may be closed given enough time.

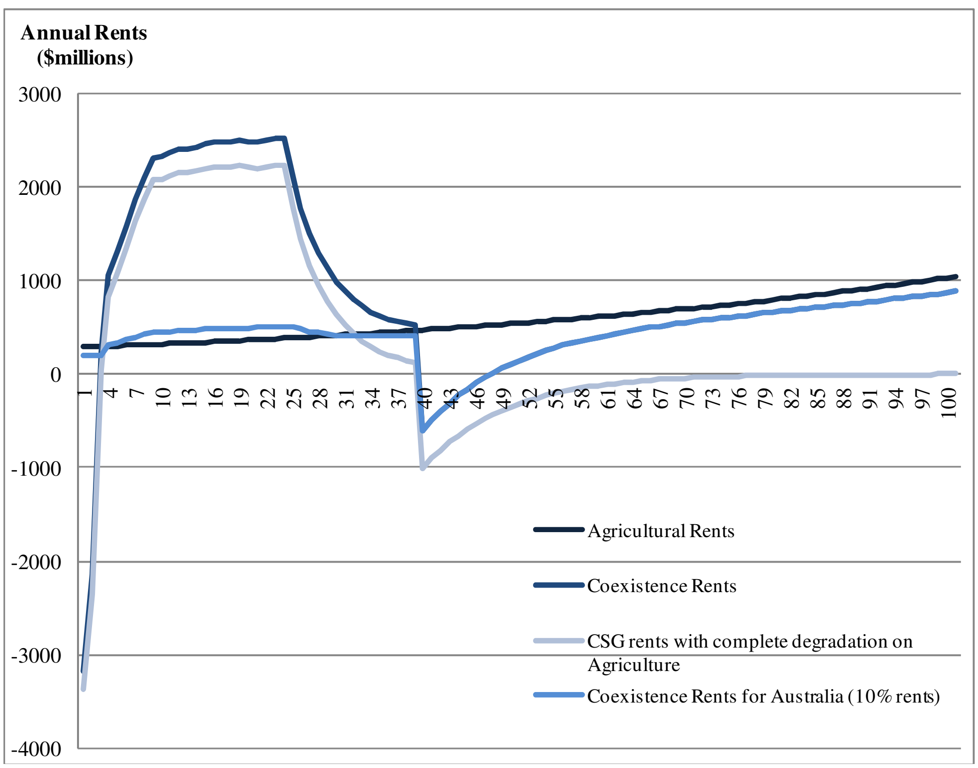

Figure 3: Time path of annual rents

Benefits retained in Australia

From a national perspective it is reasonable to evaluate CSG in terms not of its net value to the mostly international operators, but in terms of the net value retained in Australia. The most obvious economic benefits retained in Australia are the royalties of 10 percent *ad valorem* collected by state governments on petroleum and natural gas (Montoya, 2012), and we have chosen 10 percent to serve as our worst-case rent-capture scenario from an Australian perspective. From this perspective, the benefits accruing to Australians include the 10 percent estimated CSG rents, in the form of *ad valorem* royalties to state government, the proportion of environmental costs internalised by CSG companies k, and the untreated proportion $(1 - k)$ of environmental damages caused by CSG (equation 15):

$$P_R = 0.1\left(p_{z1}Z_1 + p_{z2}Z_2 - C(Z_1 + Z_2) - kC(E_t)\right) - (1 - k)C(E_t) \qquad (15)$$

Coexistence rents P_{CR} would then be the royalties from CSG production P_R plus the leftover agricultural rents (equation 16):

$$P_{CR} = P_R + (P_A - I_t) \qquad (16)$$

Similarly, the NPV of the coexistence case, which only includes CSG rents that accrued to Australians is (equation 17):

$$NPV_{CR} = \sum_{t=0}^{T} \frac{P_{CR}(t)}{(1+r)^t} \qquad (17)$$

Figure 3 shows the case of coexistence when only 10 percent of CSG net benefits are retained in Australia. The coexistence net benefits are above agriculture-only net benefits during the extraction phase and below the agriculture-only net benefits post-CSG.

