



Independent Expert Scientific Committee
on Coal Seam Gas and Large Coal Mining Development



Australian Government

Department of the Environment

Reference list for water-related coal seam gas and coal mining research

Report 4: Australia, Canada, China, India, Russia, the United Kingdom and the United States of America, October 2013 to September 2014

This report is the fourth in a series of reference lists commissioned by the Department of the Environment on the advice of the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC). It was prepared by the Water Research Laboratory of the School of Civil and Environmental Engineering at UNSW Australia.

June 2015

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Addendum

Changes to Government departments may have occurred since the finalisation of this report by the authors. Up-to-date information should be sourced from the relevant department.

On 1 January 2013, the Queensland Water Commission (QWC) ceased operations. The Office of Groundwater Impact Assessment (OGIA) retains the same powers as the former QWC under Chapter 3 of the *Water Act 2000* (Qld).

On 1 January 2014, New South Wales Catchment Management Authorities (CMA) joined with the Livestock Health and Pest Authorities and Department of Primary Industries agriculture extension to form Local Land Services. The Namoi Catchment Management Authority (Namoi CMA) has been absorbed into the North West Local Land Services.

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Summary

This reference list report is the fourth in a series of reports commissioned by the Department of the Environment on the advice of the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC). It includes summaries of research projects relating to the impacts of coal seam gas and coal mining developments on water resources, currently being undertaken or completed, in Australia, Canada, China, India, Russia, the United Kingdom, and the United States of America during the period October 2013 to September 2014.

The objective of the reference list series is to provide a resource for the Department of the Environment's Office of Water Science (OWS) and the IESC to fulfil their respective functions in delivering the bioregional assessments, identifying research priorities and delivering research products, and providing advice on coal seam gas and coal development proposals to Australian Government regulators.

The reference list will also provide others, including government regulators and industry, with project and citation information to improve their understanding of the water-related impacts of coal seam gas and coal mining.

Main findings

- A total of 187 projects relating to the impacts of coal seam gas and coal mining on water resources were identified from Australia, Canada, China, India, Russia, the United Kingdom, and the United States of America during the period October 2013 to September 2014.
- Co-produced/mine water has been the dominant research theme in over 40% of projects for each of the previous reporting periods, i.e. January 2000 to June 2012 (Report 1 and Report 2), July 2012 to September 2013 (Report 3).
- During this report's 2013 to 2014 reporting period, however, many of the other research themes have increased in importance, for example:
 - aquifer connectivity (identified as a theme of 27% of projects during this reporting period, up from 9% during July 2012 to September 2013)
 - water-dependent ecosystems (identified as a theme of 34% of projects during this reporting period, up from 14% during July 2012 to September 2013)
 - cumulative impact assessment (identified as a theme of 16% of projects during this reporting period, up from 8% during July 2012 to September 2013).
- In Australia, the themes of water-dependent ecosystems (49 projects) and aquifer connectivity (45 projects) dominate research into the water-related impacts of coal seam gas and large coal mining developments. This demonstrates a marked change in the focus of research in Australia from the previous reporting period (Report 3) in which approximately 50% of the 99 Australian projects profiled had the theme of co-produced/mine water.
- The US dominates research into the seismic effects of re-injection of co-produced water into aquifers (8 out of 9 projects identified were associated with the US).

- Of the 187 projects identified, 70% came from Australia. Forty-one percent (41%) of all projects identified were associated with one of the following Australian institutions:
 - University of Queensland (28)
 - CSIRO (18)
 - Department of the Environment (Australian Government) (18)
 - University of New South Wales (13)
- From countries outside Australia, the following institutions should be noted for their contribution to research:
 - China University of Mining and Technology (4)
 - U.S. Geological Survey (11)
- The number of projects identified from the US and China in the reporting period was less than half the number from the previous reporting period.
- Very little research could be recorded from Russia, as minimal research literature is published in English. The Embassy of the Russian Federation in Australia indicated that most research is conducted by industry.
- Since 2012, Canadian research appears to have focussed on the water-related impacts of shale and tight gas reservoirs. Only five relevant research projects from Canada were found dated between 2013 and 2014.
- Only one project was identified from India during this reporting period.

Abbreviations

General abbreviations	Description
ACARP	Australian Coal Association Research Program
ANSTO	Australian Nuclear Science and Technology Organisation
ARC	Australian Research Council
CBM	Coal bed methane
CMA	Catchment Management Authority
CMM	Coal mine methane
CO ₂	Carbon dioxide
CSG	Coal seam gas
DERM	Queensland Government Department of Environment and Resource Management (ceased operation in 2012)
EPBC Act	<i>Environment Protection and Biodiversity Conservation Act 1999</i>
GDE	Groundwater-dependent ecosystem
GW	Groundwater
IESC	Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development
IMWA	International Mine Water Association
LLS	Local Land Services
NCGRT	National Centre for Groundwater Research and Training
NICTA	NICTA (National ICT Australia) is Australia's Information Communications Technology (ICT) Research Centre of Excellence
NICNAS	National Industrial Chemicals Notification and Assessment Scheme
OGIA	Office of Groundwater Impact Assessment (Queensland)
OWS	Office of Water Science
THPSS	Temperate Highland Peat Swamps on Sandstone
UAV	Unmanned Aerial Vehicle
UK	United Kingdom
UNSW	University of New South Wales, Australia
US	United States of America
WCM	Walloon Coal Measures
WOS	Web of Science
WRL	Water Research Laboratory of the School of Civil and Environmental Engineering at UNSW Australia

Glossary

Term	Description
Aquifer	Rock or sediment in formation, group of formations or part of a formation, that is saturated and sufficiently permeable to transmit quantities of water to wells and springs
Aquifer connectivity	The degree to which groundwater can transfer between two adjacent aquifers or to the surface
Aquifer injection	The injection of liquid (for example, H ₂ O) or gas (for example, CO ₂) into an aquifer. Commonly used in Managed Aquifer Recharge schemes or groundwater remediation
Aquitard	A saturated geological unit that is less permeable than an aquifer and incapable of transmitting useful quantities of water. Aquitards often form a confining layer over an artesian aquifer
Bore/borehole	A narrow, artificially constructed hole or cavity used to intercept, collect or store fluids from an aquifer, or to passively observe or collect groundwater information. Also known as a borehole, well or piezometer
CO ₂ sequestration	The process of capture and long-term storage of atmospheric carbon dioxide
Co-produced water	The water that is pumped out of coal seams in order to extract coal seam gas. Also referred to as produced water and associated water. Over time, the volume of produced water normally decreases and the volume of produced gas increases
Coal bed methane	(CBM) See coal seam gas
Coal seam	Sedimentary layers consisting primarily of coal. Coal seams store both gas and groundwater and generally contain saltier groundwater than aquifers that are used for drinking water or agriculture
Coal seam gas	A form of natural gas (generally 95 to 97% pure methane, CH ₄) typically extracted from permeable coal seams at depths of 300 to 1000 m
Cone of depression	Occurs in an aquifer when groundwater is pumped from a well. The pumping of groundwater lowers the watertable immediately around the bore, such that drawdown decreases with distance from the well. In profile, the shape of the watertable around the well is that of a cone, hence the term cone of depression. The cone of depression grows larger as the pumping rate is increased and wider as the length of time a well is pumped increases. But once pumping stops the watertable will eventually return to its original shape, although the water levels and quality may have changed
Fracking	See hydraulic fracturing
Groundwater	Water occurring naturally below ground level (whether in an aquifer or other low-permeability material), or water occurring at a place below ground that has been pumped, diverted or released to that place for storage. This does not include water held in underground tanks, pipes or other works

Reference list for water-related coal seam gas and coal mining research (Report 4)

Term	Description
Hydraulic fracturing	Also known as 'fracking', 'fracing' or 'fracture simulation', is one process by which hydrocarbon (oil and gas) bearing geological formations are 'stimulated' to enhance the flow of hydrocarbons and other fluids towards the well. The process involves the injection of fluids, gas, proppant and other additives under high pressure into a geological formation to create a conductive fracture. The fracture extends from the well into the coal reservoir, creating a large surface area through which gas and water are produced and then transported to the well via the conductive propped fracture channel
Seismicity (induced)	Refers to typically minor earthquakes and tremors that are caused by human activity that alters the stresses and strains within the earth's crust
Shale gas	A natural gas generally extracted from a clay-rich sedimentary rock which has naturally low permeability
Solute	The substance present in a solution in the smaller amount. For convenience, water is generally considered the solvent even in concentrated solutions with water molecules in the minority
Subsidence	Usually refers to vertical displacement of a point at or below the ground surface. However, the subsidence process actually includes both vertical and horizontal displacements. These horizontal displacements, in cases where subsidence is small, can be greater than the vertical displacement. Subsidence is usually expressed in units of millimetres (mm)
Unconventional gas	A term used to encompass gas production methods apart from conventional natural gas production, including shale gas, coal bed methane and underground coal gasification
Underground coal gasification	An underground, in-situ process carried out on un-mined coal seams in which oxidants are injected to convert carbonaceous materials into carbon monoxide, hydrogen and carbon dioxide
Water quality	The physical, chemical and biological attributes of water that affects its ability to sustain environmental values
Well	A bored, drilled, or driven shaft or a dug hole whose depth is greater than the largest surface dimension and whose purpose is to reach underground water supplies or oil or to store or bury fluids below ground

1 Introduction

The extractive nature of coal seam gas (CSG) and coal mining operations has the potential to result in significant impacts on water resources and water-dependent ecosystems. Environmental impacts may include: disruption of surface water pathways caused by mining, including mining-induced subsidence; aquifer contamination caused by hydraulic fracturing chemicals; and groundwater and ecological impacts from enhanced aquifer connectivity.

In response to community concern, an expert scientific committee (now named the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development [IESC]) was established under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) in November 2012 to provide scientific advice to decision makers on the water-related impacts of coal seam gas and large coal mining development. The Office of Water Science (OWS) within the Department of the Environment supports the IESC, including by commissioning research to address some of the critical gaps in the scientific understanding of water-related impacts associated with coal seam gas and large coal mining activities.

This report is the fourth in a series of reference list reports commissioned by the Department of the Environment on the advice of IESC. The complete reference list series includes summaries of research projects relating to the impacts of coal seam gas and large coal mining developments on water resources, currently being undertaken or completed, in a number of countries including Australia, Canada, China, India, Russia, the United Kingdom (UK) and the United States of America (US) since January 2000.

The objective of this reference list series is to identify relevant research projects to:

- support targeted approaches to future research - that address critical gaps in the scientific understanding of water-related impacts associated with coal seam gas and large coal mining activities
- provide a resource to build the scientific capability of the OWS to effectively deliver bioregional assessments, research and support the IESC in the provision of advice on development proposals to regulators.

The reference list will also provide others, including government regulators, with project and citation information to improve their understanding of the water-related impacts of coal seam gas and coal mining.

1.1 Scope

This report (Report 4 in Table 1.1) includes summaries of research projects relating to the impacts of coal seam gas and coal mining developments on water resources, currently being undertaken or completed, during the period October 2013 to September 2014 from Australia, Canada, China, India, Russia, UK and the US.

Table 1.1 Scope of reports in the reference list series commissioned by the Department of the Environment

Report	Country included in the review						
	Australia	United States	Canada	China	India	Russia	United Kingdom
Report 1: January 2000 – June 2012	✓	✓	✓				
Report 2: January 2000 – June 2012				✓	✓	✓	✓
Report 3: July 2012 – September 2013	✓	✓	✓	✓	✓	✓	✓
Report 4: October 2013 – September 2014	✓	✓	✓	✓	✓	✓	✓

The research themes identified by the Department of the Environment in the scope of this report were:

R1. aquifer interconnectivity:

- baseline information (water quality and quantity)
- field-based and modelling approaches for assessing connectivity
- groundwater flow and solute transport dynamics

R2. disruption of surface water flow pathways:

- subsidence
- mine cone of depression
- stream diversions
- infrastructure

R3. co-produced water and salt management (relating to coal seam gas) and mine water and salt management (relating to coal mining):

- aquifer injection and/or water treatment (technologies, relative cost benefit)
- effect on land and water resources (including irrigation)
- effect on water-dependent ecosystems (streams, rivers, floodplains, wetlands, groundwater-dependent ecosystems (GDE), peat swamps)

R4. seismicity

R5. integrity of wells - installation, operation, decommissioning

R6. hydraulic fracturing:

- chemical - surface and groundwater quality
- physical - aquitard disruption, borehole collapse

R7. quality and reliability of water supplies, including environmental health:

- mine site and gas field remediation, including well decommissioning and post-mining voids
- long-term impacts, including timescales for water levels to return to pre-development levels (quality/quantity)
- chemical migration and toxicity
- managing salt and heavy metals

R8. water-dependent ecosystems:

- prediction of potential impacts to water-dependent ecosystems (streams, rivers, floodplains, wetlands, GDEs, peat swamps)
- response and tolerances of water-dependent ecosystems to changes in water regime (surface and groundwater quantity, seasonal patterns, variability, interactions) and water quality
- mitigation measures
- monitoring techniques

R9. cumulative impact assessments.

In undertaking this research project, it was recognised that research undertaken in related extractive/resource industries (e.g. CO₂ sequestration, underground coal gasification or shale gas) may sometimes inform water and water-dependent ecosystem knowledge gaps in the coal seam gas and coal mining sectors. For example, CO₂ sequestration researchers have been significantly more active in the examination of water well integrity and reservoir 'seals'. However, research from such industries was outside the scope of this project.

This report also does not include the following types of information:

- research outside of Australia, Canada, China, India, Russia, the United Kingdom and the US
- research not relevant to the impacts of coal seam gas and coal mining projects on water resources
- bibliographic database of completed research
- operational and compliance monitoring reports completed by mining and gas companies
- policy, regulatory and legislative material
- critical review of the collated material
- research completed prior to October 2013 and after September 2014.

2 Method

The aim of this work was to collate information about research and knowledge acquisition projects, without critical analysis of the material. The following priorities for information acquisition were determined (in order of desirability):

1. project descriptions written by the project's principal investigators
2. project descriptions written in telephone or email consultation with principal investigators
3. project descriptions as documented on the websites of research organisations
4. project descriptions inferred from the reporting outputs (i.e. a report on a project)
5. project descriptions inferred from published literature outputs (i.e. journal papers, conference papers).

Based on the above hierarchy, a project survey was created and sent out to all research organisations and authors of relevant literature. To obtain the contact information of research organisations and principal investigators it was necessary to use a variety of methods, including disseminating an information request through research networks, industry associations, embassies and social media, and literature searching using library databases. An iterative process was used as information gleaned from one method fed back into the other methods - for example, references found in a journal article that pointed to a particular research organisation active in the field of coal mining impacts on water.

The study methods are further described in Sections 2.1, 2.2 and 2.3.

2.1 Research project survey

Recognising that project descriptions obtained directly from principal investigators were likely to be the most accurate, an online survey was created to gather data for this fourth report (blank survey presented at Appendix A). The survey form was also translated into Russian and sent to Russian contacts.

An introduction and link to the online survey was emailed to every contact identified during the process of compiling Reports 2 and 3 of the reference list series, and followed up by a reminder email. A complete list of survey recipients and their subsequent participation in the survey is included at Appendix B.

2.2 Search for research organisations/researchers

Research organisations and researchers were identified using a range of methods, including:

- Connecting with research networks. The authors liaised within their own research networks to connect with national and international research organisations that are, or have been, engaged in relevant research. Industry, government and academic connections across Australia and internationally were contacted and asked to pass on the contact details of relevant researchers and research organisations or forward the research project survey form to their relevant contacts.

- Contacting partner universities. The UNSW Australia maintains a network of exchange partner universities. Each university website was visited to determine whether they maintain relevant disciplines. Where the contact details of individual researchers involved in water-related impact research could be obtained, they were preferentially contacted, otherwise Heads of Schools/Faculties or generic universities were contacted, sent the survey form and followed up with a telephone call.
- Internet searches. Web engine searches were used to find research organisations involved in water research in each country. Each website was then interrogated to determine whether they were involved in relevant research projects. The Embassy of the Russian Federation in Australia responded to our request for information stating that they were unable to identify universities or organisations conducting this research and that it is therefore likely to be completed by industry. Consequently, Russian coal and gas companies (rather than research organisations) were targeted for further contact using the Russian survey.
- Conferences. Unpublished conference proceedings or abstracts from relevant recent conferences were obtained either by attendance or from research contacts who attended. Where relevant conferences were identified that have yet to take place, the author index was used to identify researchers. These researchers were then emailed with a link to the online survey.
- Industry associations. A posting was listed on the International Mine Water Association (IMWA) LinkedIn group forum (see Social media/website dot point below). Contact details of the US EPA Coalbed Methane Outreach Programme were obtained for the relevant countries and were sent a copy of the online survey.
- Contacting embassies. The following embassies were telephoned to request the names of researchers or research organisations involved in researching the potential impacts of coal mining and coal seam gas on water and water-dependent ecosystems:
 - Embassy of the People's Republic of China
 - Embassy of the Russian Federation in Australia
 - The High Commission of India in Australia

Each embassy requested a copy of the survey form and additional information. By request of the Embassy of the Russian Federation in Australia, an official letter requesting information was sent to the Russian Ambassador.

- Social media/website. The authors called for interested parties to participate in the research project survey through the Water Resource Laboratory website on 31 March 2014 and via LinkedIn. A repeat call was posted with a link to the online survey in early September 2014. The LinkedIn groups included:
 - Hydrogeology Forum of LinkedIn (14 033 members)
 - International Association of Hydrogeologists (1282 members)
 - Water Pros (37 933 members)

- International Mine Water Association (1065 members¹).
- Interpreter services. Due to the difficulty of communicating with Russian researchers, a Russian interpreter and translator was hired for a day to translate the project survey form, search for Russian research organisations, make telephone calls and send out surveys to possible contacts.
- Literature searches. The research organisation websites of authors found through the literature review were investigated for further contacts and the authors directly contacted where possible. The reference list of each relevant article/report was further scrutinised for relevant literature and contacts. The literature search is described in more detail in Section 2.3.

2.3 Literature search

The literature search was accomplished using the UNSW library database and electronic journal subscriptions systems, which are among the most comprehensive in Australia, in addition to contemporary search engine tools. This search resulted in over 30 000 references, which were then assessed for relevance. Alerts were enabled on these searches so that additional articles published would be automatically forwarded to the Water Research Laboratory (WRL) librarian for processing.

The following databases were interrogated in the search for relevant literature and researchers:

- Researcher ID
- WOS (Web of Science)
- Scopus
- Science Direct
- Engineering Village
- OnePetroAustralian databases (Informit)
- Proquest.

Keyword searches were derived from the key research areas (see Section 1.1). More detail on the literature search, including keywords used for searches, is provided at Appendix C.

As each piece of relevant literature was identified, its references were reviewed for further leads to relevant literature.

In addition to the database search, references provided in government submission documents and publications produced by relevant national agencies were also reviewed in an attempt to source additional literature.

¹ While membership to the IMWA LinkedIn group was requested 31 March 2014, membership was granted 23 April 2014 and thus the post was made on that day.

3 Overview of research projects

A total of 187 research projects from Australia, Canada, China, India, Russia, the UK and the US were found relating to the water-related impacts and coal seam gas/coal mining, either currently being undertaken or completed, in the period October 2013 to September 2014.

3.1 Research themes

The relative proportions of projects relating to each research theme are represented in Figure 3.1. Where a project was deemed to be associated with more than one research theme, it was included in the calculation of statistics for each relevant research theme.

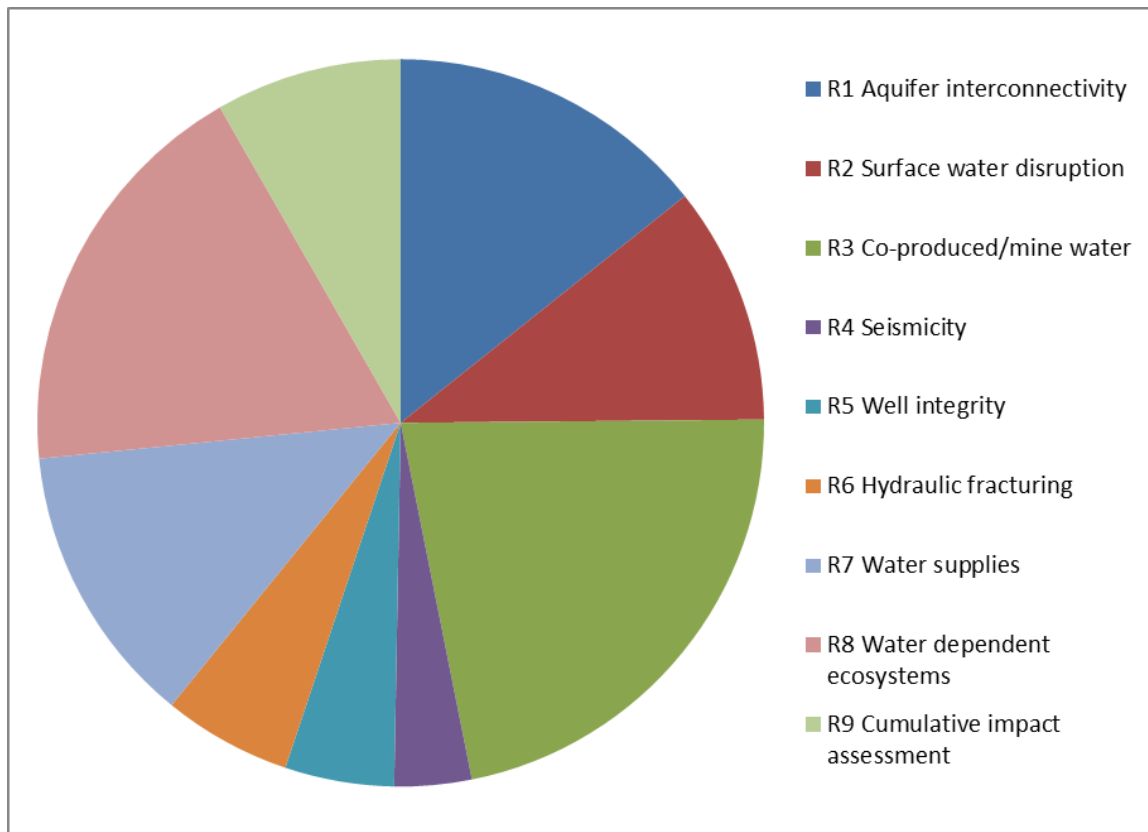


Figure 3.1 Distribution of research themes

The majority of projects were associated with research themes R3 Co-produced/mine water (77 projects) and R8 Water-dependent ecosystems (65 projects). These research themes are highly relevant topics in scientific research on coal seam gas and large coal mining, as mine water and co-produced water have the potential to directly impact on water-dependent ecosystems. R3 Co-produced/mine water has been the dominant research theme of projects previously profiled by this reference list series (i.e. Commonwealth of Australia 2014a, 2014b, 2014c). However, during this 2013 to 2014 reporting period, many of the other research themes increased in importance. For example, in comparison to the July 2012 to September 2013 reporting period (report 3; Commonwealth of Australia 2014c):

- aquifer connectivity (identified as a theme of 27% of projects during this reporting period, up from 9% during July 2012 to September 2013)
- water-dependent ecosystems (identified as a theme of 34% of projects during this reporting period, up from 14% during July 2012 to September 2013)
- cumulative impact assessment (identified as a theme of 16% of projects during this reporting period, up from 8% during July 2012 to September 2013).