The question of whether enough royalties and taxes have been collected in Australia to compensate for the depletion of exhaustible resources and the damages caused by CSG extraction is still in debate. Since the actual and desired levels of royalties and taxes on CSG remain contentious, different levels of CSG net benefits collected in Australia have been tested using sensitivity analysis to examine the economic contest of CSG versus agriculture from a national perspective.

Post-CSG project life external costs

Uncertainty applies to almost every aspect in this long-term analysis, but especially to environmental damages and treatment and remediation costs. Here we consider the different trajectories that external costs may take and the degree to which external costs affect net benefits over the time horizon of 100 years. In Figure 4, the possible paths of external costs can be traced from point A when CSG extraction ends. The path of declining external costs and rising net benefits assumes decommissioning of the CSG infrastructure is conscientious and effective, allowing a rapid recovery of land quality. The path that plateaus from point A assumes the ongoing uniform impacts of external costs on the environment and agricultural activities if decommissioning is not so effective. Another possibility is the continuous increase in costs from point A in the case of serious irreversible depletion of aquifers and other irreversible environmental impacts discussed earlier. In the complete absence of decommissioning, external costs would accelerate from point B, causing rents to decline even more steeply. At point A the annual rents are roughly negative-$0.5 billion and can be lower or higher depending on the severity of the CSG-induced environmental impacts.

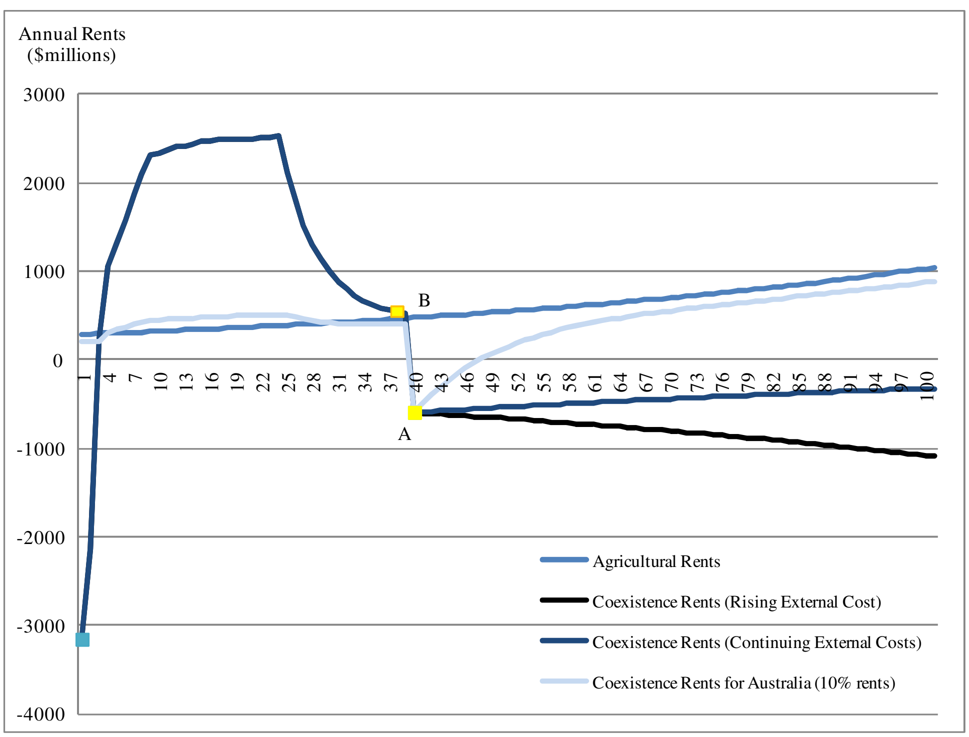

Figure 4: External costs after year 40

Although the future environmental costs of CSG are unclear, Figure 4 shows several possibilities for the course of coexistence net benefits under different external costs scenarios. The scenarios are calculated using percentage values of the impacts on agriculture from year 40, shown earlier (equation 6). If the continuing impacts of CSG are greater, recovery of agriculture is diminished and therefore the net benefits are lower. One implication of the uncertainty illustrated in Figure 4 is that a serious case can be made for requiring CSG operators to post environmental bonds consistent with the worst-case damage scenarios (Gerard 2000).

Net present value and the discount rate

To this point, net benefits have been calculated annually, and Figures 3 and 4 show the time-paths of net benefits under various scenarios. A common procedure for comparing alternatives with differently shaped time-paths, such as we see here, is to calculate net present values (equations 5, 11, 14, and 17). This generates a single net present value (NPV) number for each of the different scenarios, such as agriculture-only, CSG-only and various coexistence cases. The choice of discount rate affects the NPV of the various scenarios in absolute and also relative terms given the inter-temporal disjunction: the flow of CSG benefits is exhausted in a few decades while the environmental costs continue; and the benefits of agriculture-only are projected to keep growing indefinitely. In absolute terms, a higher discount rate reduces all NPVs; in relative terms, a higher discount rate puts more weight on near-future consequences and less on the longer term, thus favouring CSG over agriculture. Given the contentious nature of the choice of discount rate, we conduct a sensitivity analysis over a range of discount rates that have been used or advocated in the literature.

Sensitivity analysis

Uncertainty and gross ignorance about major categories of benefits and costs cast doubt on any point estimate of NPV. Instead, we report a series of sensitivity analyses showing how NPV is influenced by the values that key uncertain variables – the future demand for agricultural products and CSG, the external costs of CSG, the discount rate, and the level of agricultural degradation caused by CSG mining – might plausibly take. These variables can be categorised into two groups, variables that favour agriculture-only and the ones that favour CSG-only and/or coexistence. The variables that have a positive relationship with agriculture-only net benefits include the growth rate in agricultural value, the proportional negative impact of CSG mining on agriculture, and the external costs of CSG mining. The variable that favours CSG mining is gas prices – as gas prices increase, the economic choice shifts towards CSG. The values of the baseline (best estimates given current knowledge) and lower and upper bound parameter values are shown in Table 2. Where there is no explicit information on upper or lower bound values, a multiple of the baseline value is used to create the upper and lower bound.

Combining variables to develop scenarios

Given there are five variables tested in the sensitivity analysis and four cases for NPV calculation, it would be impractical to present all NPV possibilities. Instead, the results of sensitivity analysis are presented in terms of 4 cases and 7 scenarios (Figure 5). The 4 cases are: agriculture-only; CSG-only or coexistence where all CSG rents count; the lower-bound case for Australia where only 10 percent of CSG rents are retained; and an intermediate case where 30 percent of CSG rents are retained.

The 7 scenarios include 2 where agriculture and CSG are mutually exclusive and 5 where agriculture may coexist with CSG suffering some negative impacts in the process.

The first two scenarios (Figure 5, Table 3) assume that CSG and agriculture are mutually exclusive. In the first, agricultural NPV is set at the "favourable for agriculture" level. Of all the scenarios we have considered, this one is most compatible with the argument that agriculture should have primacy, especially on prime farmland. In the particular case where Australia keeps only 10 percent of the rents from CSG, the NPV of CSG extraction is negative. The second "mutually exclusive" scenario, shows that CSG may dominate in terms of NPV even when it eliminates agriculture if baseline values prevail and all of the resource rents count as benefits to Australia.

The 5 coexistence scenarios include the baseline scenario, "favourable to agriculture" and "favourable to CSG" scenarios, and two scenarios that vary gas prices but fix the values of all other variables. A scenario of low gas prices and all other factors contributing to agriculture set at the lower bound is represented in the scenario entitled 'all parameters low'. The second of these scenarios, 'all parameters high' sets high gas prices but fixes all other factors contributing to agriculture at the upper bound. These scenarios provide examples of situations that could be present between the extreme cases and demonstrate the extent to which the effects of gas prices are offset by other variables.