The least number of projects identified were related to the water impacts of seismic events induced by coal mining or coal seam gas operations (R4 Seismicity; 12 projects). A slightly larger number of projects were found relating to R5 Well integrity (17 projects) and R6 Hydraulic fracturing (20 projects).

3.2 Summaries by country

Research into the water-related impacts of coal seam gas and large coal mining is connected to (and often largely driven by) the production of coal seam gas and coal mining in each country. According to Flores (2014), the only countries producing significant amounts of coal seam gas are China, Australia, India, the US and Russia.

The relative distribution of the 187 research projects by country and research theme is displayed in Figure 3.2. More research projects were identified from Australia (131 projects) than from any other country.

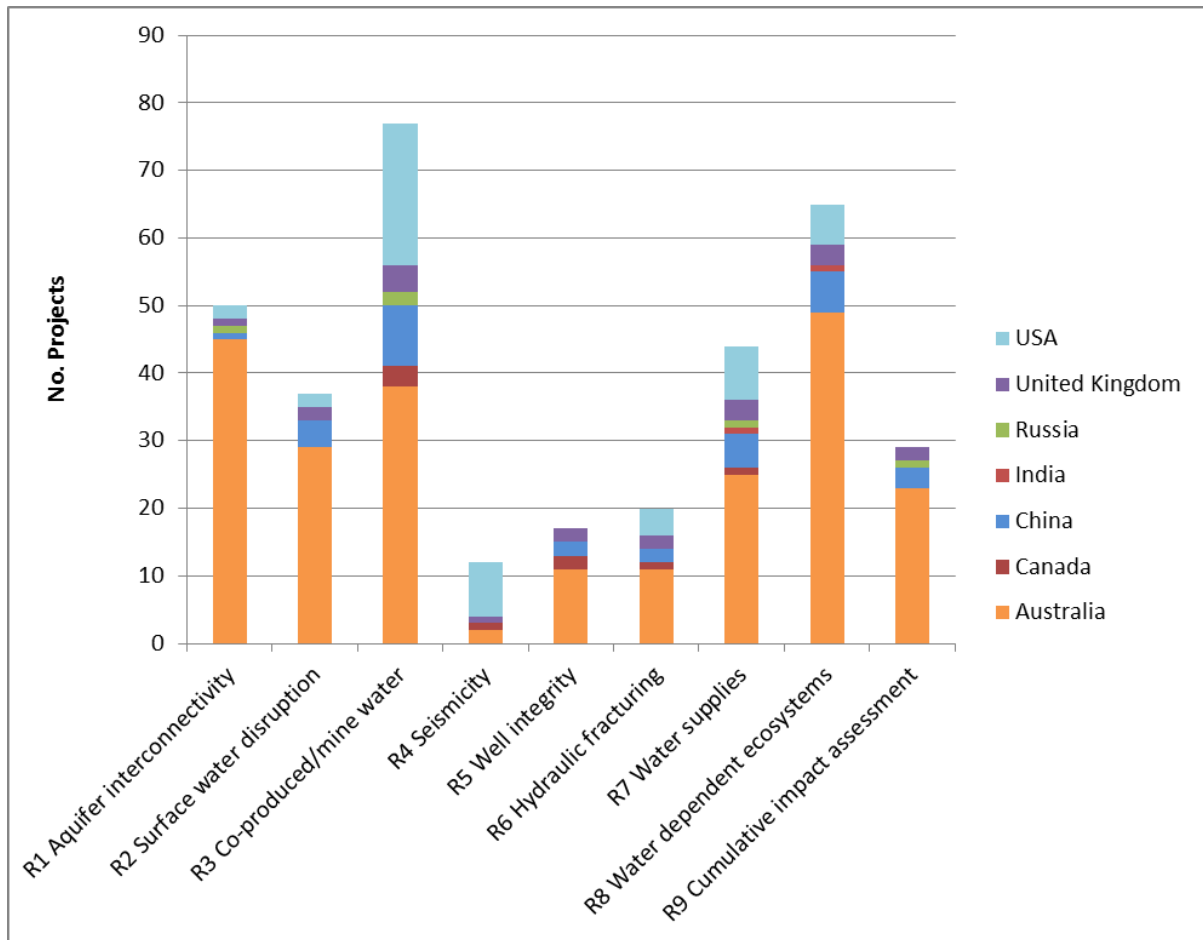


Figure 3.2 Relative proportion of projects by country and research theme

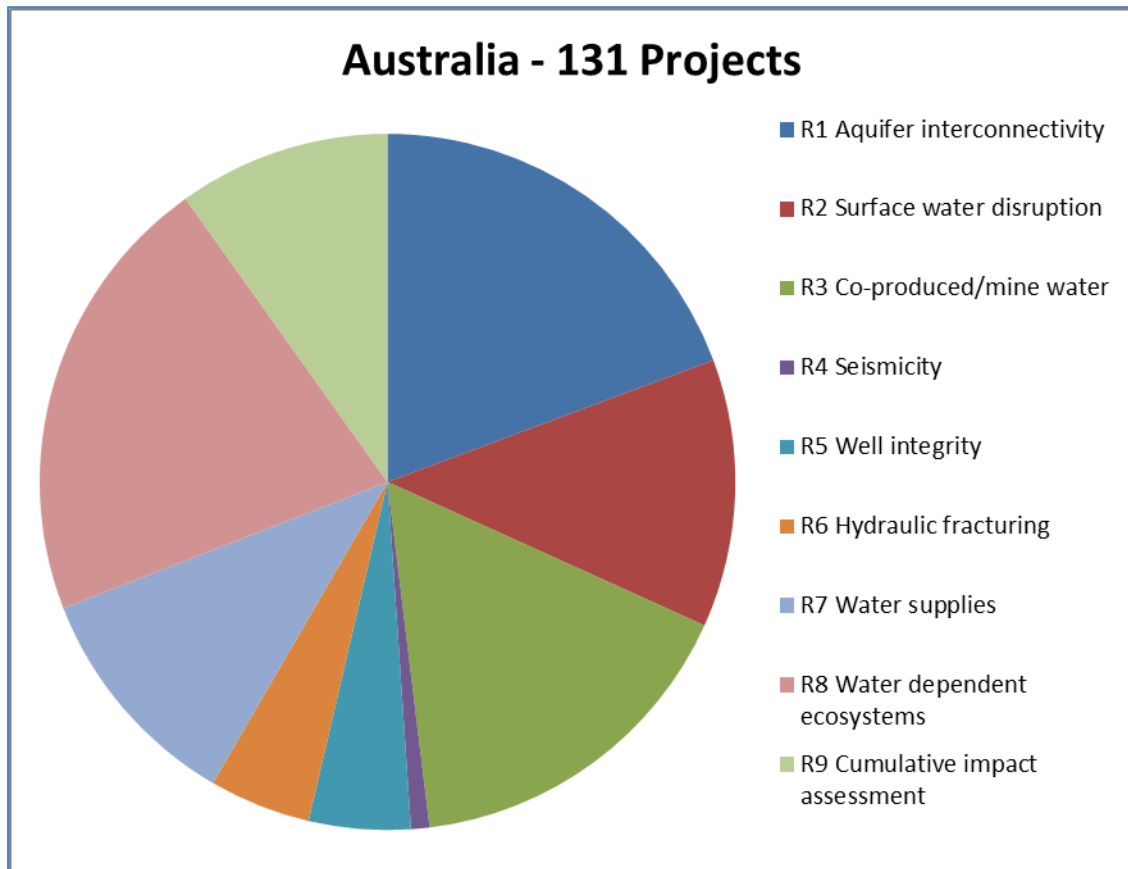
3.2.1 Australia

Australia has the most commercially successful and advanced coalbed gas industry outside of the US and Canada. While Australia contains more than 30 coal-bearing basins, the Surat and Bowen Basins in Queensland are the most gas-rich in the country (Flores 2014).

The majority of research into the water-related impacts of coal seam gas and large coal mining identified by this review was from Australian sources. Of the 187 projects profiled in this report, 131 of them originated from Australia.

The distribution of research themes represented in these projects is displayed in Note that some projects are associated with multiple themes.

Figure 3.3. While R3 Co-produced/mine water dominated the overall distribution of research themes amongst identified research projects, R8 Water-dependent ecosystems (49 projects) and R1 Aquifer connectivity (45 projects) are now more common themes of Australian projects investigating the water-related impacts of large coal mining and coal seam gas. This demonstrates a marked change in the focus of research in Australia from the previous reporting period (Report 3; Commonwealth of Australia 2014c) in which approximately 50% of projects had the theme of R3 Co-produced/mine water.

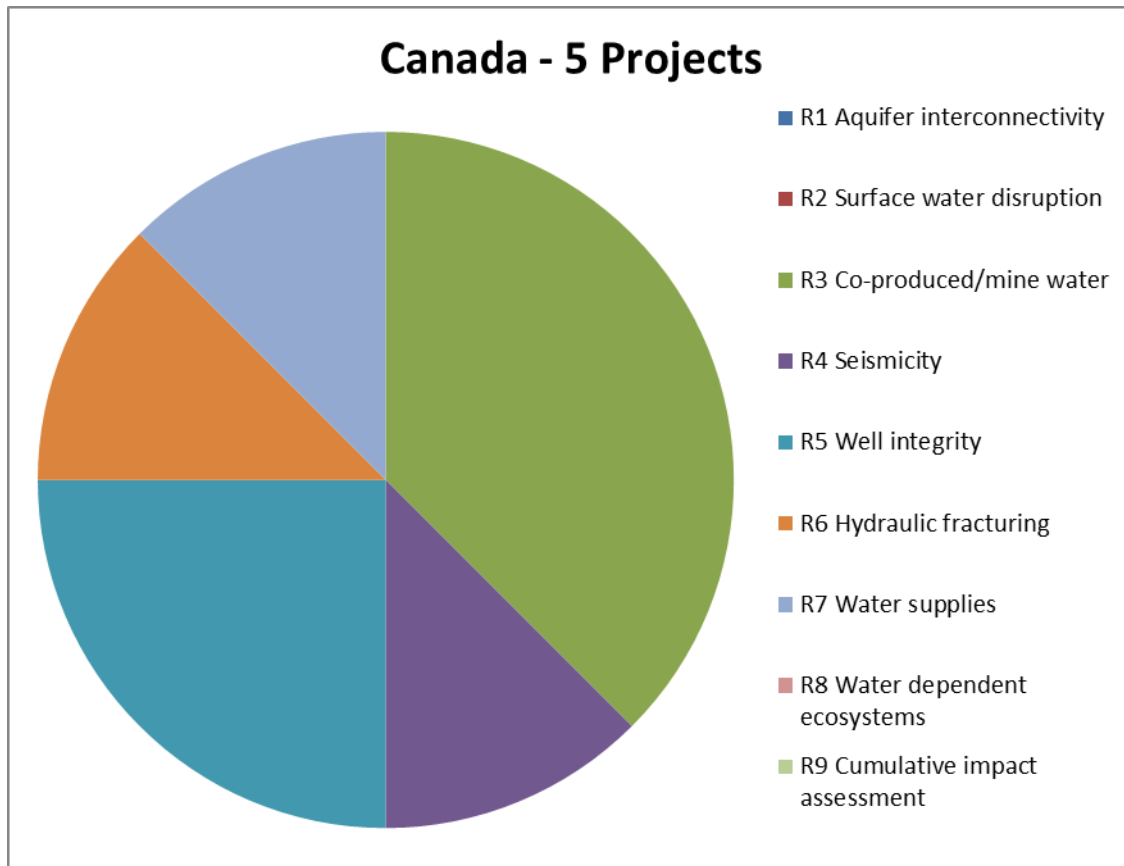


Note that some projects are associated with multiple themes.

Figure 3.3 Distribution of research themes in Australian research projects

3.2.2 Canada

There are 15 coal basins extending throughout Canada, some of which are shared with the US. The majority of the coal bed gas reserves in Canada are in the Western Canada Sedimentary Basin (Flores 2014). Production of coal seam gas commenced in 2000, with 6000 wells producing gas by 2008. Since 2012, Canadian research appears to have focused on the water-related impacts of wellbore integrity and hydraulic fracturing in shale and tight gas reservoirs (for examples see The Canadian Water Network <http://www.cwn-rce.ca/project-library/#category=hydraulic-fracturing>). Only five relevant research projects from Canada were found dated between 2013 and 2014. The distribution of research themes represented in these projects is displayed in Figure 3.4.



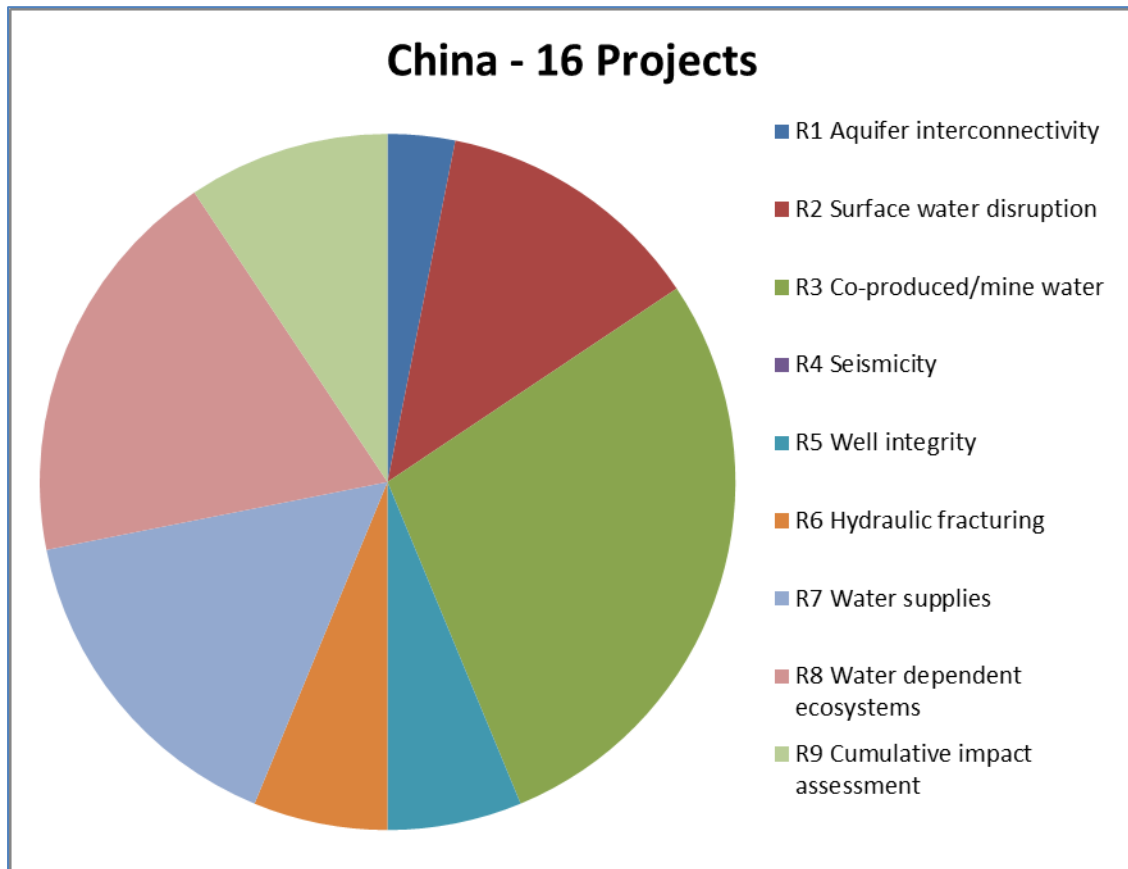
Note that some projects are associated with multiple themes.

Figure 3.4 Distribution of research themes in Canadian research projects

3.2.3 China

China is actively exploring coal seam gas resources and has commenced production. IEA (2012) in Flores (2014) predicts that China will greatly increase its dependency on coal by 2017. China produced twice as much coal as Australia and the US combined in 2011. Much of the coal gas currently produced is coal mine methane (CMM), which is recovered from active mines. However, coal seam gas production has been rapidly increasing since 2003, with the Qinshui and Ordos Basins found to be most commercially productive (Flores 2014).

Of the 187 projects identified, 16 were from researchers in China (down from 44 projects identified in the previous reporting period; Department of the Environment 2014c). The reason for this decrease in identified projects is unknown. The distribution of research themes represented in these projects is displayed in Figure 3.5. As with the overall distribution of research themes amongst the research projects, the theme of R3 Co-produced/mine water dominated the research into water-related impacts of large coal mining and coal seam gas in China.



Note that some projects are associated with multiple themes.

Figure 3.5 Distribution of research themes in Chinese research projects

3.2.4 India

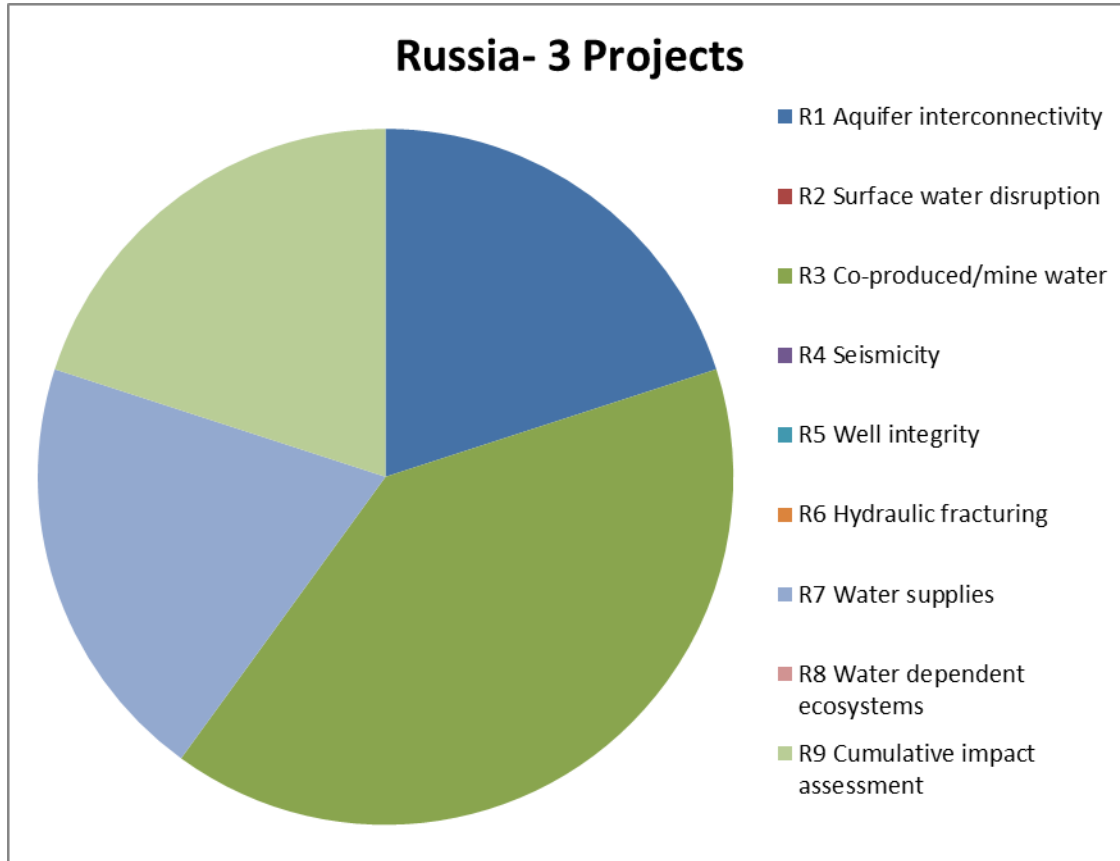
Only one project was identified to originate from India, down from four in the previous reporting period (Report 3; Department of the Environment 2014c). This project was related to both R7 Water supplies and R8 Water-dependent ecosystems.

3.2.5 Russia

Russia has the second largest coal reserve in the world (Flores 2014). While Russia is also thought to have one of the largest reserves of coal bed gas in the world, it also has abundant conventional natural gas reserves and thus, less incentive to exploit coal seam gas. Russia commenced production of coal seam gas after 2010 (Flores 2014). IEA (2012) in Flores (2014) predicted that Russia will greatly increase its dependency on coal by 2017.