Table 2: Values of variables in sensitivity analysis

Parameters	**Lower bound**	**Baseline**	**Upper bound**
Discount rate	1.4%[a]	2.8% [b]	5.0% [c]
Agricultural value growth rate	0.5%	1.3% [d]	2.6%
CSG's level of degradation on agriculture	6% during construction years[e] 4.5% until the end of well life 3.5% thereafter	30% during construction years 25% until the end of well life 15% thereafter	60% during construction years 45% until the end of well life 35% thereafter
External costs of CSG [f]	$555/GL capital cost (first 2 years) $0.347/GL (operational cost) 43% lower than best estimate	$972/GL capital cost (first 2 years) $0.903/GL (operational cost) Starting from 2049, $1000 million and declines gradually	$1389/GL capital cost (first 2 years) $2.084/GL (operational cost) 43% higher than best estimate
Gas prices	30% lower than the best estimate	Domestic and LNG gas prices projected[g]	30% higher than the best estimate

[a] Discount rate in the Stern Review of Economics of Climate Change (Stern, 2006). Stern argues that this rate is appropriate for long-time-horizon problems, and it is used here as a lower bound.
[b] Australia's long-term economic growth rate until 2034-35 calculated by BREE (2011) in table 4.
[c] Upper value of retail and investment rate of return in private sector (Reserve Bank of Australia, 2012).
[d] Agricultural value growth rate modelled by ABARES (2012).
[e] Based on CSG operator payments to Darling Downs farmers under access agreements (anecdotal evidence).
[f] Reverse osmosis costs per gigalitre of water produced (GHD, 2003); decommissioning costs approximated by offshore gas facilities, adjusted downward (Department of Resources Energy and Tourism, 2008).
[g] Refer to table 6.4 for projected domestic price (BREE, 2012b) and figure E for projected LNG index (BREE, 2011) from 2014-2035.

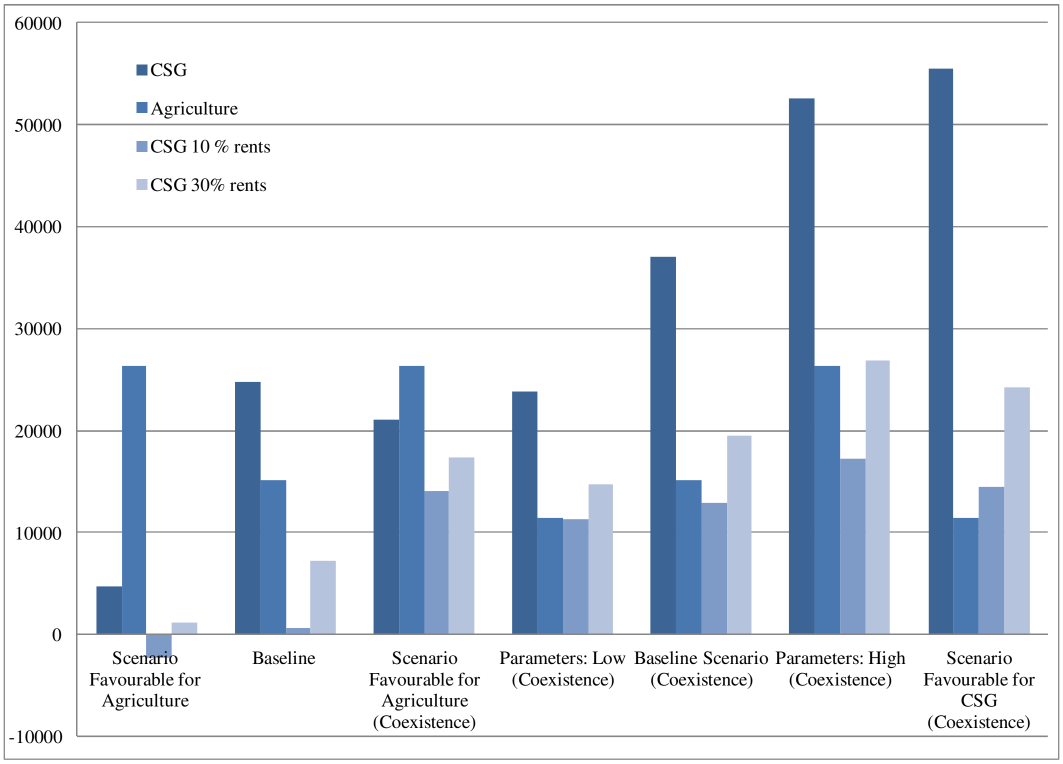

Figure 5: NPVs of 7 scenarios (in $millions)