Only three research projects were found related to the water impacts of coal mining and coal seam gas in Russia. However, accessing Russian literature and research organisations was greatly limited by language barriers. The Embassy of the Russian Federation in Australia responded to our request for information stating that they were unable to identify universities or organisations conducting this research and that it is therefore likely to be completed by industry. Consequently, Russian coal and gas companies (rather than research organisations) were targeted for further contact using the Russian survey, however none of these companies responded affirmatively.

The three research projects were related to R1 Aquifer interconnectivity, R3 Co-produced/mine water and R7 Water supplies. The distribution of research themes represented in these projects is displayed in Figure 3.6.



Note that some projects are associated with multiple themes.

Figure 3.6 Distribution of research themes in Russian research projects

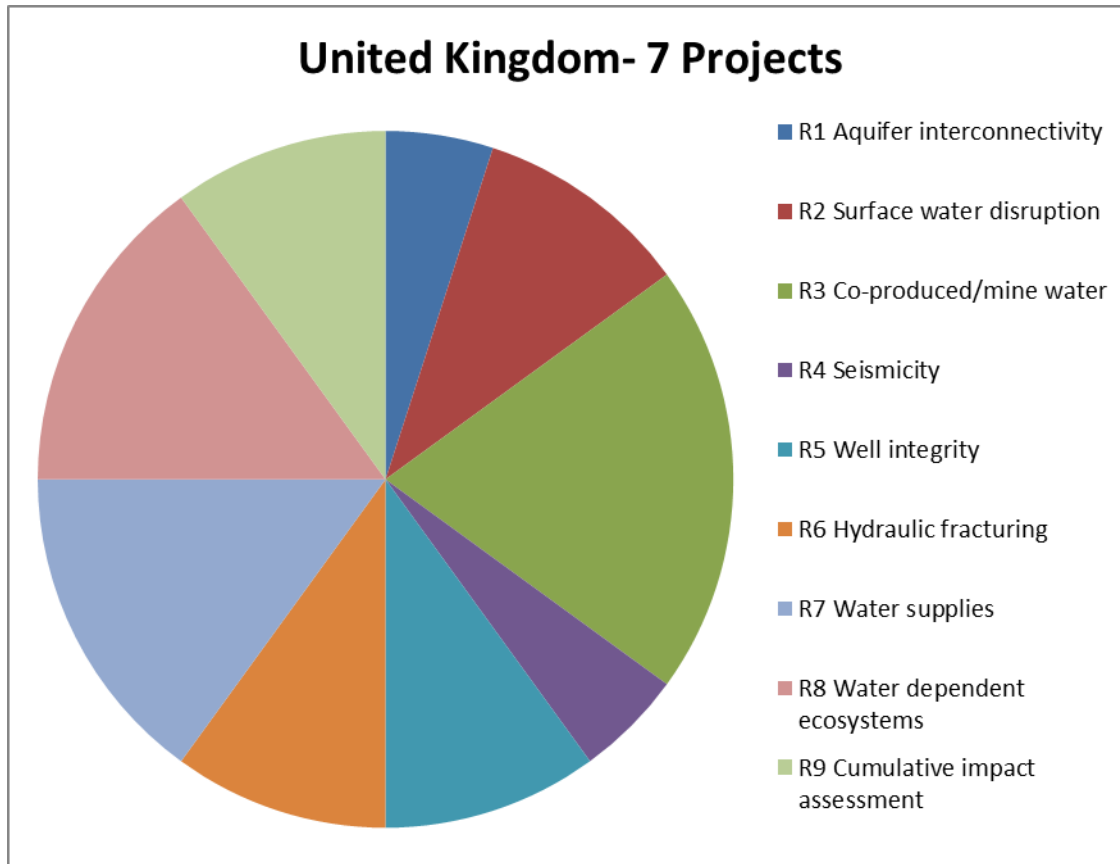
3.2.6 United Kingdom

Coal mining in the United Kingdom has decreased since 1990 and subsequently, the recovery of coal mine gas has increased (Flores 2014). However, there are no commercially active sites of coal seam gas extraction in the United Kingdom. In the United Kingdom, the term 'unconventional gas' is used to encompass shale gas, coal bed methane and underground coal gasification. Most of the literature in the United Kingdom relates to shale gas, due to the presence of large shale beds. According to the Scottish Environmental Protection Agency², exploration of unconventional gas fields is in its infancy in the United Kingdom.

Seven projects were identified from the United Kingdom between October 2013 and September 2014. The distribution of research themes represented in the projects is displayed in Figure 3.7. The theme of R3 Co-produced/mine water dominated the research

² <http://www.sepa.org.uk/environment/energy/non-renewable/shale-gas-and-coal-bed-methane/>

into water-related impacts of coal mining and coal seam gas in United Kingdom; however, projects were also well distributed across the other research themes.



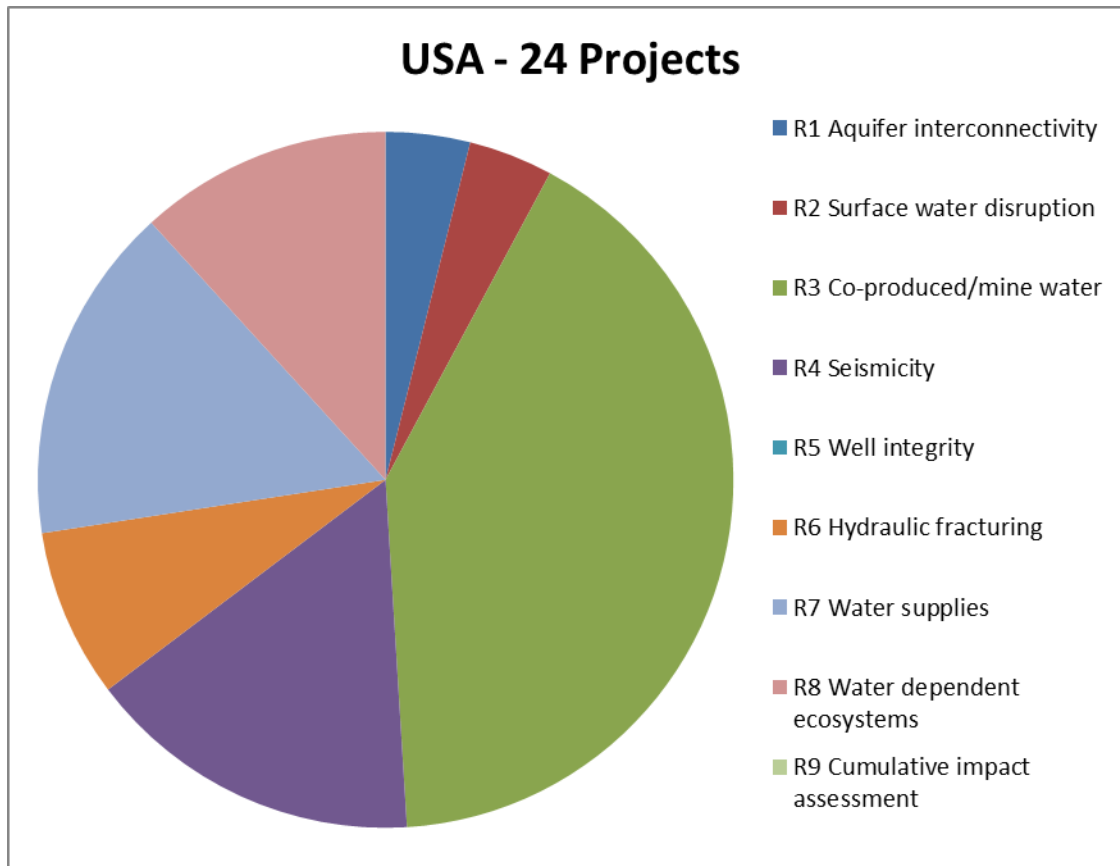
Note that some projects are associated with multiple themes.

Figure 3.7 Distribution of research themes in projects from the United Kingdom

3.2.7 United States

The US is the biggest producer of coal seam gas and has been producing coal bed gas from coal mines since the 1950s. The highest gas-producing basins are Powder River (Wyoming and Montana), San Juan (Colorado and New Mexico) and Black Warrior (Alabama), however there are 12 coal basins across the country. Much of the literature regarding the water-related impacts of coal seam gas are focused on the Powder River Basin.

Of the 187 projects, 24 came from the US, down from 50 projects during the previous reporting period (Report 3; Department of the Environment 2014c). The distribution of research themes represented in these projects is displayed in Figure 3.8. As with the overall distribution of research themes amongst the research projects, the theme of R3 Co-produced/mine water dominates the research, followed by R7 Water supplies and R4 Seismicity. No projects were identified within the scope of this report with the research themes of R5 Well integrity or R9 Cumulative impact assessment. The US dominates research into the seismic effects of re-injection of co-produced water into aquifers.



Note that some projects are associated with multiple themes.

Figure 3.8 Distribution of research themes in projects from the United States

3.3 Centres of research

The number of projects completed by each research organisation are presented in Table 3.1.

Of the 187 projects identified, 70% were completed in Australia. Of these, 41% were completed or will be completed by the following four Australian institutions:

- University of Queensland (28 projects)
- CSIRO (18 projects)
- Department of the Environment (Australian Government) (18 projects)
- University of New South Wales (13 projects).

From countries outside Australia, the following institutions should be noted for their contribution to research:

- China University of Mining and Technology (4 projects)
- U.S. Geological Survey (11 projects).

Table 3.1 Distribution of projects by research centres

Country and research organisation	No. of projects	School/department/colleges as named in literature or surveys (as applicable)
Australia		
University of Queensland	28	<ul style="list-style-type: none"> • School of Agriculture and Food Sciences • Centre for Mined Land Rehabilitation, Sustainable Minerals Institution • School of Chemical Engineering • School of Civil Engineering • School of Earth Sciences • School of Geography, Planning and Environmental Management
CSIRO	18	GISERA (Gas Industry Social and Environmental Research Alliance)
Australian Government - Department of the Environment	18	Office of Water Science (OWS)
University of New South Wales	13	<ul style="list-style-type: none"> • NCGRT (National Centre for Groundwater Research & Training) • School of Civil and Environmental Engineering • School of Mining Engineering; Water Research Laboratory
QGC	8	
Sinclair Knight Merz	7	
Queensland Department of Natural Resources and Mines	6	Office of Groundwater Impact Assessment (OGIA)
University of Newcastle, Australia	5	ARC Centre of Excellence for Geotechnical Science and Engineering
Centennial Coal	4	
Coffey Geotechnics	4	
Geoscience Australia	4	
Queensland University of Technology	4	<ul style="list-style-type: none"> • School of Earth, Environment and Biological Science • NCGRT (National Centre for Groundwater Research & Training)
Mine Subsidence Engineering Consultants	3	
Origin Energy	3	
University of Southern Queensland	3	National Centre for Engineering in Agriculture (NCEA)
APLNG (Australia Pacific LNG Pty Ltd)	2	
Arrow Energy	2	
Macquarie University	2	

Reference list for water-related coal seam gas and coal mining research (Report 4)

Country and research organisation	No. of projects	School/department/colleges as named in literature or surveys (as applicable)
NCGRT (National Centre for Groundwater Research & Training)	2	
Pells Consulting	2	
Santos	2	
AGL Energy	1	
ANSTO	1	
Bureau of Meteorology	1	
Central Queensland University	1	
CH2M Hill	1	
CDM Smith	1	
Curtin University	1	
Department of Parliamentary Services, Victoria	1	
Department of Primary Industries	1	
Ditton Geotechnical Services Pty Ltd	1	
Eberhard Consulting	1	
Eco Logical Australia	1	
Edith Cowan University	1	
Flinders University	1	
Golder Associates	1	
Metropolitan Coal	1	
MWH	1	
NICNAS	1	
NICTA	1	
North West Local Land Services	1	
NSW Office of Water	1	
NSW Office of Environment and Heritage	1	
Parsons Brinckerhoff	1	
RPS	1	
Schlumberger Water Services	1	
Southern Cross University	1	
Sydney Catchment Authority	1	
University of Adelaide	1	<ul style="list-style-type: none"> • Insitute for Photonics and Advanced Sensing • Deep Exploration Technology CRC

Reference list for water-related coal seam gas and coal mining research (Report 4)

Country and research organisation	No. of projects	School/department/colleges as named in literature or surveys (as applicable)
University of Technology Sydney	1	
URS Australia	1	
Victoria University	1	
Watermark Numerical Computing	1	
Canada		
Geofirma Engineering	2	
University of Waterloo	2	
Alberta Geological Survey	1	
University of British Colombia	1	Royal Military College of Canada
University of Calgary	1	
China		
China University of Mining and Technology	4	<ul style="list-style-type: none"> • College of Petroleum Engineering, State Key Lab Petroleum Resources & Prospecting • Key Laboratory of CBM Resource and Reservoir-Generating Process, Ministry of Education, School of Resources and Geoscience • School of Resources and Safety Engineering
China Coal Technology and Engineering Group	1	Hangzhou Research Institute
China University of Geoscience	1	<ul style="list-style-type: none"> • School of Energy Resources • School of Land Science and Technology • School of Marine Sciences • School of Water Resources and Environment
China University of Petroleum	1	<ul style="list-style-type: none"> • MOE Key Laboratory of Petroleum Engineering • Department of Petroleum Engineering • College of Petroleum Engineering, State Key Lab Petroleum Resources & Prospecting
Chongqing University of Science & Technology	1	
Hebei University of Engineering	1	Key Laboratory of Hebei Province for Resource Exploration Research
National CBM Engineering Centre	1	Coal Reservoir Laboratory
National Development and Reform Commission	1	Energy System Analysis Center, Energy Research Institute
North China Institute of Science and Technology	1	Hebei State Key Laboratory of Mine Disaster Prevention
Taiyuan University of Technology	1	Department of Surveying and Mapping Science and Technology, College of Mining Engineering

Reference list for water-related coal seam gas and coal mining research (Report 4)

Country and research organisation	No. of projects	School/department/colleges as named in literature or surveys (as applicable)
India		
North-Eastern Hill University	1	
Russia		
Far East Federal University	1	
SRK Consulting	1	
United Kingdom		
British Geological Survey	1	
Environment Agency	1	United Kingdom
Queen's University Belfast	1	
Scottish Government	1	
University of Edinburgh	1	School of Geosciences
University of Glasgow	1	
United States		
U.S. Geological Survey	11	Columbia Environmental Research Center, PA Water Science Center
University of Texas	3	<ul style="list-style-type: none"> Community Science Institute, Great Wilderness, Department of Neurology School of Public Health (University of North Texas Health Science Center) Bureau of Economic Geology
University of Wyoming	3	
Cipher Coal Consulting Limited	1	
Columbia University	1	Lamont-Doherty Earth Observatory
Durham University	1	<ul style="list-style-type: none"> Durham Energy Institute Department of Earth Sciences
Kennedy/Jenks Consultants	1	
Southern Methodist University	1	
University of Cornell	1	Department of Earth and Atmospheric Sciences
US Army Corps Engineers	1	
West Virginia University	1	Department of Mining Engineering

4 Research project profiles

This section profiles the 187 recently commissioned or completed research and knowledge acquisition projects found during this review. The projects are organised by:

- research theme, then
- country, and finally
- research organisations.

Where a project is relevant to several of the identified themes, it has been categorised by its primary theme and its relevance to secondary themes also noted.

The data source of each project profile is specified at the bottom of each project table. Where the information was received directly from the project survey, it has been formatted for consistency. Where the data source is directly from literature, Endnote fields have been adapted to fit the required information, where possible. Objectives and achievements of the projects were interpreted from the literature. Project summaries have been copied directly from abstracts rather than interpreting the project findings, with corrections made to spelling (but not to grammar) to maintain the integrity of the information presented by the author.

It should be noted that the year of literature publication has been used for the project duration and to categorise each project into one of the four reports in this reference list series. It may be that this does not accurately reflect the timeframe of the project, which may have finished long before the publication or may be ongoing.

Of the 187 projects identified, 75 were sourced from project surveys, 70 from literature, 16 from the University of Queensland Centre for Coal Seam Gas (UQ CCSG) database, 8 from the ACARP website, 7 from the GISERA website, 4 from the ARC website and 3 from the University of Queensland's website. A complete list of these projects is summarised in Table D1 at Appendix D, in the order they appear in this report.

4.1 Aquifer interconnectivity

The R1 Aquifer interconnectivity research theme examines the water-related impacts of coal seam gas and large coal mining due to the connections between aquifers. Topics under this category included: the collection of water quality and quantity baseline data; field based and modelling approaches for assessing connectivity; and groundwater flow and solute transport dynamics.

A total of 36 projects were collated with the primary theme of R1 Aquifer interconnectivity; from Australia (34 projects), Russia (1 project) and the US (1 project).

4.1.1 Australia

Table 4.1 Project 1: Fuzzy reliability index used for quantification of uncertainties in the groundwater impact assessment in a coal seam gas field

Project characteristics	Details
Project title	Fuzzy reliability index used for quantification of uncertainties in the groundwater impact assessment in a coal seam gas field
Project location	Australia
Principal investigator	Wang, Xuyan
Lead institution	Arrow Energy; University of Queensland
Project budget	Unknown
Source of funding	Unknown
Project duration	Unknown—Literature output 2013
Current status	Unknown—Literature output 2013
Project summary	Groundwater modelling as one of the most representative approaches has been widely utilised for groundwater impact assessment in the coal seam gas (CSG) development. Uncertainty always is a critical issue in such groundwater modelling due to the limited amount of data available at complex multilayer aquifers in the basin width and the lack of knowledge in understanding of gas and water hydraulic/mechanical behavior in a large scale. This paper is to capture the dispersion of random hydraulic variables in the aquifer monitoring system with the first order reliability method (FORM) and absorption of imprecision information in site hydrogeological characterisations with fuzzy logic to enhance regional valid information for the model calibration and accordingly reduce modelling uncertainty. An effective fuzzy reliability index (FRI) approach, which incorporated random probability and fuzzy set theory, was introduced for quantification of uncertainty in modelling process. A simple FRI framework in calculation sheet was developed and applied for a regional groundwater flow model calibration in a proposed CSG development site for analysing model parameter sensitivity and quantifying propagation of the uncertainty through the model prediction. The result obtained with the FRI approach demonstrated that the imprecision information can provide a significant support in model parameter calibration and the FRI provides a useful framework to quantify the various uncertainties in groundwater modelling for multilayer aquifer system and offers a more reliable support for decision making.
Objectives	This paper aims to capture the dispersion of random hydraulic variables in the aquifer monitoring system with the first order reliability method (FORM) and absorption of imprecision information in site hydrogeological characterisations with fuzzy logic to enhance regional valid information for the model calibration and accordingly reduce modelling uncertainty.
Achievements	A simple FRI framework in calculation sheet was developed and applied for a regional groundwater flow model calibration in a proposed CSG development site for analysing model parameter sensitivity and quantifying propagation of the uncertainty through the model prediction.
Outputs	Wang X, Herbert J and Li L (2013) "Fuzzy reliability index used for quantification of uncertainties in the groundwater impact assessment in a coal seam gas field". 40 th IAH Congress on Solving the Groundwater Challenges of the 21 st Century.

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
	Perth, Australia.
Key personnel	Wang, Xuyan; Herbert, John; Li, Ling
Research themes	Aquifer interconnectivity
Project information source	40 th IAH Congress

Table 4.2 Project 2: Aquitard hydraulic properties estimation from wireline logs analysis: an application to the Surat Basin, Queensland

Project characteristics	Details
Project title	Aquitard hydraulic properties estimation from wireline logs analysis: an application to the Surat Basin, Queensland
Project location	Australia
Principal investigator	Ricard, L
Lead institution	CSIRO
Project budget	Unknown
Source of funding	CSIRO
Project duration	Unknown—presentation July 2014
Current status	Unknown
Project summary	<p>Aquitards are key elements of the subsurface hydraulic framework acting as sealing and compartmentalisation units that affect many usages of the pore space. These include hydrocarbon or water production, as well as storage of contaminants, carbon dioxide or nuclear waste. Aquitards are also critical in the context of multiple resource exploitation where they can act as barriers between different zones of usage. However, as aquitards do not contribute directly to the resource recovery or storage, their hydraulic characterisation is often lacking, especially on the regional scale. Also, pump or production testing is difficult to perform in aquitards due to the low permeability and flow rates; hence inherent long time frames for acquiring reliable test results.</p> <p>Alternatively, hydraulic properties such as porosity and permeability can be estimated from well-based measurements such as geophysical wireline logs and those acquired from core sample analyses. In this work, we applied a standard petrophysical workflow combining wireline log measurement analysis in conjunction with core sample data for aquitard characterisation. The process is tested on the Westbourne Formation of the Surat Basin, Queensland.</p> <p>Data availability and reliability show that limited measurements are available for a regional assessment. To evaluate the robustness of the techniques and to determine the applicability of the technique to a wider set of data, a comparison of different estimation methods for porosity was conducted. Then, within a geographical area of interest, several wells were selected with different data availability. Porosity and permeability estimations were performed in combination with wireline log porosity estimates and core measurements. Finally, the upscaling of the hydraulic properties from the wireline logs to the formation scale is discussed in light of data availability and possible lateral variations</p>
Objectives	To evaluate the robustness of geophysical wireline logs and core sample log techniques for hydraulic characterisation of aquitards and to determine the applicability of the techniques to a wider set of data.
Achievements	A comparison of different estimation methods for porosity was conducted. Porosity and permeability estimations were performed in combination with wireline log porosity estimates and core measurements for several wells were selected with different data availability. Finally, the upscaling of the hydraulic properties from the wireline logs to the formation scale was considered in light of data availability and possible lateral variations.

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Outputs	Ricard L, Godel B, Smerdon B and Esteban L (2014). Aquitard hydraulic properties estimation from wireline logs analysis: an application to the Surat Basin, Queensland. Geological Society of Australia, 2014 Australian Earth Sciences Convention (AESC), Sustainable Australia. Abstract No 110 of the 22nd Australian Geological Convention, Newcastle City Hall and Civic Theatre, Newcastle, New South Wales. July 7–10.
Key personnel	Ricard, L; Godel, B; Smerdon, B; Esteban, L
Research themes	Aquifer interconnectivity, modelling
Project information source	Conference

Table 4.3 Project 3: Background review: Aquifer connectivity within the Great Artesian Basin, and the Surat, Bowen and Galilee Basins

Project characteristics	Details
Project title	Background review: Aquifer connectivity within the Great Artesian Basin, and the Surat, Bowen and Galilee Basins
Project location	Australia
Principal investigator	Harrington, Glenn
Lead institution	CSIRO; Department of the Environment (Australian Government)
Project budget	\$121 068 (GST inclusive)
Source of funding	Australian Government - Department of the Environment
Project duration	2012 – 2014
Current status	Completed
Project summary	<p>This background review describes the state of knowledge of aquifer connectivity, both in terms of the range of scientific methods that have been developed to measure and model connectivity in various hydrogeological settings, and the specific knowledge of aquifer connectivity for the Great Artesian Basin (GAB) and the Surat, Bowen and Galilee geological basins. The focus of the report includes:</p> <ul style="list-style-type: none"> • type of connectivity, its implications and measurement • groundwater flow models, which may both rely on an understanding of aquifer connectivity and predict the extent of connectivity between aquifers • actions that can alter connectivity • connectivity within the GAB and the Surat, Bowen and Galilee geological basins, which are linked to the GAB and are highly prospective areas for coal seam gas development and/or coal mining • knowledge gaps.
Objectives	<p>The primary objective of this review is to document the range of scientific methods that have been developed to measure and model connectivity in any hydrogeological setting, and the specific knowledge of aquifer connectivity for the GAB, Surat Basin, Bowen Basin and Galilee Basin. The review captures expert knowledge from each of the primary authors and their respective organisations, as well as published material from text books and international peer-reviewed journals. However, this review does not attempt to report every publication that has mentioned aquifer connectivity. It also does not utilise nor report every investigation and dataset that is publicly available for each of the four specific basins.</p>
Achievements	<p>Aquifer connectivity is a major determining factor in how groundwater pumping will affect other aquifers.</p> <p>There are many techniques available to investigate and evaluate aquifer connectivity that provide information at different spatial and temporal scales. Natural features (e.g. fractures and faults) and manmade structures (e.g. boreholes) and activities (e.g. longwall coal mining) can influence aquifer connectivity by providing preferential pathways for flow and contaminant transport.</p> <p>Few studies explicitly focus on connectivity and inter-aquifer leakage between</p>

Project characteristics	Details
	<p>the GAB (a major groundwater basin), the Surat (geological) Basin and the linked Bowen and Galilee (geological) Basins (of which the latter three have significant coal seam gas resources).</p> <p>Most existing groundwater models that claim to address aquifer connectivity via implementation of measured, site-specific hydraulic conductivity data will under-predict the magnitude of inter-aquifer leakage.</p> <p>Priorities for future work include:</p> <ul style="list-style-type: none"> • development of an agreed methodology for determining formation-scale hydraulic conductivity of aquitards and a consistent approach for modelling inter-aquifer leakage • understanding dual-phase flow (i.e. the flow of both gas and water within coal seams) and the conditions under which it needs to be incorporated into groundwater flow predictions • understanding how desorption of coal bed methane may alter the hydraulic properties of the surrounding formations.
Outputs	<p>Published on the Australian Government - Department of the Environment website and Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) website.</p> <ul style="list-style-type: none"> • Commonwealth of Australia (2014d) Aquifer connectivity within the Great Artesian Basin, and the Surat, Bowen and Galilee Basins, Background review. Australian Government Department of the Environment, Canberra. http://www.environment.gov.au/water/publications#iesc • Fact Sheet – Connectivity between water systems. Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC). http://iesc.environment.gov.au/publications
Key personnel	Harrington, Glenn; Peeters, Luk; Evans, Rick; Villeneuve, Stephanie; Karsten, Michael; Kozuskanich, John; Turnadge, Chris; Smerdon, Brian; Ezzy, Tim; Cox, Malcolm; Parsons, Stephen
Research themes	Aquifer interconnectivity, groundwater flow, solute transport dynamics
Project information source	Survey

Table 4.4 Project 4: Review of QGC groundwater modelling – upscaling Eclipse insight into Modflow for the Surat Basin

Project characteristics	Details
Project title	Review of QGC groundwater modelling – upscaling Eclipse insight into Modflow for the Surat Basin
Project location	Australia
Principal investigator	Unknown
Lead institution	CSIRO; QGC; Schlumberger Water Services
Project budget	Unknown
Source of funding	CSIRO, QGC
Project duration	2013 – Unknown
Current status	Unknown
Project summary	Comparison and Contrast of the differences and limitations between Eclipse (dual flow) and Modflow (single phase flow) modelling for water production from the Gasfields. Development of a useable basin-wide groundwater model based on dual flow regimes (Eclipse) to get a true picture of groundwater movement within the basin.
Objectives	To compare the main functionalities between the reservoir simulator Petrel-Eclipse H ₂ O and other existing traditional groundwater simulators.
Achievements	Demonstration of the successful applications of the Petrel-Eclipse H ₂ O modeling tools through case study examples of an aquifer storage and recovery project in the Middle East and the Surat Basin regional aquifer study in Queensland, Australia.
Outputs	http://research.ccsq.uq.edu.au/projects/review-qgc-groundwater-modelling-upscaling-eclipse-insight-modflow-surat-basin-csiro-qgc Herrmann R and de Verteuil D (2013) "Non-conventional groundwater modeling using the reservoir simulator Petrel-Eclipse H ₂ O". 40 th IAH Congress on Solving the Groundwater Challenges of the 21st Century. Perth, Australia
Key personnel	Herrmann, Rolf; de Verteuil, Daniel
Research themes	Aquifer interconnectivity, water-dependent ecosystems
Project information source	UQ CCSG Online Portal, 40 th IAH Congress

Table 4.5 Project 5: Upscaling of two-phase, near-source groundwater flow in CSG regional modelling

Project characteristics	Details
Project title	Upscaling of two-phase, near-source groundwater flow in CSG regional modelling
Project location	Australia
Principal investigator	Moore, CR
Lead institution	CSIRO; Watermark Numerical Computing Pty Ltd; QGC
Project budget	Unknown
Source of funding	Unknown
Project duration	Unknown—Literature output 2013
Current status	Unknown—Literature output 2013
Project summary	<p>A great deal of effort is being spent on predicting the effects of CSG extraction on regional groundwater systems. Most regional models simulate movement of only a single fluid phase, i.e. water. Furthermore they represent complex sequences of coal and interburden stratigraphy comprising thick coal measure formations using only a small number of model layers. In reality, once CSG extraction commences, both water and desorbed gas occupy pore spaces within coal seams that are continuous over only relatively short distances. Taken together, these circumstances create a tendency for single phase regional modelling to over-predict propagation of drawdown induced by CSG pumping. A study was undertaken which sought to explore the magnitude of such drawdown overprediction. It also explored whether it could be mitigated through adoption of appropriate upscaling strategies in conjunction with use of a single phase model that is modified to accommodate partial desaturation of upscaled coal measure layers and reduction of relative coal permeabilities, at pressure heads at which gas is desorbed. A detailed, high-resolution ECLIPSE model was first built in which drawdowns induced by de-pressurisation and gas desorption within a complex coal/interburden sequence were accurately calculated. An appropriately-modified version of MODFLOWNWT was then parameterized using a suite of analytical and inversion-based upscaling strategies employed both individually and in concert. The ability of the thus-parameterized, modified, single-phase model to match ECLIPSE-generated, vertically averaged, transmissivity-weighted drawdowns when supplied with identical water extraction rates was then investigated. It was concluded that the problem of drawdown over-prediction can indeed be mitigated to some extent through use of an appropriately modified MOD FLOW. However exact replication of ECLIPSE-generated drawdowns was not possible. While some upscaling methodologies performed far better than others, it was demonstrated that the assignment of upscaled properties to a thus-modified single phase model is not straightforward. The study suggests that parameterization of such a model may be satisfactorily effected through calibration against locally measured drawdowns, or drawdowns calculated through concomitant two-phase reservoir modelling .</p>
Objectives	To explore the magnitude of drawdown overprediction for single phase regional modelling in by CSG pumping.
Achievements	<p>A detailed, high-resolution ECLIPSE model was first built.</p> <p>An appropriately-modified version of MODFLOWNWT was then parameterized</p>

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
	using a suite of analytical and inversion-based upscaling strategies employed both individually and in concert.
Outputs	Moore CR, Doherty JE, Howell S and Erriah L (2013) "Upscaling of two-phase, near-source groundwater flow in CSG regional modelling". 40 th IAH Congress on Solving the Groundwater Challenges of the 21st Century. Perth, Australia.
Key personnel	Moore, CR; Doherty, John; Howell, S; Erriah, L
Research themes	Aquifer interconnectivity, water-dependent resources
Project information source	40 th IAH Congress

Table 4.6 Project 6: Groundwater hydrochemical characterisation of the Surat region and Laura Basin – Queensland. Final technical report for the National Collaboration Framework Hydrochemical Characterisation Project

Project characteristics	Details
Project title	Groundwater hydrochemical characterisation of the Surat region and Laura Basin – Queensland. Final technical report for the National Collaboration Framework Hydrochemical Characterisation Project
Project location	Australia
Principal investigator	Geoscience Australia
Lead institution	Geoscience Australia; Australian Government – Department of the Environment
Project budget	\$1 601 000 (GST inclusive)
Source of funding	Australian Government – Department of the Environment
Project duration	2012 – 2015
Current status	Being finalised for publication
Project summary	<p>The coal seam gas (CSG) industry has expanded rapidly in Queensland over the last decade and is expected to develop CSG production in the future across each of the coal basins in eastern Australia. This has led to widespread community concern about environmental and human health issues associated with the CSG industry. Of primary concern to many people are the potential impacts to water resources of CSG and large coal mining developments. To enable earlier and better informed decision making, analysis of baseline groundwater chemistry and environmental values is required in each coal basin. Hydrochemical analyses of aquifers in CSG regions could provide a useful tool to discriminate between coal seam groundwater and associated aquifers.</p> <p>Existing groundwater chemistry data in the Surat Region and Laura Basin have been collated and analysed to characterise the hydrochemistry of aquifers and coal seams. The results of this analysis have been used to explore if isotopic and ionic signatures can be used to distinguish between coal seam groundwater and associated aquifers.</p> <p>This study has adopted the Great Artesian Basin Water Resources Assessment Surat Region Boundary, which extends beyond the Surat Basin geological boundary (Smerdon and Ransley 2012). For that reason the term ‘Surat Region’ is adopted for this assessment rather than the term ‘Surat Basin’.</p> <p>Geologically and hydrogeologically, the Surat Region is relatively well understood. It contains an extensive network of water bores and abundant chemistry data and is a good candidate for determining whether groundwater chemistry can discriminate between aquifers. In contrast, the Laura Basin is less well studied and understood. There are limited data on subsurface geology, hydrogeology and groundwater chemistry and consequently hydrochemical analysis in this basin is comparatively limited. The Laura Basin was chosen to assess the limit to which hydrochemical characterisation could be usefully applied in data poor areas.</p>
Objectives	<p>The objective of this project was to collate and interpret existing groundwater chemistry data from the Surat Region and the Laura Basin in order to:</p> <ul style="list-style-type: none"> • Provide comprehensive hydrochemical, ionic, organic, gaseous, and isotopic (radiogenic and stable) characterisation of groundwater, including water

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Project characteristics	Details
	<p>within coal seams, to determine baseline conditions and, if possible, to distinguish between coal seam water and that of surrounding aquifers.</p> <ul style="list-style-type: none"> • Identify gaps in our current data and knowledge of coal seam and aquifer hydrochemistry. • Analyse groundwater quality data with respect to national water quality guidelines for drinking water use (NHMRC/NRMMC 2011), livestock, irrigation and aquatic ecosystem protection (ANZECC and ARMCANZ 2000) to assess the environmental values of groundwater, and to determine the treatment that may be required prior to reuse or discharge.
Achievements	Project achievements expected to be publicly available in 2015
Outputs	<p>Ransley TR, Somerville PD, Tan KP, Feitz AJ, Cook S, Yates G, Schoning G, Caruana L, Sundaram B and Wallace LJ (in press) <i>Groundwater hydrochemical characterisation of the Surat Region and Laura Basin - Queensland</i> : Final technical report for the National Collaboration Framework Hydrochemical Characterisation Project. Geoscience Australia, Canberra.</p> <p>To be published by Geoscience Australia in 2015.</p>
Key personnel	Geoscience Australia
Research themes	Baseline information (water quantity and quality); quality and reliability of water supplies, including environmental health; groundwater flow and transport dynamics
Project information source	Survey

Table 4.7 Project 7: Technical reports for the National Collaboration Framework Regional Hydrogeology Project – four reports on regional hydrogeological characterisations of the Laura Basin, the Maryborough Basin, the St Vincent Basin and the Otway Basin.

Project characteristics	Details
Project title	Technical reports for the National Collaboration Framework Regional Hydrogeology Project – four reports: <ul style="list-style-type: none"> • Regional Hydrogeological Characterisation of the Laura Basin, Queensland • Regional Hydrogeological Characterisation of the Maryborough Basin • Regional Hydrogeological Characterisation of the St Vincent Basin • Regional Hydrogeological Characterisation of the Otway Basin
Project location	Australia
Principal investigator	Geoscience Australia
Lead institution	Geoscience Australia; Australian Government – Department of the Environment
Project budget	\$1 664 443 (GST inclusive)
Source of funding	Australian Government – Department of the Environment
Project duration	Start 2012 – Finish 2015
Current status	Being finalised for publication
Project summary	<p>These reports were commissioned under the National Collaboration Framework (NCF) between the Department of the Environment and Geoscience Australia. As a key research priority identified under the NCF, the regional characterisation of priority coal basins not covered by initial Bioregional Assessments focussed on four coal basins; the Laura, Maryborough, St Vincent and the Otway Basins.</p> <p>The main objectives of the reports are to develop an improved knowledge base relating to the hydrogeological and groundwater resource characteristics of coal-bearing sedimentary basins that are of strategic national importance but are not the subject of initial Bioregional Assessments. This work focussed particularly on developing an integrated basin-scale conceptual understanding of regional groundwater flow systems, including a hydrostratigraphic framework that identifies the main water-bearing geological formations (aquifers), and their key hydrogeological parameters and connectivity relationships.</p>
Objectives	The main objective of the reports is to develop an improved knowledge base relating to the hydrogeological and groundwater resource characteristics of coal-bearing sedimentary basins that are of strategic national importance but are not the subject of initial Bioregional Assessments.
Achievements	Project achievements expected to be published in 2015
Outputs	<p>Project reports to be published by Geoscience Australia.</p> <p>Marshall SK and Lewis S (2013) "Hydrogeological assessment of the Maryborough Basin, Queensland". 40th IAH Congress on Solving the Groundwater Challenges of the 21st Century, 15–20 September 2013, Perth, Australia.</p>
Key personnel	Geoscience Australia

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Project characteristics	Details
Research themes	Baseline information (water quantity and quality); quality and reliability of water supplies, including environmental health; groundwater flow and transport dynamics; water-dependent ecosystems
Project information source	Survey

Table 4.8 Project 8: Monitoring with Intent: a proposal for measuring and responding to groundwater impacts from coal seam gas activities

Project characteristics	Details
Project title	Monitoring with Intent: a proposal for measuring and responding to groundwater impacts from coal seam gas activities
Project location	Australia
Principal investigator	Yates, Gabrielle
Lead institution	Geoscience Australia
Project budget	Unknown
Source of funding	Unknown
Project duration	Unknown—Literature output 2013
Current status	Unknown—Literature output 2013
Project summary	<p>Coal seam gas (CSG) activities will have an impact on groundwater. But what will be the magnitude, extent and timing of that impact? Faced with this question, and in the absence of comprehensive datasets, groundwater professionals are unable to respond with confidence. Coal seam gas activities, with some notable exceptions, are mostly carried out in stratigraphic units far below, or at a lateral distance from, those monitored by existing groundwater monitoring networks. How then can groundwater experts advise regulators and industry appropriately as to the likelihood and nature of impacts to groundwater from CSG activities? Commonwealth approval conditions for the development of CSG projects in the Surat Basin are empowered by the <i>Environment Protection and Biodiversity Conservation Act 1999</i> (EPBC Act) as it pertains to the protection of Matters of National Environmental Significance (MNES) including springs that host EPBC-listed threatened species and communities. The projects are approved on the basis that there will be no significant impact to MNES. The approval conditions include the requirement for regional monitoring of groundwater levels and quality for the early detection of impacts to springs. In the absence of sufficient time series data that would support sophisticated modelling, the predictive power of simple groundwater flow calculations, together with regional groundwater models, may be deployed to evaluate the envelope of magnitude, extent and timing of groundwater responses. It is proposed that these same tools may be used to develop both monitoring networks and triggers for remedial action that can adapt to increased data availability and changing production scenarios and take account of the inertia in both the physical response within the groundwater system and the institutional response from either the regulator or industry. This will facilitate the protection of groundwater-dependant ecosystems through timely and adaptive management responses whilst ensuring that CSG projects are neither injudiciously promoted, nor prematurely curtailed, through lack of monitoring data or through misinterpretation of changes in those data.</p>
Objectives	To develop a system for measuring and responding to groundwater impacts from coal seam gas activities.
Achievements	Unknown

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Project characteristics	Details
Outputs	Yates G, Smith M, Lytton L and Slatter E (2013) "Monitoring with Intent: a proposal for measuring and responding to groundwater impacts from coal seam gas activities". 40 th IAH Congress on Solving the Groundwater Challenges of the 21st Century. Perth, Australia
Key personnel	Yates, Gabrielle; Smith, Martin; Lytton, Lucy; Slatter, Emily
Research themes	Aquifer interconnectivity
Project information source	40 th IAH Congress

Table 4.9 Project 9: Application of hydrochemistry for the detection of inter-aquifer connectivity at coal seam gas fields

Project characteristics	Details
Project title	Application of hydrochemistry for the detection of inter-aquifer connectivity at coal seam gas fields
Project location	Australia
Principal investigator	Sundaram, Baskaran
Lead institution	Geoscience Australia
Project budget	Unknown
Source of funding	Unknown
Project duration	Unknown—Literature output 2013
Current status	Unknown—Literature output 2013
Project summary	<p>There is community concern regarding the impact coal mining and coal seam gas production could have on water resources. One of the key concerns is whether hydraulic connectivity could be established between coal seams during the de-watering and production process with aquifers that supply groundwater for agriculture and domestic use. Geoscience Australia (GA) and the Office of Water Science (DSEWPAC) have undertaken an initial collaborative study to determine whether monitoring the hydrochemistry of coal seams and their adjacent aquifers could be used as a tool to detect occurrences of inter-aquifer connectivity. A comprehensive compilation of available hydrochemistry data for the primary aquifers and coal seams in the Surat and Laura Basins was undertaken. The study builds on the Queensland Healthy Headwaters CSG water feasibility study, results of groundwater surveys conducted by Geoscience Australia and the Geological Survey of Queensland, and other government and industry datasets. All water chemistry data was subject to a quality control process before use. The results show there is significant spatial variability of water chemistry within the aquifers but variability between different aquifers at the same location is less obvious. Nevertheless, water from coal seams is typically more saline than from the adjacent aquifers and the isotopic signature of the gases is significantly different. Methane from the primary aquifers has an isotopic signature consistent with bacterial (methanogenic) carbonate reduction source whereas methane from the coal seam has an isotopic signature consistent with a mixed source. Other water chemistry relationships for discrimination between aquifers and adjacent coal seams are presented and the effectiveness of hydrochemistry for detecting inter-aquifer connectivity is discussed.</p>
Objectives	The study builds on the Queensland Healthy Headwaters CSG water feasibility study, results of groundwater surveys conducted by Geoscience Australia and the Geological Survey of Queensland, and other government and industry datasets.
Achievements	The results from this study show there is significant spatial variability of water chemistry within the aquifers but variability between different aquifers at the same location is less obvious.