Table 3: NPVs of 7 scenarios and 4 cases (in $millions)

Agriculture and CSG are mutually exclusive	**CSG only**	**Agriculture**	**CSG 10% rents**	**CSG 30% rents**
Scenario favourable for agriculture	4767.47	26288.76	-2235.14	1116.32
Baseline scenario	24723.07	15182.58	572.04	7186.69
Agriculture and CSG coexistence	**Coexistence**	**Agriculture**	**Coexistence rents 10%**	**Coexistence rents 30%**
Scenario favourable for agriculture	21054.21	26288.76	14051.61	17403.07
Parameters: low	23887.68	11500.23	11257.04	14765.41
Baseline scenario	37002.37	15182.58	12851.33	19465.99
Parameters: high	52619.16	26288.76	17208.10	26872.55
Scenario favourable for CSG	55452.63	11500.23	14413.53	24234.89

In NPV terms, agriculture will prevail over coexistence under favourable conditions for agriculture (Figure 5), even if all CSG rents are captured in Australia. If Australians retain only 10 percent of the CSG net benefits, then in most cases except in the scenario favourable for CSG, agriculture will generate greater NPV than CSG mining. This result has important implications for policy makers; if net benefits accruing to Australians are confined to 10 percent of the CSG rents and if the national interest in economic outcomes extends to 100 years and beyond, then the CSG operations on prime farmland are likely to be a losing proposition.

If 30 percent of rents from CSG are retained in Australia, the coexistence case may prove to be economically efficient in most cases except when parameters are favourable for agriculture, and/or agriculture is fully displaced by CSG. This highlights the national interest in capturing more of the CSG rents – otherwise Australia will be depleting its CSG resources, content to be paid little more than the value of its work of extraction and processing. Among others, Sinner and Scherzer (2007) and Garnaut (2010) have discussed the economic considerations in designing a minerals resource rent tax that could be implemented to meet the economic sustainability condition suggested by Solow (1974) and Hartwick (1977).

Given the substantial external costs incurred after the project life of CSG mining and the persistent growth of agricultural value into the distant future, we have identified several sets of conditions under which agriculture-only prevails. These results demonstrate that markets, which seem to be offering unambiguous endorsement of CSG development in Australia, provide a seriously incomplete guide to CSG benefits and costs and, especially, those CSG benefits and costs that accrue to Australia.

The influence of parameters on NPV

A final set of analyses casts additional light upon the parameters that have significant impacts on NPV. Elasticities can be derived that allow us to compare the rate of change of NPV with respect to changes in the parameter values. The elasticity of a variable can be computed as the percentage change of NPV divided by the percentage change in the parameter values with parameters represented by X (Pannell, 1997).

$$\varepsilon = \%\Delta NPV / \%\Delta X \tag{18}$$

Table 4: Elasticity (in absolute value) of the variables, 100 years time-frame

Elasticity of the variable	Elasticity: Coexistence	Elasticity: Agriculture
Upper range discount rate	0.447	0.958
Lower range discount rate	0.539	1.037
High agricultural growth rate	0.253	0.732
Low agricultural growth rate	0.135	0.394
High level of impact on agriculture	0.154	0.000
Low level of impact on agriculture	0.030	0.000
Complete elimination of agriculture	0.111	0.000
High external costs of CSG	0.262	0.000
Low external costs of CSG	0.244	0.000
High gas prices	1.422	0.000
Low gas prices	1.422	0.000

The price of gas is the most influential variable to coexistence NPV, followed by the discount rate, and then external costs (Table 4). The agricultural growth rate and the discount rate are most influential on the agricultural NPV since agricultural value continues to grow after 40 years, by which time CSG has only negative impacts.