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Project characteristics	Details
Outputs	Sundaram B, Wallace L, Somerville P, Tan KP, Bell J, Kuske T, Schoning G, Ransley T and Feitz A (2013) "Application of hydrochemistry for the detection of inter-aquifer connectivity at coal seam gas fields". 40 th IAH Congress on Solving the Groundwater Challenges of the 21st Century. Perth, Australia:
Key personnel	Sundaram, Baskaran; Wallace, Luke; Somerville, Peter; Tan, Kok Piang; Bell, Joseph; Kuske, Tehani; Schoning, Gerhard; Ransley, Tim; Feitz, Andrew
Research themes	Aquifer interconnectivity
Project information source	40 th IAH Congress

Table 4.10 Project 10: Review of dissolved hydrocarbons in groundwater in the Surat and Bowen Basins

Project characteristics	Details
Project title	Review of dissolved hydrocarbons in groundwater in the Surat and Bowen Basins
Project location	Australia
Principal investigator	Douglas, Grant
Lead institution	GISERA (CSIRO)
Project budget	\$571 781
Source of funding	GISERA and CSIRO
Project duration	Oct 2014 – Sep 2015
Current status	In progress
Project summary	<p>This research proposal relates to carrying out a review and evaluating existing open source and company held data on the presence of organic compounds in groundwater in the Surat and Bowen Basins, Queensland. The study will include assessments of the relationships of the compounds with geological setting, coal characteristics, hydraulic fracturing and related Hydrocarbons in groundwater, Surat and Bowen Basins drilling fluids, and where relevant any correlation with seeps or microbial processes. Equal emphasis will be placed on the volatile, partially water-soluble volatiles, semi-volatile and water soluble hydrocarbons (HCs) and organic compounds, found in sedimentary basins (i.e. aliphatic HCs, TPH (Total Petroleum Hydrocarbons), BTEX and PAHs (Benzene, Toluene, Ethyl benzene, Xylenes; Poly Aromatic Hydrocarbons) and phenols); particularly if they are a potential compound of concern and for which the companies will have relevant available data. Acquiring and interpreting comprehensive datasets on water compositions, and consequently increasing scientific understandings of the entire chemical/geological/hydrogeological systems will inform public discussion of water quality and the complexities involved. The broad-based, integrated approach should allow insights to be made into the complex interactions involved in sedimentary basins, aquifers and coal seam gas (CSG) related water production. To meet these requirements, the research program involves chemistry, organic geochemistry, petrology, coal geology, physics/petrophysics, hydrology, hydrogeochemistry and hydrogeology to understand the interaction of sedimentary strata including organic rich strata, with water and gases at depth.</p>
Objectives	<p>The research objectives are:</p> <ul style="list-style-type: none"> • To collate and provide a summary, of the available information on existing hydrocarbons in groundwater in the Surat and Bowen Basins, Queensland leading to: <ul style="list-style-type: none"> – a robust and scientifically defensible data set and interpretations to support the research conclusions – context and potential explanations for possible future detection and reporting of hydrocarbons during compliance monitoring programmes. • Outline strategies related to differentiation of naturally occurring hydrocarbons and those inadvertently introduced during drilling, completion and hydraulic stimulation (e.g. stable isotopic fingerprinting of the

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
	<p>hydrocarbons could assist with delineating coal derived hydrocarbons versus 'refined' petroleum derived hydrocarbons).</p> <ul style="list-style-type: none"> • Interpretations on possible sources of the hydrocarbons encountered based on previous studies and new information gained in the proposed study.
Achievements	None yet
Outputs	http://gisera.org.au/research/waterprojects/water-project-5-hydrocarbons.pdf
Key personnel	Douglas, Grant; Schinteie, Richard
Research themes	Aquifer interconnectivity, water supplies
Project information source	GISERA website

Table 4.11 Project 11: Innovative characterisation of aquifers and aquitards- NCGRT Program 1

Project characteristics	Details
Project title	Innovative characterisation of aquifers and aquitards- NCGRT Program 1
Project location	Australia
Principal investigator	Acworth, I
Lead institution	NCGRT; University of New South Wales; Queensland University of Technology
Project budget	\$69.5 million over 5 years spread over programs 1 to 5
Source of funding	Australian Research Centre and National Water Commission
Project duration	2009 – 2014
Current status	In progress
Project summary	<p>Groundwater is a crucial resource, but to manage it effectively we need to know much more about our underground water systems. When data on underground geological properties is limited or non-existent, incorrect management decisions could be made.</p> <p>Addressing these concerns is the focus of Program 1. NCGRT seek to develop new field and laboratory methods to gather subsurface hydrogeological data, and to develop novel analytical methods to build accurate 3D geological models that link geological and hydrogeological processes.</p> <p>As part of NCGRT research, a centrifuge facility has been established, which allows the measurement of the very slow rates of water movement in aquitards. Novel geophysical and geochemical techniques are also being used to characterise water movement in both aquifers and aquitards. Furthermore, geological modelling is being focusing on novel geostatistical approaches to improve 3D geological models and to better quantify uncertainty.</p> <p>Researchers within the program collaborate across the NCGRT, and work closely with the NSW Department of Primary Industries and Geoscience Australia. NCGRT also make extensive use of the Super Science long-term monitoring sites at Wellington and Namoi in NSW.</p>
Objectives	To meet the NCGRT strategic plan, which is available at: http://www.groundwater.com.au/publications
Achievements	<ul style="list-style-type: none"> Core permeability testing methods: Testing of drill core permeability using helium-gas permeation and geotechnical centrifuge under variable stress conditions. A PhD by Katarina David in underway about groundwater leakage through overburden strata above longwall mining. An investigation on the role of aquitards (sediments and rock) in disconnecting shallow waters and deep coal seams that are de-pressurised for CSG or mining. NCGRT training courses and publications.
Outputs	<ul style="list-style-type: none"> Anderson D and Timms W (2014) "Vertical permeability of aquitards – core tests to basin scale modelling". In Geological Society of Australia, 2014

Project characteristics	Details
	<p>Australian Earth Sciences Convention (AESC), Sustainable Australia. Abstract No 110 of the 22nd Australian Geological Convention, Newcastle City Hall and Civic Theatre, Newcastle, New South Wales. July 7–10.</p> <ul style="list-style-type: none"> • Timms WA, Whelan M, Acworth I, McGeeney D, Bouzalakos S, Crane R, McCartney J and Hartland A (eds.) (2014) "A novel centrifuge permeameter to characterize flow through low permeability strata.", in <i>Physical Modelling in Geotechnics: Proceedings of the 8th International Conference on Physical Modelling in Geotechnics 2014 (ICPMG2014)</i>, Perth, Australia, 14–17 January 2014, Taylor & Francis Ltd (CRC Press), pp. 193–199, presented at International Congress on Physical Modelling in Geotechnics, Perth, WA, 14–17 January 2014, http://www.crcpress.com/product/isbn/9781138001527. • Timms W, Acworth I and Hartland A (2012) "Leading practices for assessing the integrity of confining strata: Application to mining and coal-seam gas extraction." In: McCullough CD, Lund MA and Wyse L. <i>Proceedings of International Mine Water Association</i>, September 29–October 4, 2012, Bunbury, Western Australia. Bunbury, Western Australia: International Mine Water Association. • Bouzalakos S, Timms W, Rahman P, McGeeney D and Whelan M (2013) "Geotechnical centrifuge permeater for characterizing the hydraulic integrity of partially saturated confining strata for CSG operations". In: Brown A, Figueroa L, Wolkersdorfer Ch (eds) (2013) <i>Reliable Mine Water Technology (Vol I)</i>. 1–778; Denver, Colorado, USA (Publication Printers). <i>Proceedings of the International Mine Water Congress</i>, Colorado School of Mines, August 5–9, 2013. • Timms W, Bouzalakos S, Kelly B, Crane R, Guinea A, Acworth I and David K (2013) "When is an aquitard an aquiclude? Evaluating the integrity of low permeability strata for mining and CSG developments". 40th IAH Congress on Solving the Groundwater Challenges of the 21st Century, 15–20 September 2013, Perth, Australia. • Bouzalakos S and WA Timms (2013) "The importance of confining strata integrity in mining, coal seam gas extraction and geological storage of industrial waste (CO₂ and nuclear): to-wards early detection indicators of potential groundwater contamination." 6th SDIMI congress, 30 June–3 July 2013, Milos island, Greece. • Bouzalakos S, Crane R, Liu H and Timms W (2014) "Geotechnical and modeling studies of low permeability barriers to limit mine water seepage". <i>Water in Mining Congress</i>, 28–30th May 2014, Chile. • Timms W, Liu H and Laurence D (2014) "Design of low permeability barriers to limit subsurface mine water seepage". <i>Water in Mining Conference</i>, 26–28th November 2013, Brisbane, Australia. • David K, Timms W and Mitra R (2014) "Overview of groundwater responses to longwall coal mining in the Sydney Basin, Australia". Geological Society of Australia, 2014 Australian Earth Sciences Convention (AESC), Sustainable Australia. Abstract No 110 of the 22nd Australian Geological Convention, Newcastle City Hall and Civic Theatre, Newcastle, New South Wales. July 7–10.
Key personnel	Acworth, I; Andersen, Martin; Cox, Malcolm; Kelly, Bryce; Mariethoz, Grégoire; Timms, Wendy; David, Katarina
Research themes	Water supplies, aquifer interconnectivity
Project	Survey

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Project characteristics	Details
information source	

Table 4.12 Project 12: Influence of geological structures on groundwater flow project

Project characteristics	Details
Project title	Influence of geological structures on groundwater flow project
Project location	Australia
Principal investigator	Phillipson, Keith
Lead institution	Office of Groundwater Impact Assessment (OGIA), Queensland Department of Natural Resources and Mines
Project budget	Undisclosed
Source of funding	OGIA through an industry levy
Project duration	2012 – 2015
Current status	In progress
Project summary	<p>As part of its work in gaining a better understanding about groundwater flow systems in the Surat Basin and improving the predictions of the impacts of Coal Seam Gas (CSG) water extractions on groundwater water resources in the Surat Cumulative Management Area (CMA), the Office of Groundwater Impact Assessment (OGIA) is carrying out the Geological Structures Project (the GSP).</p> <p>The Surat Underground Water Impact Report (UWIR) was approved in December 2012. It contains predictions of the impacts of CSG water extractions on groundwater water resources. To prepare the Surat UWIR, the OGIA constructed a regional groundwater flow model. The conceptual model or geological model underpinning this flow model was based dominantly on secondary data available at that time. In addition, the original geological model did not explicitly contain geological structures such as faults.</p> <p>The GSP is improving understanding of the influence of geological structures on the regional groundwater flow system with the Surat CMA. Outcomes from the GSP will be incorporated into the next revision of the regional groundwater flow model that will be used to update the Surat UWIR in late 2015.</p>
Objectives	To better understand the influence of geological structures on the regional groundwater flow system in the Surat CMA.
Achievements	Collation and analysis of existing data and knowledge (in progress).
Outputs	<ul style="list-style-type: none"> Assessment of the influence of geological structures on groundwater flow (in progress). Project outcomes will be included in the groundwater conceptualisation, regional flow modelling and reporting for the next Surat CMA UWIR (in December 2015). Pandey S and Foster L (2013) "The preparation of the Surat Underground Water Impact Report - the basis for cumulative management of impacts from coal seam gas water extraction in the Surat and Southern Bowen basins in Queensland". 40th IAH Congress on Solving the Groundwater Challenges of the 21st Century, 15–20 September 2013, Perth, Australia. https://www.dnrm.qld.gov.au/ogia/2013-annual-report-summary
Key personnel	Phillipson, Keith; Sliwa, Renate; Foster, Linda
Research themes	Influence of geological structures on groundwater dynamics, aquifer interconnectivity, cumulative impact assessments

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Project characteristics	Details
Project information source	Survey

Table 4.13 Project 13: Geological modelling project

Project characteristics	Details
Project title	Geological modelling project
Project location	Australia
Principal investigator	Sliwa, Renate; McKillop, Michael; Esterle, Joan; Foster, Linda
Lead institution	Office of Groundwater Impact Assessment (OGIA), Queensland Department of Natural Resources and Mines
Project budget	Undisclosed
Source of funding	OGIA through an industry levy
Project duration	2012 – 2015
Current status	In progress
Project summary	<p>As part of its work in gaining a better understanding about groundwater flow systems in the Surat Basin and improving the predictions of the impacts of Coal Seam Gas (CSG) water extractions on groundwater water resources in the Surat Cumulative Management Area (CMA), the Office of Groundwater Impact Assessment (OGIA) is carrying out the Geological Modelling Project (the GMP).</p> <p>The Surat Underground Water Impact Report (UWIR) was approved in December 2012. It contains predictions of the impacts of CSG water extractions on groundwater water resources. To prepare the Surat UWIR the OGIA constructed a regional groundwater flow model. The conceptual model or geological model underpinning this flow model was based dominantly on secondary data available at that time. In addition the original geological model did not explicitly represent geological structures such as faults.</p> <p>The GMP is redeveloping the geological model through primary stratigraphic interpretation of coal seam gas (CSG) wells and water bores and subsurface geological and facies modelling. The refined model will provide input into the Modelling methodology project which is developing the second generation groundwater flow model.</p> <p>The project is being undertaken in partnership with the School of Earth Sciences at the University of Queensland (UQ) and Geological Survey of Queensland (GSQ).</p>
Objectives	To develop an improved geological model for the Surat Cumulative Management Area (CMA).
Achievements	<ul style="list-style-type: none"> • Stratigraphic interpretation of coal seam gas (CSG) wells and water bores and subsurface geological and facies modelling. • Draft working geological model (in progress).
Outputs	<ul style="list-style-type: none"> • Regional geological model (in progress). • Project outcomes included in the groundwater conceptualisation, regional flow modelling and reporting for the next Surat CMA UWIR (in December 2015). <p>https://www.dnrm.qld.gov.au/ogia/2013-annual-report-summary</p>
Key personnel	Pandey, Sanjeev; Foster, Linda

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Project characteristics	Details
Research themes	Geological modelling, cumulative impact assessments, aquifer interconnectivity
Project information source	Survey

Table 4.14 Project 14: Condamine connectivity project

Project characteristics	Details
Project title	Condamine connectivity project
Project location	Australia
Principal investigator	Pandey, Sanjeev
Lead institution	Office of Groundwater Impact Assessment (OGIA), Queensland Department of Natural Resources and Mines
Project budget	Unknown
Source of funding	OGIA through an industry levy
Project duration	2012 – 2015
Current status	In progress
Project summary	<p>As part of its work in gaining a better understanding about groundwater flow systems in the Surat Basin, the Office of Groundwater Impact Assessment (OGIA) is carrying out the Condamine Connectivity Project (the CCP). The CCP is part of the implementation of the Surat Underground Water Impact Report (UWIR) which was approved in December 2012.</p> <p>The CCP is improving understanding of the connectivity between the Condamine Alluvium (CA) – a significant aquifer in the region – and the Walloon Coal Measures (WCM). Outcomes from the CCP will be incorporated into the next revision of the regional groundwater flow model that will be used to update the Surat UWIR in late 2015. This will include updated predictions about the potential leakage of water from CA based on planned CSG development.</p>
Objectives	To improve understanding of the connectivity between the Condamine Alluvium and Walloon Coal Measures.
Achievements	<ul style="list-style-type: none"> • Water level mapping and hydrochemistry analysis. • Geological modelling.
Outputs	<ul style="list-style-type: none"> • Assessment of connectivity between the Condamine Alluvium and Walloon Coal Measures based on water level, hydrochemical, aquifer pump test and geophysical analysis. • Project outcomes will be included in the groundwater conceptualisation, regional flow modelling and reporting for the next Surat CMA UWIR (in December 2015). • Developing an improved monitoring approach for springs potentially impacted by coal seam gas development in the Surat Cumulative Management Area, Queensland • Pandey S and Foster L (2013) "The preparation of the Surat Underground Water Impact Report - the basis for cumulative management of impacts from coal seam gas water extraction in the Surat and Southern Bowen basins in Queensland". 40th IAH Congress on Solving the Groundwater Challenges of the 21st Century, 15–20 September 2013, Perth, Australia.
Key personnel	Pandey, Sanjeev; Gallagher, Mark; Dickinson, Chris; Singh, Dhananjay
Research themes	Aquifer interconnectivity, cumulative impact assessment

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Project characteristics	Details
Project information source	Survey

Table 4.15 Project 15: Spring knowledge projects

Project characteristics	Details
Project title	Spring knowledge projects
Project location	Australia
Principal investigator	Flook, Steven
Lead institution	Office of Groundwater Impact Assessment (OGIA), Queensland Department of Natural Resources and Mines
Project budget	Unknown
Source of funding	OGIA through an industry levy
Project duration	2012 – 2015
Current status	In progress
Project summary	<p>The Surat Underground Water Impact Report (UWIR) was approved in December 2012. It contains predictions of the impacts of CSG water extractions on groundwater water resources in the Surat Cumulative Management Area (CMA). To prepare the Surat UWIR the Office of Groundwater Impact Assessment (OGIA) constructed a regional groundwater flow model.</p> <p>The Surat UWIR will be updated in December 2015. To update the UWIR, OGIA will build a new regional groundwater flow model. The new model will incorporate new knowledge about the groundwater flow system resulting from a range of hydrogeological research projects being carried out by OGIA.</p> <p>In parallel with the other research projects, OGIA is also carrying out a project to advance understanding in relation to springs in the following areas:</p> <ul style="list-style-type: none"> • improving knowledge about the hydrogeological setting of springs • improving the techniques and selection of attributes used for monitoring springs • identifying watercourse that are receiving a groundwater contribution. <p>The outcomes from this research will be used to inform the future assessments of risks to springs and the monitoring and management arrangements established under the UWIR in December 2015.</p>
Objectives	To enhance existing knowledge of flow vulnerability of springs to impacts from CSG water extraction in the Surat CMA and inform best practice spring monitoring and management arrangements.
Achievements	<ul style="list-style-type: none"> • Preliminary assessment of the local scale hydrogeological understanding of springs in the Surat CMA. • Field investigations to test hypotheses for spring occurrence (in progress). • Evaluation of best practice approaches for monitoring springs. • Pilot program to trial spring monitoring techniques (in progress).
Outputs	<ul style="list-style-type: none"> • Refined assessment of the local scale understanding of springs in the Surat CMA (in progress). • Identification of best practice spring monitoring techniques (in progress). • Identification of watercourses receiving groundwater contribution in the CMA (in progress). • Documentation of improvements in spring knowledge (in progress).

Project characteristics	Details
	<ul style="list-style-type: none"> Project outcomes will also form part of the groundwater conceptualisation, regional flow modelling and spring impact management plan for the next Surat CMA UWIR (in December 2015). <p>Flook S, Pandey S and Foster L (2013) "The management of springs in the area of coal seam gas development in the Surat and southern Bowen Basins in Queensland". 40th IAH Congress on Solving the Groundwater Challenges of the 21st Century, 15–20 September 2013, Perth, Australia.</p>
Key personnel	Flook, Steven
Research themes	Aquifer interconnectivity, water-dependent ecosystems, cumulative impact assessments
Project information source	Survey

Table 4.16 Project 16: Modelling methodology project

Project characteristics	Details
Project title	Modelling methodology project
Project location	Australia
Principal investigator	Doherty, John
Lead institution	Office of Groundwater Impact Assessment (OGIA), Queensland Department of Natural Resources and Mines; Flinders University
Project budget	Undisclosed
Source of funding	OGIA through an industry levy
Project duration	2012 – 2015
Current status	In progress
Project summary	<p>The Surat Underground Water Impact Report (UWIR) contains predictions of the impacts of CSG water extractions on groundwater water resources in the Surat Cumulative Management Area (CMA). To prepare the Surat UWIR, the Office of Groundwater Impact Assessment (OGIA) constructed a regional groundwater flow model.</p> <p>The Surat UWIR will be updated in December 2015. To update the UWIR, OGIA will build a new regional groundwater flow model. The new model will incorporate new knowledge about the groundwater flow system resulting from a range of hydrogeological research projects being carried out by OGIA.</p> <p>In parallel with the hydrogeological research projects, OGIA is also carrying out a Modelling Methodology Project (MRP). The MRP will determine the best modelling method to use to simulate groundwater flow in the updated understanding of the groundwater flow system.</p> <p>When the MRP and the hydrogeological research projects are complete, construction of a new regional groundwater flow model will commence.</p>
Objectives	To determine the most practicable modelling method for simulating groundwater flow, and groundwater drawdown impacts of CSG activities, in the Surat CMA.
Achievements	Development and testing of different modelling techniques (in progress).
Outputs	<ul style="list-style-type: none"> • Identification of the modelling methodology to be used in the next OGIA regional groundwater flow model. • Project outcomes will be used to construct the regional groundwater flow model that will support the preparation of the next Surat UWIR (in December 2015). <p>https://www.dnrm.qld.gov.au/ogia/2013-annual-report-summary</p> <p>Wallis I, Moore C, Post V, Prommer H, Wolf L, Martens E and Simmons C (2013) "Using predictive uncertainty analysis to optimise experimental design and data acquisition from field trials for CSG water reinjection". 40th IAH Congress on Solving the Groundwater Challenges of the 21st Century. Perth, Australia.</p>
Key personnel	Doherty, John; Gallagher, Mark; Herckenrath, Daan; Pandey, Sanjeev
Research themes	Regional groundwater flow modelling, cumulative impact assessments, quality and reliability of water supplies (long-term impacts), aquifer interconnectivity

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Project characteristics	Details
Project information source	Survey

Table 4.17 Project 17: Temporal groundwater level responses in groundwater monitoring bores and their significance, Surat Basin, Queensland

Project characteristics	Details
Project title	Temporal groundwater level responses in groundwater monitoring bores and their significance, Surat Basin, Queensland
Project location	Australia
Principal investigator	Horgan, MJ
Lead institution	Origin Energy
Project budget	Unknown
Source of funding	Unknown
Project duration	Unknown—Literature output 2013
Current status	Unknown—Literature output 2013
Project summary	<p>The production of coal seam gas (CSG) generally requires the pumping of groundwater to reduce pressure within coal seams. In the Surat Basin the main target unit for CSG is the Walloon Coal Measures. Aquitards separate these target units from significant regional aquifers such as the Mooga, Gubberamunda and Springbok Sandstones above, and the Hutton and Precipice Sandstones below. Significant regional monitoring of groundwater levels and quality is being conducted within the target coal seam gas horizons, aquitards and aquifers. Groundwater levels, as observed in the groundwater monitoring bores Origin is managing on behalf of Australia Pacific LNG, are impacted by a range of factors that include without limitation:</p> <ul style="list-style-type: none"> • barometric influences • earth tides • the temperature of the water column in the observation bores • groundwater supply pumping by landholders not associated with CSG production • loading of the stratigraphic pile during major wet season events • pumping impact from CSG production wells. <p>Origin, on behalf of Australia Pacific LNG, has established nested monitoring bore sites where groundwater levels in different aquifers at different depths can be readily observed both manually and using automatic groundwater level loggers. Data obtained by Origin has demonstrated appreciable temporal groundwater level variation exists in most of the aquifers assessed due to barometric influences, earth tides and likely due to loading impacts after the 2011 major wet season/flooding event. These impacts need to be taken into account in establishing baseline conditions. The cooling of groundwater in deep groundwater monitoring bores (up to 1000 m) is also very significant, with differences between surface water column temperatures and bottom hole temperatures in the order of 30 degrees Celsius. These temperature differences may result in observed groundwater levels being up to 10 m less than would be the case if the whole water column was at bottom hole temperature.</p>
Objectives	To discuss the issues relevant to temporal groundwater level responses in groundwater monitoring bores and their significance in the Surat Basin, Queensland.

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Project characteristics	Details
Achievements	Unknown
Outputs	Horgan MJ and Evans P (2013) "Temporal groundwater level responses in groundwater monitoring bores and their significance, Surat Basin, Queensland". 40 th IAH Congress on Solving the Groundwater Challenges of the 21 st Century. Perth, Australia.
Key personnel	Horgan, MJ; Evans, PA
Research themes	Aquifer interconnectivity
Project information source	40 th IAH Congress

Table 4.18 Project 18: Implementation of a regional groundwater monitoring programme in the developing coal seam gas (CSG) fields, Surat and Southern Bowen Basins, Queensland, Australia

Project characteristics	Details
Project title	Implementation of a regional groundwater monitoring programme in the developing coal seam gas (CSG) fields, Surat and Southern Bowen Basins, Queensland, Australia
Project location	Australia
Principal investigator	Hamer, Ned
Lead institution	Origin Energy
Project budget	Unknown
Source of funding	Unknown
Project duration	Unknown—Literature output 2013
Current status	Unknown—Literature output 2013
Project summary	<p>The expanding coal seam gas (CSG) industry in Queensland is well underway in the development of a network of more than 500 monitoring points, comprising individual or groups ("nests") of groundwater monitoring bores into numerous aquifers. This monitoring infrastructure, together with data being collected from several thousand existing groundwater bores during a water bore baseline monitoring programme, forms the core of the CSG industry and Government's ongoing assessment of cumulative groundwater impacts from the CSG and other industries utilising groundwater in the Surat and Southern Bowen Basins. The monitoring network has been designed for monitoring pressure and water quality trends in geological zones above and below the coal seams for early detection, as well as in aquifers more widely utilised for water supply, and within the coal measures themselves. A basin-wide groundwater flow model was developed by the Queensland Water Commission (now Office of Groundwater Impact Assessment (OGIA)) to assess potential effects from the production of CSG water. This model utilised relevant publically available geological and hydrogeological data, as well as a considerable data set provided by the CSG industry gathered through recent exploration programmes. This modelling has been utilised to inform the locations and timing of implementation of the monitoring network. Currently there are around 1400 producing CSG wells, compared with more than 13 000 existing water bores being utilised for existing industries across the same area. A significant escalation in CSG production activity is predicted, necessitating the up-scaling of the monitoring network. A number of monitoring bores had already been installed by the CSG industry prior to modelling completion. The OGIA have since established a timeframe for installation of remaining bores which is planned to occur in advance of the expanding CSG industry.</p> <p>Design of the monitoring infrastructure has considered the longevity of the expected monitoring programme, as well as the significant temperatures, pressures, and in some cases corrosive water qualities of the subsurface environment. A balance has been reached between trialling newer but relatively un-tested technology under such conditions, along with adoption of "tried and tested" conventional methods. Experiences from monitoring programmes that have been in place for some decades in US CBM fields has been applied. Trials are continuing and are planned to improve data collection efficiencies and quality.</p>

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Project characteristics	Details
Objectives	Design and implementation of a CSG monitoring network.
Achievements	Design and implementation of a CSG monitoring network in a difficult working environment, as well as presentation of some early monitoring data and trends.
Outputs	Hamer N and Harris K (2013) "Implementation of a regional groundwater monitoring programme in the developing coal seam gas (CSG) fields, Surat and Southern Bowen Basins, Queensland, Australia". 40 th IAH Congress on Solving the Groundwater Challenges of the 21 st Century. Perth, Australia
Key personnel	Hamer, Ned; Harris, Kathryn
Research themes	Aquifer interconnectivity
Project information source	40 th IAH Congress

Table 4.19 Project 19: AGL Gloucester water studies

Project characteristics	Details
Project title	AGL Gloucester water studies
Project location	Australia
Principal investigator	Duggleby, James
Lead institution	Parsons Brinckerhoff, Sydney; AGL Energy, Sydney
Project budget	Unknown
Source of funding	AGL
Project duration	Unknown—Literature output 2013
Current status	Unknown—Literature output 2013
Project summary	<p>AGL acknowledges that both surface and groundwater resource protection is a key issue for the Gloucester community. AGL believes it is critical to protect water resources and manage produced water as part of the sustainable development of coal seam gas. An extensive water monitoring network has been installed across the Gloucester area and as at December 2013 includes:</p> <ul style="list-style-type: none"> • forty two (42) groundwater monitoring bores installed with dataloggers to record water levels • five (5) stream gauges installed with dataloggers recording salinity and water levels (surface water), and five dam monitoring locations • two (2) shallow gas monitoring bores • two (2) seepage monitoring bores to detect any seepage from the Tiedman produced water dams. <p>More monitoring sites (mostly across the broader Gloucester Basin) are planned for 2014.</p> <p>Groundwater investigations for the Gloucester Gas Project are well advanced. The investigation studies that are completed and ongoing comprise the following phases:</p> <ul style="list-style-type: none"> • Phase 1: Desktop study (completed) • Phase 2: Detailed groundwater investigations and Stage 1 network (completed) • Phase 3: Numerical models (commenced) • Phase 4: Monitoring programs - Stage 1 and beyond (ongoing) • Phase 5: Additional investigations - Stage 1 and beyond (commenced) <p>As part of ongoing site investigations and required compliance monitoring programs, Parsons Brinckerhoff in an independent scientific advisory role is currently undertaking staged groundwater investigations and monitoring programs for AGL in their Hunter, Camden and Gloucester exploration areas in parallel with future planning for CSG developments. Following the installation of groundwater monitoring networks that provide broad spatial coverage of groundwater conditions, groundwater monitoring involves continuous groundwater level monitoring, groundwater quality monitoring (including isotope studies) and hydraulic conductivity testing. At the Gloucester site a constant rate pumping test and a long term flow test examining connectivity around a local fault and with deeper coal seams was also undertaken.</p>

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Project characteristics	Details
Objectives	Design, specification and implementation of large scale monitoring programs developed to determine the connectivity of shallow water supply/beneficial use aquifers that people and ecosystems depend on, and deeper coal seam water bearing zones.
Achievements	<ul style="list-style-type: none"> • Development of conceptual geological model. • Assessment of aquifer interconnectivity.
Outputs	<p>For a complete list of outputs, go to: http://www.agl.com.au/about-agl/how-we-source-energy/natural-gas/natural-gas-projects/gloucester-gas-project/water-management</p> <p>Duggleby J, Ross J, McLean W and Kwantes E (2013) "Monitoring shallow & deep groundwater systems for coal seam gas impact in NSW, Australia". 40th IAH Congress on Solving the Groundwater Challenges of the 21st Century. Perth, Australia.</p>
Key personnel	Duggleby, James; Ross, John
Research themes	Aquifer interconnectivity, water supplies, surface water
Project information source	Website, conferences

Table 4.20 Project 20: Introducing dual phase to integrated regional groundwater numerical modelling of large scale coal seam gas development

Project characteristics	Details
Project title	Introducing dual phase to integrated regional groundwater numerical modelling of large scale coal seam gas development
Project location	Australia
Principal investigator	de Verteuil, Daniel
Lead institution	QGC
Project budget	Unknown
Source of funding	Unknown
Project duration	Unknown—Literature output 2013
Current status	Unknown—Literature output 2013
Project summary	Traditional regional groundwater flow models have relied on single phase modelling techniques and software. This was the case with previous generations of groundwater models built in MODFLOW to quantify the impact of the four proposed large coal seam gas (CSG) development projects in the Surat Basin. However, recently there has been recognition that the drawdown progression in the coal bearing formations due to CSG production is strongly influenced by the presence of free gas and as such single phase modelling struggles to characterise the de-watering of the coals. QGC has used oil & gas industry expertise in dual phase modelling to overcome this limitation and thereby revolutionise regional groundwater modelling for CSG production. This paper seeks to detail how QGC has applied oil & gas industry standard software (PETREL & ECLIPSE) and best practice to build, calibrate and simulate a regional groundwater model including the productive Walloon Coal Measures (WCM). Innovative workflows have been devised to overcome the inherent "closed-system" standard of ECLIPSE numerical simulation models while a dual porosity system is applied to accurately capture the physics of evolving gas from the surface of coal as it is de-watered. Building on the knowledge gained from previous generations of groundwater model, a revised hydrogeological conceptualisation has been coupled with a more refined structural and stratigraphic geocellular model. Using available hydrogeological data, calibration of the ECLIPSE model was completed with a range of cases generated to represent the inherent uncertainty. The model is being used to test groundwater management scenarios with predictive cases including production from ~7000 QGC CSG wells being run to quantify the impact of the development and potential recovery.
Objectives	To detail how QGC has applied oil & gas industry standard software (PETREL & ECLIPSE) and best practice to build, calibrate and simulate a regional groundwater model including the productive Walloon Coal Measures (WCM).
Achievements	Unknown
Outputs	de Verteuil D, Howell S, Campbell L, Guiton S and Ryan D (2013) "Introducing dual phase to integrated regional groundwater numerical modelling of large scale coal seam gas development." 40 th IAH Congress on Solving the Groundwater Challenges of the 21 st Century. Perth, Australia.

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Key personnel	de Verteuil, Daniel; Howell, Stephen; Campbell, Lindsey; Guiton, Sam; Ryan, Damien
Research themes	Aquifer interconnectivity, water-dependent resources
Project information source	40 th IAH conference

Table 4.21 Project 21: GEN3 Surat Basin dual phase regional groundwater flow model

Project characteristics	Details
Project title	GEN3 Surat Basin dual phase regional groundwater flow model
Project location	Australia
Principal investigator	de Verteuil, Daniel
Lead institution	QGC - a BG Group business
Project budget	\$2 000 000
Source of funding	QGC
Project duration	1/03/2012 - Unknown
Current status	In progress
Project summary	Build, Calibrate & Run the GEN3 Dual Phase Regional Groundwater flow model to predict the impact of QGC's CSG development on the groundwater resources of the Surat Basin.
Objectives	<ul style="list-style-type: none"> • To re-evaluate the conceptual hydrogeological model of the Surat Basin. • To develop a consistent regional groundwater model that is compliant with the 2012 Australian Groundwater Modelling Guidelines. • To create a model that can predict drawdown to protect EPBC springs: <ul style="list-style-type: none"> – modelling impacts for existing users – predicting the effectiveness of response actions – monitoring uncertainty reduction. <p>These requirements provide the context for the detailed GEN3 model objectives, namely:</p> <ul style="list-style-type: none"> • to advance the modelling of CSG de-pressurisation for the Surat Basin hydrogeological system • to account for the impact of dual phase phenomenon on the drawdown associated with CSG production (as prescribed by the 2012 Australian Groundwater Modelling Guidelines) • to incorporate the latest subsurface data from QGC's operations • to develop procedures that allow the modelling team to: <ul style="list-style-type: none"> – improve the permeability model of the Walloon coals – integrate a robust regionally consistent stratigraphic framework of the major geological units in the Surat Basin – account for heterogeneity in the Walloon Coal Measures and Springbok formations and thus improve upscaling for regional models – refine the assumptions for model boundary conditions to reflect the latest understanding – qualify and quantify the uncertainty associated with the model and how that translates into a range of outcomes – to align QGCs geology and hydrogeological data into one model – to create a 3D visual and numerical representation of the Surat hydrogeological system which is of a Class 2 (Australian Groundwater Modelling Guidelines) confidence level and can be used to predict potential impacts and changes in water level spatially over time due to

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
	predicted QGC CSG production.
Achievements	Project is still in progress so not all achievements can be listed yet. World's 1 st dual phase regional groundwater flow model to predict the impact of CSG development.
Outputs	GEN3 Model Conceptualisation, Design & Build Report GEN3 Model Calibration Report GEN3 Model Predictive Uncertainty Analysis and Scenario Modelling Report SPE Paper 167049 - The Future of Integrated Groundwater and CSG Simulation - <i>Modelling the Surat Basin</i> , Queensland IAH 2013 Presentation - Introducing dual phase to integrated regional groundwater numerical modelling of large scale coal seam gas development.
Key personnel	de Verteuil, Daniel; Vaughan, Rhodri; Campbell, Lindsey; Guiton, Sam; Howell, Stephen; Ryan, Damien
Research themes	Aquifer interconnectivity
Project information source	Survey

Table 4.22 Project 22: Surat Basin aquifer connectivity study

Project characteristics	Details
Project title	Surat Basin aquifer connectivity study
Project location	Australia
Principal investigator	McKelvey, Patrick
Lead institution	QGC Pty Ltd
Project budget	\$20 000 000
Source of funding	QGC Pty Ltd
Project duration	8/09/2012 - Unknown
Current status	In progress
Project summary	Use a variety of static and dynamic data at different spatial and temporal scales to understand aquifer connectivity in the Surat Basin.
Objectives	Understand and predict the impacts of CSG abstraction.
Achievements	<ul style="list-style-type: none"> • Collation of a significant data set. • Substantial completion of three pilot tests. • Reconceptualisation of Surat hydrostratigraphy.
Outputs	Internal reports. All data submitted to OGIA.
Key personnel	McKelvey, Patrick; Evans, Rick
Research themes	Aquifer interconnectivity; well integrity; water-dependent ecosystems; cumulative impact assessments
Project information source	Survey

Table 4.23 Project 23: Development of 3D geological model of the Clarence-Moreton Basin and the eastern part of the Surat Basin

Project characteristics	Details
Project title	Development of 3D geological model of the Clarence-Moreton Basin and the eastern part of the Surat Basin
Project location	Australia
Principal investigator	Owen, Daniel D.R.
Lead institution	Queensland University of Technology
Project budget	Unknown
Source of funding	Unknown
Project duration	Unknown—Literature output 2013
Current status	Unknown—Literature output 2013
Project summary	Development of a 3D hydrogeological model of the Queensland section of the CMB and the eastern part of the Surat Basin using GoCAD modelling software and integration of isotopic and hydrochemical data. Use of multi-variate statistical techniques and integration of isotopes and water chemistry will help to assess interactions between aquifers and determine the water chemistry baseline of different aquifers. Prior to large-scale coal seam gas extraction it is essential to understand the existing hydrochemical character of the different aquifers and to establish any potential linkages.
Objectives	Establish the connectivity between the Condamine alluvium and the Walloon Coal Measures by integration of aquifer geology and lithology, the use of hydrochemical and isotopic data, and the development of a 3D conceptual model of aquifer interactions. The results of this study will support a holistic approach to management of groundwater extraction for irrigation and for coal seam gas production.
Achievements	The assessment has been used to identify hydrochemical facies and baselines within the different aquifers of the Upper Condamine River catchment.
Outputs	<p>Owen D, Raiber M and Cox M (2014) The use of simple hydrochemical indicators to identify CSG groundwaters and delineate groundwater flow paths within and between aquifers. In Geological Society of Australia, 2014 <i>Australian Earth Sciences Convention (AESC), Sustainable Australia. Abstract No 110 of the 22nd Australian Geological Convention</i>, Newcastle City Hall and Civic Theatre, Newcastle, New South Wales. July 7–10.</p> <p>Raiber M, Cendon D, Feitz A, Sundaram B and Suckow A (2014) Hydrochemical and isotopic fingerprinting of the Walloon Coal Measures and adjacent aquifers in the Clarence-Moreton and Eastern Surat Basins in southeast Queensland. In Geological Society of Australia, 2014 <i>Australian Earth Sciences Convention (AESC), Sustainable Australia. Abstract No 110 of the 22nd Australian Geological Convention</i>, Newcastle City Hall and Civic Theatre, Newcastle, New South Wales. July 7–10.</p> <p>Owen D, Raiber M and Cox M (2013) "Using multivariate statistics to assess hydrochemical facies within the alluvial aquifers of the upper Condamine River, southeast Queensland: implications for connectivity between alluvial and bedrock aquifers in the Surat Basin." 40th IAH Congress on Solving the Groundwater Challenges of the 21st Century. Perth, Australia.</p>

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Key personnel	Raiber, Matthias; Cox, Malcolm E
Research themes	Aquifer interconnectivity
Project information source	Conferences, website, UQ CCSG Online Portal

Table 4.24 Project 24: Groundwater chemistry baseline of the Walloon Coal Measures in the Clarence-Moreton and Surat Basins, Queensland, Australia

Project characteristics	Details
Project title	Groundwater chemistry baseline of the Walloon Coal Measures in the Clarence-Moreton and Surat Basins, Queensland, Australia
Project location	Australia
Principal investigator	Raiber, M
Lead institution	Queensland University of Technology; CSIRO; ANSTO; University of New South Wales
Project budget	Unknown
Source of funding	Unknown
Project duration	Unknown—Literature output 2013
Current status	Unknown—Literature output 2013
Project summary	<p>The Walloon Coal Measures (WCM) are a major target for coal seam gas exploration in the Surat and Clarence-Moreton basins in Queensland and New South Wales, Australia. It is now widely acknowledged that an improved understanding of the groundwater baseline is essential. Fundamental is determining the geological framework and an unbiased examination of the natural range, or baseline, of groundwater chemistry of the coal seams and adjacent aquifers. In order to determine the processes that control the spatial variability and evolution of groundwater chemistry, the chemistry baseline data of the WCM or the Surat and Clarence-Moreton basins are placed within the framework of a 3D geological model. In the assessment of the water chemistry baseline, four groundwater chemistry groups were identified from the hierarchical cluster analysis (HCA) which was applied to historical groundwater chemistry records from the Department of Natural Resources and Mines (DNRM) groundwater database. Each of these distinct groups contains groundwaters of a similar composition, which result from a number of different processes (e.g. groundwater recharge or interaction with other aquifers). However, groundwater of only one group has the typical composition of CSG waters, as documented by very high HCO_3^-, and simultaneously low SO_4^{2-}, Ca and Mg concentrations, whereas the chemical composition of groundwater assigned to the other groups suggests that these follow a different evolutionary pathway. Following this initial screening, a total of ~60 samples was collected from the different groundwater chemistry groups for analysis of water chemistry (major, trace, rare earth elements and dissolved gasses) and isotopic fingerprinting ($\text{d}2\text{H}$, $\text{d}2\text{H}-\text{CH}_4$, $\text{d}13\text{C}-\text{DIC}$, $\text{d}13\text{C}-\text{CH}_4$, $\text{d}18\text{O}$, $87\text{Sr}/86\text{Sr}$, $14\text{C}-\text{DIC}$ and $36\text{Cl}/\text{Cl}$). The analyses were combined with results from a similar groundwater chemistry study undertaken in the Surat Basin during 2009 to 2011 that aimed to establish a groundwater chemistry baseline for geological storage of CO_2. The analyses of dissolved gases shows that there is a strong variability of dissolved CH_4 concentration within groundwaters of the WCM, ranging from values below the reporting limit to ~50 mg/L. Likewise, isotope signatures and groundwater residence times within these coal-bearing sequence are highly variable spatially, reflecting the range of processes involved in groundwater evolution as well as the variable composition of these sedimentary rocks.</p>

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Objectives	To develop a groundwater chemistry baseline of the Walloon Coal Measures in the Clarence-Moreton and Surat Basins.
Achievements	A total of ~60 samples was collected from the different groundwater chemistry groups for analysis of water chemistry (major, trace, rare earth elements and dissolved gasses) and isotopic fingerprinting (d2H, d2H-CH4, d13C-DIC, d13C-CH4, d18O, 87Sr/86Sr, 14CDIC and 36Cl/Cl).
Outputs	Raiber M, Cox ME, Cendon DJ and Feitz AJ (2013) "Groundwater chemistry baseline of the Walloon Coal Measures in the Clarence-Moreton and Surat basins, Queensland, Australia". 40 th IAH Congress on Solving the Groundwater Challenges of the 21 st Century. Perth, Australia.
Key personnel	Raiber, M; Cox, Malcolm E; Cendon, DJ; Feitz, AJ
Research themes	Aquifer interconnectivity
Project information source	40 th IAH Congress, website

Table 4.25 Project 25: Aquifer interconnectivity in the Galilee and Eromanga basins

Project characteristics	Details
Project title	Aquifer interconnectivity in the Galilee and Eromanga basins
Project location	Australia
Principal investigator	Moya, Claudio
Lead institution	Queensland University of Technology; NCGRT
Project budget	Unknown
Source of funding	NCGRT
Project duration	Unknown—Literature output 2014
Current status	Unknown—Literature output 2014
Project summary	An integrated hydrogeological study is currently being undertaken in the Galilee and Eromanga basins as the basis of an aquifer interconnectivity study of Permian coal seams and the overlying aquifers of the Great Artesian Basin (GAB). This study aims to understand the stratigraphic relationships between the different formations, their water-bearing character, and the potential for hydrological interaction between them.
Objectives	<ul style="list-style-type: none"> Understand the stratigraphic relationships between the different formations, their water-bearing character, and the potential for hydrological interaction between them. Develop a three-dimensional geological model. Develop a structural model, which will incorporate folds and faults. Hydrochemical analysis of groundwater samples to characterise the differences in hydrochemistry between coal seams and GAB aquifers.
Achievements	<ul style="list-style-type: none"> A three-dimensional geological model has been developed using Gocad software based on drill hole data from 125 wells from the Queensland Digital Exploration Report System, supported by 5 seismic surfaces. Improved understanding of the geology of the area. Use of the 3D geo-framework has been highly effective in establishing hydrostratigraphy, understanding bore locations and depths, and in assessing hydrochemical variations and their causes. Multivariate analysis of historical hydrochemical data, leading to the identification of four distinct hydrochemical clusters. Strontium isotope analysis suggested that aquifer mineralogy is a major control on the groundwater composition.
Outputs	<ul style="list-style-type: none"> Moya C, Raiber M and Cox M (2014) Assessment of aquifer/aquitard connectivity in the galilee and eromanga basins using geology, hydrochemistry and 87sr/86sr isotopes. In Geological Society of Australia, 2014 Australian Earth Sciences Convention (AESC), Sustainable Australia. Abstract No 110 of the 22nd Australian Geological Convention, Newcastle City Hall and Civic Theatre, Newcastle, New South Wales. July 7–10. PhD thesis http://research.ccsq.uq.edu.au/projects/galilee-gab-aquitard-properties Moya C, Cox M and Raiber M (2013) "Aquifer interconnectivity in the Galilee and Eromanga basins - Preliminary results". 40th IAH Congress on Solving