Sensitivity testing: summary of results

Given our data and analysis, if the net benefits retained in Australia are limited to 10 percent of the total economic rents, CSG mining will create relatively little net benefits compared with existing agriculture in most circumstances. As more net benefits of resource extraction are collected, as seen in the 30 percent and 100 percent cases, CSG mining on agricultural land becomes economically desirable compared with agriculture unless conditions are favourable for agriculture. Nevertheless, the external costs of CSG projects are speculative and difficult to quantify. If the external costs were to remain significantly large for many years into the future, coexistence could be defeated by agriculture in all circumstances. If future gas prices are low enough and all other factors are close to the best estimates, coexistence may not make a convincing economic case. On the other hand if agriculture disappoints the optimistic expectations, the CSG net benefits may dominate given moderate external costs and gas prices.

Conclusions

The economic contest between CSG and agriculture on prime farmland presents a textbook inter-temporal dilemma: CSG extraction creates negative impacts on agriculture and the environment long after the gas and associated economic activity are gone, whereas foregoing CSG development would require us to sacrifice substantial economic benefits over the next several decades.

We have framed the economic contest in net present value terms, identified the key economic drivers, assembled evidence from primary and secondary sources for a case-study region in the Darling Downs, and examined a variety of scenarios that are considered plausible given the gross ignorance that persists concerning some potential impacts and the uncertainty about most of them. Depending on assumptions about the magnitudes of variables – especially future gas prices, external costs of CSG, and the growth rate of agricultural value – the economic contest could be resolved in favour of CSG or agriculture. Two key findings can be highlighted.

First, the present-valued economic rents from CSG are insufficient to defeat agriculture, or to justify the CSG-and-agriculture coexistence solution, in the scenario favourable for agriculture where variables favouring agriculture are set at high levels and the future price of LNG is low.

Second, the Australian national interest depends on how much of the CSG rents (i.e. the economic value of resources depleted) are retained in the country. After all, it is well known that an exhaustible-resource-extracting country can achieve economic sustainability only if all of the rents from resources depleted are reinvested in productive capital (Solow, 1974; Hartwick, 1977). The total rent from CSG comes in two parts: rents earned by those who organise and accomplish the work of finding, extracting, processing and marketing the gas; and rents that reflect the scarcity value of the resource itself – it is that second component of the rents that concerned Solow and Hartwick. The 10 percent *ad valorem* royalties collected by Australian state governments represent an attempt to capture the scarcity rent, but the 10 percent figure is attributable more to custom than to market-generated information or careful analysis. Hogan and McCallum (2010) suggest that Australia is leaving substantial minerals rents on the table. The CSG jobs for Australians and the company taxes collected by the Commonwealth government are real and important, but they represent mostly some fraction of the rents from organising and accomplishing the work – they are not connected directly to the scarcity rent from depleted resources. So it is clear that the CSG rents calculated in this study overstate the rents actually captured by Australia.

In our baseline scenario, a middle-of-the-road scenario that might be considered most likely from today's perspective, agriculture-only defeats coexistence if only 10 percent of the CSG rents are captured in Australia, while coexistence comes out ahead if 30 percent of rents are captured.

Our results show that the economic contest between CSG and agriculture is closer than we may have thought: under some plausible scenarios, the long-term economic net benefits from agriculture-only exceed those from CSG-only and CSG-agriculture coexistence cases.

Finally, we should emphasise the extent of the environmental unknowns. The impacts of cumulative water withdrawals from the Great Artesian Basin and the economic and environmental costs of treating these huge volumes and disposing of the sludge, and the ultimate costs of disturbing aquifers and subsurface geo-systems are truly unknown and perhaps unknowable *ex ante*, suggesting that our upper-bound environmental cost estimates are "guesstimates" that could be exceeded in the worst cases.

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