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
	the Groundwater Challenges of the 21 st Century. Perth, Australia.
Key personnel	Moya, Claudio; Cox, Malcolm; Raiber, Matthias
Research themes	Aquifer interconnectivity
Project information source	UQ CCSG Online Portal; conferences

Table 4.26 Project 26: Geological framework model for the Surat Cumulative Management Area (Surat and southern Bowen Basin)

Project characteristics	Details
Project title	Geological framework model for the Surat Cumulative Management Area (Surat and southern Bowen Basin)
Project location	Australia
Principal investigator	Esterle, Joan
Lead institution	School of Earth Sciences, University of Queensland
Project budget	Unknown
Source of funding	University of Queensland, Santos, QGC, Arrow Energy, Australia Pacific LNG
Project duration	May 2014 - October 2016
Current status	Underway
Project summary	The model will include all formations from Permian to Cenozoic and where able will define coal formations to subgroup and coal seam group levels. The latter will require areas to be subdivided into smaller areal domains where correlations are robust.
Objectives	The objective is to develop a regional geological model for the Surat and southern Bowen basins for the Surat Cumulative Management Area (CMA).
Achievements	Unknown
Outputs	http://research.ccsq.uq.edu.au/projects/geological-framework-model-surat-cumulative-management-area-surat-and-southern-bowen-basin
Key personnel	Esterle, Joan; Tyson, Steve
Research themes	Aquifer connectivity
Project information source	UQ CCSG Online Portal

Table 4.27 Project 27: Estimation and measurement of vertical connectivity in the Surat Basin, Australia

Project characteristics	Details
Project title	Estimation and measurement of vertical connectivity in the Surat Basin, Australia
Project location	Australia
Principal investigator	Evans, R
Lead institution	Sinclair Knight Merz, Australia; QGC
Project budget	Unknown
Source of funding	Unknown
Project duration	Unknown—Literature output 2013
Current status	Unknown—Literature output 2013
Project summary	<p>The prediction of the potential temporal and spatial scale of regional groundwater de-pressurisation due to coal seam gas extraction in the Surat Basin of Queensland requires an assessment of vertical groundwater flux into the de-pressurised coal seams. There exists few studies which have measured vertical connectivity in the field, particularly on a regional scale. An important part of Queensland Gas Company's (QGC) connectivity assessment program is the detailed field monitoring of three pilot CSG water/gas recovery tests. These tests generally involve up to six months of extraction of Walloon Subgroup (WSG) water, followed by six months recovery, from several wells in a cluster, termed a pilot. It is envisaged that the detailed monitoring of the overlying and underlying formations will provide valuable hydraulic information enabling an assessment of pressure changes and hence vertical flow rates and thus vertical hydraulic conductivity (K). This paper describes a theoretical assessment of the groundwater flow in the layered groundwater systems at the Woleebee Creek pilot site in the northern Surat Basin. The pressure response in low permeability formations as a function of elapsed time, the vertical hydraulic conductivity (K), and the imposed pressure difference induce by pumping was investigated. The results illustrate that the ability of a field testing program to determine values of f_v is controlled by the magnitude of the imposed stress (pressure difference) on the system. As greater stress is imposed, lower values of f_v can be discerned. At the typical stress created by a pilot test, mid to higher values of K_v will result in a measureable pressure response. Even if no pressure response is observed in a field test, the maximum possible value of f_v for the system can still be estimated, which is an instructive result.</p>
Objectives	To describe a theoretical assessment of the groundwater flow in the layered groundwater systems at the Woleebee Creek pilot site in the northern Surat Basin.
Achievements	An investigation of the pressure response in low permeability formations as a function of elapsed time, the vertical hydraulic conductivity (K), and the imposed pressure difference induce by pumping.
Outputs	Evans R, Arunakumaren J and Grounds J (2013) "Estimation and measurement of vertical connectivity in the Surat Basin, Australia." 40 th IAH Congress on Solving the Groundwater Challenges of the 21 st Century. Perth, Australia.
Key personnel	Evans, R; Arunakumaren, J; Grounds, J

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Research themes	Aquifer interconnectivity, water-dependent resources
Project information source	40 th IAH Congress

Table 4.28 Project 28: A baseline groundwater methane survey in the Richmond River catchment; a potential coal seam gas exploration area

Project characteristics	Details
Project title	A baseline groundwater methane survey in the Richmond River catchment; a potential coal seam gas exploration area
Project location	Australia
Principal investigator	Santos, Isaac
Lead institution	Southern Cross University
Project budget	Unknown
Source of funding	ARC
Project duration	Unknown - presentation 2014
Current status	Active
Project summary	<p>Unconventional natural gas extraction, such as coal seam gas (CSG), is rapidly expanding globally and a number of exploration wells have been drilled in the Northern Rivers district in NSW. However, the effect of unconventional CSG on groundwater systems is not well understood. CSG production processes may lead to a range of environmental issues such as aquifer depletion and changes in groundwater quality. Few studies have assessed these potential impacts in Australia, and no previous studies have focused on the Richmond River Catchment.</p> <p>We hypothesise that CH₄ may be used as a tracer of changes in aquifer connectivity potentially associated with CSG exploration.</p> <p>In order to better monitor and understand the implications of CSG production on aquifer connectivity, baseline research on the chemical composition of groundwater is critical. We have sampled 98 groundwater bores, measuring water parameters such as CH₄, CO₂, carbon isotopic CH₄ signature ($\delta^{13}\text{C}-\text{CH}_4$), carbon isotopic CO₂ signature ($\delta^{13}\text{C}-\text{CO}_2$) and radon (²²²Rn). Groundwater CH₄</p> <p>CH₄ source of groundwater constituents. $\delta^{13}\text{C}-\text{CH}_4$ ranges for bedrock bores was -88.45 to -35.08‰ while Quaternary sediment bores had $\delta^{13}\text{C}-\text{CH}_4$ ranging from -90.88 to -27.36‰. Since CH₄ is unlikely to be of thermogenic origin, the carbon signatures indicate the biogenic CH₄ production pathways of CO₂ reduction and acetate fermentation. The heavier carbon signatures are indicative of CH₄ oxidation. This research delivers a snapshot of current groundwater dynamics to enable comparisons of 'before and after' CSG exploration.</p>
Objectives	To conduct baseline research on the chemical composition of groundwater in the Northern Rivers district of NSW. A major component of this project is determining the baseline chemical composition of groundwater in the Richmond River Catchment. Perform high precision measurements of methane concentrations and isotopes which may act as early indicators of aquifer connectivity in CSG production sites.
Achievements	Sampled 98 bores to deliver a snapshot of current groundwater dynamics in the Northern Rivers catchment to enable comparisons of 'before and after' CSG exploration.

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Outputs	Atkins M, Santos I and Maher D (2014) A baseline groundwater methane survey in the Richmond River catchment; a potential coal seam gas exploration area. In Geological Society of Australia, 2014 Australian Earth Sciences Convention (AESC), Sustainable Australia. Abstract No 110 of the 22nd Australian Geological Convention, Newcastle City Hall and Civic Theatre, Newcastle, New South Wales, July 7–10.
Key personnel	Atkins, Marnie; Santos, Isaac; Maher, Damien
Research themes	Aquifer interconnectivity; baseline data; groundwater flow
Project information source	Conference; website

Table 4.29 Project 29: The role of mining driven de-pressurisation in deep coal seams at the AGL Broke/Bulga exploration sites

Project characteristics	Details
Project title	The role of mining driven de-pressurisation in deep coal seams at the AGL Broke/Bulga exploration sites
Project location	Australia
Principal investigator	Willgoose, Garry
Lead institution	University of Newcastle, Australia
Project budget	\$5000 and uncosted in-kind
Source of funding	Newcastle Innovation
Project duration	2013
Current status	Completed
Project summary	The project developed a vertical 1D groundwater model to explore the relative roles of vertical leakage and horizontal connection to local coal mines (5 km away) in causing a de-pressurisation trends at AGL's Broke and Bulga exploration and monitoring sites.
Objectives	To see what was the cause of a de-pressurisation trend in AGL's deep monitoring wells. Possible causes including: <ul style="list-style-type: none"> • lagged effects from pump testing in AGL pilot wells • de-pressurisation from drainage resulting from coal mining about 5 km to the north of the site • lagged effects of the drought as a result of reduced vertical recharge.
Achievements	The project showed that the mostly likely explanation was de-pressurisation from coal mining.
Outputs	Internal report not for publication. Please contact the project CI for further information.
Key personnel	Willgoose, Garry
Research themes	Aquifer interconnectivity; disruption of surface water flow pathways; integrity of wells; quality and reliability of water supplies; cumulative impact assessments
Project information source	Survey

Table 4.30 Project 30: Screening model of the groundwater regime in the Murrurrundi Trough, Upper Hunter

Project characteristics	Details
Project title	Screening model of the groundwater regime in the Murrurrundi Trough, Upper Hunter
Project location	Australia
Principal investigator	Willgoose, Garry
Lead institution	University of Newcastle, Australia
Project budget	\$5000 and uncosted in-kind
Source of funding	Newcastle Innovation
Project duration	2013
Current status	Completed
Project summary	The project was a first attempt to look at groundwater flow and recharge zones in the Murrurrundi Trough, as precursor to a more sophisticated model of the potential impacts of planned CSG extraction by SANTOS.
Objectives	To develop a MODFLOW model of the Permian measures (focused on the upper measures where irrigation water is sourced) in the Murrurrundi Trough, as a precursor to the development of a more sophisticated model of the potential impacts of planned CSG extraction by SANTOS.
Achievements	A model of the southern half of the Trough was developed encompassing all the potential southern and eastern recharge zones of the Trough. The results indicated that natural regional groundwater flow is likely to be west to east from the upper reaches of the Goulburn River Gorge to the lower Goulburn River and Hunter River upstream of Denman.
Outputs	Internal report not for publication. Please contact the project CI for further information.
Key personnel	Willgoose, Garry
Research themes	Aquifer interconnectivity; disruption of surface water flow pathways; co-produced water and salt management (CSG) and mine water & salt management (coal mines); integrity of wells; cumulative impact assessments
Project information source	Survey

Table 4.31 Project 31: A water chemistry atlas for CSG fields

Project characteristics	Details
Project title	A water chemistry atlas for CSG fields
Project location	Australia
Principal investigator	Vink, Sue
Lead institution	University of Queensland
Project budget	Unknown
Source of funding	University of Queensland, Santos, QGC, Arrow Energy, Australia Pacific LNG
Project duration	24 June 2013 – Unknown
Current status	In progress
Project summary	A technical feasibility study will be undertaken to determine if there is sufficient groundwater quality data available to develop a Water Chemistry Atlas with the capability to address key questions regarding regional water quality trends and provide valuable information to government, industry and the community.
Objectives	<ul style="list-style-type: none"> • Develop a prototype database containing groundwater chemistry and geological data. • Develop 3D visualisation capability and interrogation tools. • Use statistical and geochemical data analysis methods in conjunction with 3D visualisation tools to undertake preliminary trends analysis.
Achievements	Prototype database and 3D visualisation tools have been developed. Initial data analysis has been completed and reporting is in progress.
Outputs	<p>Reports and journal articles will be published.</p> <p>http://www.ccsq.uq.edu.au/Research/waterchemistryatlas.aspx</p> <p>Brooking C, Hunter J, Vink S and Esterle J (2014). Interpreting groundwater chemistry to frame water risks of CSG development. In Geological Society of Australia, 2014 Australian Earth Sciences Convention (AESC), Sustainable Australia. Abstract No 110 of the 22nd Australian Geological Convention, Newcastle City Hall and Civic Theatre, Newcastle, New South Wales. July 7–10.</p>
Key personnel	Vink, Sue; Hunter, Jane; Tyson, Steve; Esterle, Joan; Reading, Lucy
Research themes	Aquifer interconnectivity, cumulative impact assessments
Project information source	Survey, conference, UQ CCSG Online Portal

Table 4.32 Project 32: Gas distribution is fundamental to estimation and management of fugitive emissions C21061

Project characteristics	Details
Project title	Gas distribution is fundamental to estimation and management of fugitive emissions C21061
Project location	Australia
Principal investigator	Burra, A
Lead institution	University of Queensland
Project budget	\$330 000
Source of funding	Australian Coal Association Research Program (ACARP)
Project duration	Unknown—Literature output 2014
Current status	Unknown—Literature output 2014
Project summary	<p>This paper reviews various coal seam gas (CSG) models that have been developed for the Sydney Basin, and provides an alternative interpretation for gas composition layering and deep-seated CO₂ origins. Open file CSG wells, supplemented by mine-scale information, were used to examine trends in gas content and composition at locations from the margin to the centre of the basin. Regionally available hydrochemistry data and interpretations of hydrodynamics were incorporated with conventional petroleum well data on porosity and permeability. The synthesised gas and groundwater model presented in this paper suggests that meteoric water flow under hydrostatic pressure transports methanogenic consortia into the subsurface and that water chemistry evolves during migration from calcium-rich freshwaters in inland recharge areas towards sodium-rich brackish water down-gradient and with depth. Groundwater chemistry changes result in the dissolution and precipitation of minerals as well as affecting the behaviour of dissolved gases such as CO₂. Mixing of carbonate-rich waters with waters of significantly different chemistries at depth causes the liberation of CO₂ gas from the solution that is adsorbed into the coal matrix in hydrodynamically closed terrains. In more open systems, excess CO₂ in the groundwater (carried as bicarbonate) may lead to precipitation of calcite in the host strata. As a result, areas in the central and eastern parts of the basin do not host spatially extensive CO₂ gas accumulations but experience more widespread calcite mineralisation, with gas compositions dominated by hydrocarbons, including wet gases. Basin boundary areas (commonly topographic and/or structural highs) in the northern, western and southern parts of the basin commonly contain CO₂-rich gases at depth. This deep-seated CO₂-rich gas is generally thought to derive from local to continental scale magmatic intrusions, but could also be the product of carbonate dissolution or acetate fermentation.</p>
Objectives	This paper presents an alternative explanation for the distribution of deep, CO ₂ -rich seam gas in these areas through the integration of hydrogeochemical trends at a basin scale.
Achievements	<ul style="list-style-type: none"> Reviewed various coal seam gas (CSG) models that have been developed for the Sydney Basin. Provides an alternative interpretation for gas composition layering and deep-seated CO₂ origins.

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Outputs	Burra A, Esterle JS and Golding SD (2014) "Coal seam gas distribution and hydrodynamics of the Sydney Basin, NSW, Australia". <i>Australian Journal of Earth Sciences</i> , 61 (3).
Key personnel	Burra, Agi; Esterle, Joan; Golding, SD
Research themes	Aquifer interconnectivity
Project information source	Literature

Table 4.33 Project 33: Hydraulic connectivity between mines and adjacent river and groundwater systems in the Hunter River Valley- C20022

Project characteristics	Details
Project title	Hydraulic connectivity between mines and adjacent river and groundwater systems in the Hunter River Valley- C20022
Project location	Australia
Principal investigator	Bringemeier, Betlef
Lead institution	University of Queensland
Project budget	\$377 810
Source of funding	Australian Coal Association Research Program (ACARP)
Project duration	2011 - September 2014
Current status	Complete
Project summary	This project will improve the understanding of the hydraulic connectivity between mines and adjacent river and groundwater systems in the Hunter River Valley and other Australian coal mining regions. It will also develop a set of criteria for assessing the mining impact on the rivers and aquifers. The work will combine mathematical modelling and field measurements of key hydrogeological and hydraulic parameters within the study area. A mathematical model is being developed to simulate the interactions between the mines and adjacent aquifer systems.
Objectives	<ul style="list-style-type: none"> • Characterise the risks with respect to the uncertainty of the hydrogeological regimes. • Evaluate the impacts of mine extension on groundwater and surface water. • Estimate rates of saline groundwater seepage into the pit. • Assess the impact of fault structures and fracture zones on the strip and high-wall designs and the geotechnical performance of the pit excavation during operations and closure.
Achievements	Work has covered the field investigation and numerical modelling component. Various methods and techniques for the field work have been established and tested. The first field campaign was undertaken in 2011. Data collected from the field site was analysed and presented at the 11 th Coal Operators' Conference (COAL2012). The second field campaign was undertaken in 2012. Data collected from this field campaign have been analysed. The third field campaign was undertaken in 2013 and the collected samples and data have been analysed and will be presented in an international conference, UNSAT2014.
Outputs	<ul style="list-style-type: none"> • One field campaign report submitted to ACARP (December 2013). • One conference paper published in Coal Operation's Conference (2012). • Two conference papers accepted for UNSAT 2014, Perth. • Two conference papers submitted for IMWA 2014, Xu Zhou. • One journal manuscript submitted to Experiments in Fluids. • One journal manuscript written and to be submitted to International Journal of Coal geology. • One journal manuscript written and to be submitted to Geophysical Research Letters.

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
	http://www.acarp.com.au/Media/ACARPCurrentProjectsReport.pdf Bringemeier, B. and Li, L. (2013). "Hydraulic connectivity between mines and adjacent river and groundwater systems in the Hunter River Valley". (C20022).
Key personnel	Bringemeier, Betlef; Li, Ling
Research themes	Aquifer interconnectivity; water-dependent ecosystems
Project information source	ACARP website

Table 4.34 Project 34: Controls on the isotope and molecular composition of coal seam gases and production waters of the Walloon Subgroup, Surat Basin, Queensland, Australia

Project characteristics	Details
Project title	Controls on the isotope and molecular composition of coal seam gases and production waters of the Walloon Subgroup, Surat Basin, Queensland, Australia.
Project location	Australia
Principal investigator	Baublys, Kim
Lead institution	University of Queensland, Australia
Project budget	Unknown
Source of funding	This is a part-time PhD project which is indirectly associated with a Microbial methane ARC Linkage grant with Prof. Sue Golding as C.I.
Project duration	7/01/2013 - Unknown
Current status	In progress
Project summary	<p>The coal bed methane produced from the Walloon subgroup in the Surat Basin is an important economic resource for Queensland. Understanding of the origins, recharge and co-evolution of the coal seam water and gas is vital to the possible future regeneration of this mainly biogenic gas. This research continues on from the work of S.K. Hamilton and extends the study to all three of the gas production regions in the Surat.</p> <p>This study aims to enhance the understanding of:</p> <ul style="list-style-type: none"> the geochemical evolution of Walloon coal bed waters and gases down groundwater flow-paths test whether co-produced water compositional and stable isotopic data show relationships with gas-in-place and gas stable isotopes, to elucidate further evidence for microbial CO₂ reduction combine these data with age tracer (14C and $\delta^{13}\text{CDIC}$) information, to constrain the timing of microbial methane generation and assist hypothesis testing for one or more phases of generation compare these findings with previous results of Walloon and major unconventional microbial gas reservoir studies elsewhere.
Objectives	<p>Expected outcomes:</p> <ul style="list-style-type: none"> A database of coupled water and gas samples for the main production regions in the Walloon Subgroup of the Surat Basin (generated through analysis of samples from five field trips in combination with data from other members of the group). Enhanced understanding of the evolution down dip of individual geochemistry of the waters for each production region. The influence of lithology of the adjacent recharge zones on the recharge waters. Enhanced understanding of interplay between water geochemistry and bacterial population on the coal bed methane (Stable isotope analysis of waters and gases, D, O, C, S).

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Achievements	PhD project is in early stages while ARC Linkage on Microbial methane has only 1 year left to run. There are many reports and papers associated with the project but the Principal investigator is still editing the first paper associated with PhD. Details below.
Outputs	Three papers are expected from this project, this first of which is hoped to be submitted by November 2014 to IJCG. Reports have also been generated for the two companies involved: Santos and QGC. Baublys KA, Hamilton SK, Golding SD, Vink S and Esterle JS (unpublished) Stable isotope and hydrochemistry of coal bed methane production waters and gases of the Walloon Subgroup, Surat Basin, Australia. <i>International Journal of Coal Geology</i> (goal submission date November 2014).
Key personnel	Baublys, Kim; Golding, Sue; Hamilton, Stephanie; Esterle, Joan; Vink, Sue
Research themes	Aquifer interconnectivity, co-produced/mine water
Project information source	Survey, UQ CCSG Online Portal

4.1.2 Russia

Table 4.35 Project 35: Implication of the permafrost on hydrogeological conditions and on mine environment controls: case of the Amaan Coking Coal Project in north-eastern Russia

Project characteristics	Details
Project title	Implication of the permafrost on hydrogeological conditions and on mine environment controls: case of the Amaan Coking Coal Project in north-eastern Russia
Project location	Russia
Principal investigator	Ogier-Haliml, Sylvie
Lead institution	SRK Consulting, Perth, WA, Australia and African Minerals, Tonkolili, Sierra Leone
Project budget	Unknown
Source of funding	Unknown
Project duration	Unknown—Literature output 2013
Current status	Unknown—Literature output 2013
Project summary	<p>The Amaam Coking Coal Project is located in the extreme north-east of Russia, near the Arctic Circle and comprises the following key components: a large scale open cast mine producing premium coking coal, a sea port, and road and rail connection from the mining areas to the port. In this environment, two main groundwater systems within the project area have been identified:</p> <ul style="list-style-type: none"> • a shallow groundwater regime above the permafrost zone made of an active layer aquifer and postglacial alluvial deposit aquifer(s), and • a deep groundwater regime beneath permafrost made of deep bedrock aquifer(s). <p>Within these regimes, fresh to brackish groundwater is anticipated to occur within Quaternary and post glacial unconsolidated sediments, weathered and fractured bedrock and deep bedrock formations containing the coal seams. Although the project is located within a widespread permfrost region, it is understood that the low-lying areas adjacent to surface water bodies, rivers and lagoons, are unfrozen throughout the year, and therefore lie in a talik area (or unfrozen grounds encountered within the permafrost zone). The intermediate bedrock aquifer(s) within the flood plain taliks may be hydraulically connected to the deep bedrock aquifer(s), and fractures/faults present in these areas can potentially conduct surface waters into the various water-bearing strata during seasonal thawing if not acting as groundwater barriers.</p> <p>Although the surface-groundwater coupling is not fully understood, the following likely changes to the groundwater conditions resulting from the mine development may include:</p> <ul style="list-style-type: none"> • potential changes to groundwater flow • changes to groundwater quality • changes to surface water/groundwater interactions • changes to geotechnical conditions. <p>Preliminary estimates of potential groundwater seepage into mine areas are in the range of 2000 to 55 000 m³/d. Most of this flow is anticipated to originate from the unconsolidated Quaternary. Refinement of these estimates will occur</p>

Project characteristics	Details
	following a better appreciation of the thickness of permafrost and the location and thickness of talik areas. The hydrogeology of the Project is therefore substantially controlled by the permafrost characteristics and its spatial and temporal distribution.
Objectives	To investigate the influence of permafrost on hydrogeological conditions and on mine environment controls for the Amaan Coking Coal Project.
Achievements	The hydrogeological assessment of the Amaan project identified two groundwater systems within the project area: a shallow groundwater regime above the permafrost zone and a deep groundwater regime beneath permafrost.
Outputs	http://www.srk.com.au/files/pdfs/implication_of_the_permafrost_on_hydrogeological_conditions_by_sylvie_ogier-halim_2013.pdf Ogier-Haliml S, Berry T and Schaeffer J (2013) "Implication of the permafrost on hydrogeological conditions and on mine environment controls: case of the Amaan Coking Coal Project in north-eastern Russia". 40 th IAH Congress on Solving the Groundwater Challenges of the 21 st Century. Perth, Australia.
Key personnel	Ogier-Haliml, Sylvie; Berry, Tim; Schaeffer, Jurgen
Research themes	Aquifer interconnectivity
Project information source	40 th IAH Congress

4.1.3 United States

Table 4.36 Project 36: Stream methane sampling for evaluating groundwater impacts associated with unconventional gas development

Project characteristics	Details
Project title	Stream methane sampling for evaluating groundwater impacts associated with unconventional gas development
Project location	USA
Principal investigator	Heilweil, Victor M
Lead institution	U.S. Geological Survey
Project budget	Unknown
Source of funding	Unknown
Project duration	Unknown—Literature output 2013
Current status	Unknown—Literature output 2013
Project summary	<p>Gaining streams can provide an integrated signal of the groundwater system. Impacts from natural gas drilling and hydraulic fracturing may be evaluated at the watershed scale by sampling such streams. We have developed a streambased methane (CH₄) monitoring technique for determining groundwater concentrations, potentially useful for establishing baseline conditions and detecting contamination caused by unconventional gas development. While ionic tracers will remain in the stream water, CH₄ will eventually escape to the atmosphere and/or undergo microbial biodegradation (oxidation).</p> <p>To evaluate gas loss from the stream and calculate groundwater CH₄ from measured stream concentrations, both groundwater discharge and gas transfer velocity (GTV) measurements are required. To test this method, combined bromide and dissolved-gas tracer injections were conducted at both Nine-Mile Creek (NMC), a high-gradient stream in an arid/steppe climate (Utah, USA), and West Bear Creek (WBC), a lower-gradient stream in a humid/coastal plain setting (North Carolina, USA). In each stream, Br was used to quantify groundwater discharge and CH₄ was used to determine apparent GTVs. At WBC, Kr was also injected to determine the true GTV for evaluating CH₄ loss due to microbial degradation. The injected CH₄ persisted in the stream for more than 1.5 and 2.5 km at NMC and WBC, respectively. 1-D stream transport modeling of the NMC data indicates a GTV of 4.5 m d⁻¹; simulation of background stream CH₄ concentrations with this model indicates a groundwater methane load of about 200 grams/day discharging to NMC. The estimated GTV based on an earlier gas injection and modeling for WBC is about 1.5 m d⁻¹, as expected for this less turbulent stream. The lower gas transfer rate for WBC explains the greater downstream persistence of the injected CH₄. Comparison of the GTVs determined from CH₄ and Kr at WBC will indicate whether microbial degradation of CH₄ is a significant process. These tests illustrate that sampling gases in streams is a promising tool for evaluating methane contamination of groundwater and surface water from natural gas drilling. Such an approach has the advantage of using stream-integrated chemistry to indirectly monitor aquifer contamination at the watershed scale, rather than relying on point values from groundwater wells.</p>
Objectives	To develop a streambased methane (CH ₄) monitoring technique for determining groundwater concentrations, potentially useful for establishing baseline

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Project characteristics	Details
	conditions and detecting contamination caused by unconventional gas development.
Achievements	<p>Combined bromide and dissolved-gas tracer injections were conducted at both Nine-Mile Creek (NMC), a high-gradient stream in an arid/steppe climate (Utah, USA), and West Bear Creek (WBC).</p> <p>In each stream, Br was used to quantify groundwater discharge and CH₄ was used to determine apparent GTVs. At WBC, Kr was also injected to determine the true GTV for evaluating CH₄ loss due to microbial degradation.</p>
Outputs	<p>https://ngwa.confex.com/ngwa/2014gws/webprogram/Paper9781.html</p> <p>Heilweil VM, Stolp BJ, Solomon DK and Darrah T (2013) "Stream methane sampling for evaluating groundwater impacts associated with unconventional gas development". 40th IAH Congress on Solving the Groundwater Challenges of the 21st Century. Perth, Australia.</p>
Key personnel	Heilweil, Victor M; Stolp, Bert J; Solomon, D. Kip; Darrah, Thomas
Research themes	Aquifer interconnectivity
Project information source	40 th IAH Congress

4.2 Disruption of surface water flow pathways

This research theme encompasses research that describes how surface water flows may be disturbed due to coal seam gas and coal mining. This may be through mining-induced subsidence, the mine cone of depression due to de-watering, stream diversions or the physical placement of infrastructure causing disruption of surface water flows.

Twenty-two projects were collated with the primary theme of disruption of surface water flow pathways; from Australia (19 projects), China (2 projects) and the United States (1 project).

4.2.1 Australia

Table 4.37 Project 37: Monitoring of ground movements at Sandy Creek Waterfall and implications for understanding the mechanics of valley closure movements

Project characteristics	Details
Project title	Monitoring of ground movements at Sandy Creek Waterfall and implications for understanding the mechanics of valley closure movements
Project location	Australia
Principal investigator	Walsh, R
Lead institution	BHP Billiton Illawarra Coal/Mine Subsidence Engineering Consultants
Project budget	Unknown
Source of funding	Unknown
Project duration	1 March 2011 to 1 May 2014
Current status	Completed
Project summary	<p>BHP Billiton-Illawarra Coal operates Dendrobium Mine in an area 10 to 20 km west-northwest of Wollongong in New South Wales, Australia. The mine recently completed mining the Wongawilli Seam in Area 3A adjacent to a natural rock overhang known as Sandy Creek Waterfall. Illawarra Coal undertook to protect the waterfall and the section of Sandy Creek immediately upstream of the waterfall from the effects of adjacent longwall mining using an innovative management process and an array of very high resolution monitoring systems. This paper describes the results of the high resolution monitoring systems and the implications of these results for general understanding of natural and mining induced ground movements around valleys.</p> <p>The program of monitoring conducted at Sandy Creek Waterfall measured closure, stress changes, microseismic activity and shear movements adjacent to the waterfall during mining of Longwalls 6, 7 and 8. These measurements provided insights into the mechanics of both mining induced valley closure and natural erosion processes. At the completion of Longwall 8, the monitoring strategy and the management decisions based on this monitoring have been effective in protecting the overhanging sandstone rock structure that forms Sandy Creek Waterfall and the upstream section of Sandy Creek, as required by the NSW Department of Planning and Infrastructure. The measurements and observations made at Sandy Creek Waterfall and the interpretation placed on these results are considered to provide a coherent understanding of the relatively complex deformation mechanics at this site. These mechanics are consistent with measurements and observations made at other sites.</p>

Project characteristics	Details
Objectives	To describe the results of high resolution ground movement monitoring systems and the implications of these results for general understanding of natural and mining induced ground movements around valleys.
Achievements	The provision of a coherent understanding of the relatively complex deformation mechanics at this site.
Outputs	Walsh R, Mills K, Nicholson M, Barbato J, Hebblewhite B, Li G and Brannon P (2014) "Monitoring of ground movements at Sandy Creek Waterfall and implications for understanding the mechanics of valley closure movements". 9 th Triennial Conference on Mine Subsidence, 11–13 May 2014, Hunter Valley, NSW. http://www.mstsociety.org/
Key personnel	Walsh, R; Mills, K; Nicholson, M; Barbato, J; Hebblewhite, B; Li, G; Brannon, P
Research themes	Surface water, well integrity, water-dependent ecosystems
Project information source	Survey

Table 4.38 Project 38: Valley closure impact model for rock bar controlled streams in the Southern Coalfield

Project characteristics	Details
Project title	Valley closure impact model for rock bar controlled streams in the Southern Coalfield
Project location	Australia
Principal investigator	Barbato, James
Lead institution	BHP Billiton Illawarra Coal and Mine Subsidence Engineering Consultants Pty Ltd
Project budget	Unknown
Source of funding	Private sector funding
Project duration	1 January 2011 – 1 May 2014
Current status	Completed
Project summary	Longwall mining adjacent to or directly beneath rock bar controlled streams can result in fracturing and the diversion of the surface water flows into subterranean flows beneath the beds. In the Southern Coalfield, the potential for these impacts is generally governed by the valley related movements. An impact model has been developed to assess the potential for surface water diversions along rock bar controlled streams, based on the predicted valley closure, using the experience of previous longwall mining adjacent to and directly beneath these types of streams. This model has been used by BHP Billiton-Illawarra Coal to determine the appropriate longwall setbacks from major streams for recent mining operations at Appin, West Cliff and Dendrobium Mines.
Objectives	To develop a valley closure impact model for rock bar controlled streams in the Southern Coalfield.
Achievements	The development of an impact model to assess the potential for surface water diversions along rock bar controlled streams.
Outputs	Barbato J, Brassington G and Walsh R (2014) "Valley closure impact model for rock bar controlled streams in the Southern Coalfield". 9 th Triennial Conference on Mine Subsidence, 11–13 May 2014, Hunter Valley, NSW. http://www.mstsociety.org/ Barbato J, Brassington G and Walsh R (2014) "Valley closure impact model for rock bar controlled streams in the Southern Coalfield". 9th Triennial Conference on Mine Subsidence. Hunter Valley, NSW.
Key personnel	Barbato, James; Brassington, Gary; Walsh, Richard
Research themes	Surface water, hydraulic fracturing, water supplies, cumulative impact assessments
Project information source	Survey

Table 4.39 Project 39: Investigation into the height of discontinuous fracturing above longwall panels at Springvale Mine

Project characteristics	Details
Project title	Investigation into the height of discontinuous fracturing above longwall panels at Springvale Mine
Project location	Australia
Principal investigator	Corbett, Peter
Lead institution	Centennial Coal
Project budget	\$200 000
Source of funding	Centennial Coal
Project duration	1 April 2014 - Unknown
Current status	In progress
Project summary	Drilling of boreholes above areas previously undermined by longwall panels to determine the impacts of mine subsidence to aquifers on the Newnes Plateau.
Objectives	Analysis of boreholes through geophysical analysis, downhole camera and video, and core analysis to determine effects to aquifers which supply water to Temperate Highland Peat Swamps on Sandstone communities.
Achievements	Identification of height of discontinuous fracturing above mine workings and affects to aquifers overlying mine workings.
Outputs	Unknown
Key personnel	Corbett, Peter
Research themes	Aquifer interconnectivity; surface water; water-dependent ecosystems
Project information source	Survey

Table 4.40 Project 40: Case studies of groundwater response to mine subsidence in the Western Coalfields of NSW

Project characteristics	Details
Project title	Case studies of groundwater response to mine subsidence in the Western Coalfields of NSW
Project location	Australia
Principal investigator	Corbett, Peter
Lead institution	Centennial Coal
Project budget	\$200 000
Source of funding	Centennial Coal
Project duration	4 January 2010 – 5 May 2014
Current status	Completed
Project summary	In 2008 and 2009 monitoring detected impacts caused by mining-related activities at Kangaroo Creek Swamp and East Wogan Swamp. Investigations have been conducted to determine the cause of these impacts and why they occurred where they did.
Objectives	To understand the factors that have led to historical mining-related impacts, in order to mitigate future impacts to Temperate Highland Peat Swamps on Sandstone (THPSS) from mining related activities.
Achievements	The results of investigations have allowed Centennial to understand the multiple co-incident factors that have led to historical mining-related impacts. The investigation included case studies of THPSS which have been undermined in the past. The investigative process and its findings have been used to enable a comprehensive multi-disciplinary risk-based approach to mine planning and mine design.
Outputs	Proceedings of the 9 th Triennial Conference on Mine Subsidence, 2014: Corbett P, White E and Kirsch B (2014) Case studies of groundwater response to mine subsidence in the Western Coalfields of NSW.
Key personnel	Corbett, Peter; White, Edwina; Kirsch, Bernard
Research themes	Surface water
Project information source	Survey

Table 4.41 Project 41: Analytical modelling of subsidence due to coal seam gas extraction

Project characteristics	Details
Project title	Analytical modelling of subsidence due to coal seam gas extraction
Project location	Australia
Principal investigator	Rotter, Ben E
Lead institution	Coffey Geotechnics Pty Ltd, Chatswood, NSW, Australia
Project budget	Unknown
Source of funding	Unknown
Project duration	Unknown—Literature output 2013
Current status	Unknown—Literature output 2013
Project summary	<p>Coal seam gas (CSG) is an increasing source of natural gas around the world. Extraction of CSG involves de-watering target coal formations to reduce their reservoir pressure, thereby releasing the adsorbed gas. The pressure reductions caused by CSG extraction induce compression of soil and rock (hydrogeological units), potentially resulting in land subsidence.</p> <p>Land subsidence can impact a variety of infrastructure (such as buildings, roads, railways, pipelines, dams, water channels, levees and electrical infrastructure) and environmental assets (such as aquifers, streams, lakes and springs). Subsidence assessment models are utilised to predict the magnitude and extent of subsidence. Model results may then be used to inform subsidence monitoring schemes, and to assist in the management or mitigation of potential impacts of subsidence on assets.</p> <p>A common subsidence modelling approach, particularly adopted for underground coal mining, involves prediction of potential subsidence by extrapolation of the results of experience. However, at present there is a paucity of monitoring records for subsidence arising from CSG extraction. Therefore, subsidence assessment involves predictive analysis of:</p> <ul style="list-style-type: none"> • the compression within the ground profile due to changes in groundwater pressure induced by coal seam gas extraction, and • compression of the coal seam due to degassing. <p>This work presents an analytical approach for modelling subsidence associated with CSG. The analytical approach presented accounts for the influence of groundwater flow (in the vicinity of the CSG wellfield) on de-pressurisation, and the consequent compression of hydrogeological units, with consideration of hydrogeological and geotechnical properties. The advantages and disadvantages of various subsidence modelling approaches in the context of CSG production are discussed.</p>
Objectives	This work aims to present an analytical approach for modelling subsidence associated with CSG.
Achievements	The advantages and disadvantages of various subsidence modelling approaches in the context of CSG production are discussed.
Outputs	Rotter BE and Best RJ (2013) "Analytical modelling of subsidence due to coal seam gas extraction". 40 th IAH Congress on Solving the Groundwater Challenges of the 21 st Century. Perth, Australia.

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Project characteristics	Details
Key personnel	Rotter, Ben E; Best, Ross J
Research themes	Aquifer interconnectivity, disruption of surface water flow pathways
Project information source	40 th IAH Congress

Table 4.42 Project 42: Coal seam gas extraction: modelling groundwater impacts

Project characteristics	Details
Project title	Coal seam gas extraction: modelling groundwater impacts
Project location	Australia
Principal investigator	Coffey Geotechnics Pty Ltd
Lead institution	Coffey Geotechnics Pty Ltd; Australian Government – Department of the Environment
Project budget	\$155 100 (GST inclusive)
Source of funding	Australian Government – Department of the Environment
Project duration	Start 2012 – September 2014
Current status	Completed
Project summary	<p>This report describes typical sedimentary Australian coal seam gas environments and processes involved in coal seam gas extraction as well as outlining a range of modelling tools and approaches used to simulate groundwater impacts associated with coal seam gas extraction. The physical processes that occur within coal seam gas extraction are identified and the effectiveness of groundwater models to represent hydrogeological conditions at specific scales is discussed.</p> <p>Conceptualisation of the modelling process requires rigorous consideration of objectives, assumptions, scale, connectivity of bores, data worth and uncertainty levels. Modelling approaches from simple analytical models to more complex numeric regional groundwater models with many assumptions are discussed. The functionality and optimal spatial resolution of numeric groundwater models are also outlined and summarised. A single modelling approach may not be able to represent a complex environment and therefore testing of assumptions, multiple models or approaches and model development may be necessary.</p> <p>Finally, the report identifies issues to consider when modelling the groundwater impacts from coal seam gas extraction. These may be useful for model evaluations, selection, approach, appropriate application, understanding scale limitations and model uncertainty analysis. Further knowledge requirements and future research areas also identified.</p>
Objectives	This report has been prepared for the informed public, water managers, regulators, state authorities and interested parties who are not familiar with coal seam gas production.
Achievements	<p>The report outlines issues to be considered when designing an approach to simulate the groundwater impacts from coal seam gas extraction. In addition, to improve the knowledge base, the report outlines four areas which could be the subject of future research:</p> <ul style="list-style-type: none"> • the influence of flow phenomena and geomechanical effects (such as accounting for dual-phase flow, dual porosity of coal, gas liberation from coal and the effects of general groundwater de-pressurisation) • surface water-groundwater interactions and access to more detailed groundwater monitoring data sets • quantifying and reducing model uncertainty • improved representation of hydrogeologic features, spatially varying

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
	hydraulic conductivity will increase our understanding of their influences on local and regional groundwater flow and allow for greater understanding of the regional significance of results.
Outputs	<p>Published on the Australian Government – Department of the Environment website and the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) website.</p> <ul style="list-style-type: none"> Commonwealth of Australia (2014) Coal seam gas extraction: modelling groundwater impacts, prepared by Coffey Geotechnics for the Australian government Department of the Environment, Commonwealth of Australia. http://www.environment.gov.au/water/publications#iesc http://iesc.environment.gov.au/publications
Key personnel	Best, Ross; Rotter, Ben; Blackam, Michael
Research themes	Disruption of surface water flow pathways, subsidence
Project information source	Survey

Table 4.43 Project 43: Monitoring and management of subsidence induced by coal seam gas extraction

Project characteristics	Details
Project title	Monitoring and management of subsidence induced by coal seam gas extraction
Project location	Australia
Principal investigator	Coffey Geotechnics
Lead institution	Coffey Geotechnics; Australian Government – Department of the Environment
Project budget	\$241 500 (GST inclusive)
Source of funding	Australian Government – Department of the Environment
Project duration	2012 – 2014
Current status	Completed
Project summary	<p>The aim of the research is to conduct analysis of the subsidence impacts arising from coal seam gas activities to better predict its effects on water resources and land use. Analysis of subsidence impacts is assessed by review of examples of subsidence impacts, development of subsidence modelling tools as a basis for predicting subsidence impacts, demonstrated use of subsidence modelling tools against observed subsidence impacts, and discussion of subsidence monitoring tools. The criteria for assessment, and the uncertainty associated with assessments, are delineated.</p> <p>Coal seam gas extraction involves the extraction of groundwater to facilitate de-pressurisation (reducing of groundwater levels with consequent lowering of groundwater pressure) of the target coal seam. The disposal or re-use of this collected water is an area of great public interest. De-pressurisation may reduce access to groundwater resources in the vicinity of the coal seam gas extraction well field. This de-pressurisation results in compression of the ground and leads to settlement of the ground surface described as subsidence.</p> <p>This summary report provides review of Australian and international experience of development of subsidence as a result of coal seam gas extraction, and methods used to predict the magnitude of subsidence and to measure subsidence.</p> <p>The report addresses the hydrogeological settings under which coal seam gas production takes place, the extraction systems, and their impacts on groundwater. Further issues related to extraction are also identified. A review of modelling tools and approaches is then conducted within the context of the issues identified.</p>
Objectives	<p>The project was undertaken to build scientific understanding of water-related impacts associated with subsidence induced by coal seam gas production. It was one of a number of projects commissioned by the Department of the Environment on the advice of the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC).</p> <p>Collectively, the projects aim to capture the state of knowledge on the water-related impacts of coal seam gas and large coal mining development, and build on the evidence base by documenting the results of monitoring and field surveys, detailing an analysis and evaluation of methods for identifying and managing impacts, developing improved models to help predict impacts, and</p>

Project characteristics	Details
	<p>providing guidance to help improve the management of unavoidable impacts. The aim of this project was to conduct an analysis of potential subsidence impacts from coal seam gas production activities, and to better predict the effects on water resources and land use. A desk-based analysis of subsidence impacts was undertaken by a review of case studies, subsidence modelling tools to assist with predicting subsidence impacts, the performance of subsidence modelling tools against observed subsidence impacts, and a discussion of subsidence monitoring tools. The criteria for assessment, and the uncertainty associated with assessments, were also delineated.</p>
Achievements	<p>This report provides a synthesis and assessment of the management and monitoring of subsidence induced by coal seam gas production from Australian and international experiences, including:</p> <ul style="list-style-type: none"> • the different causes and environmental contexts of subsidence from coal seam gas production • existing predictions and experiences relating to coal seam gas subsidence in Australia and overseas • the potential impacts of subsidence • approaches to subsidence assessment • a review of models to predict the scale and extent of subsidence • monitoring and management options and key knowledge gaps.
Outputs	<p>Published on the Australian Government – Department of the Environment website and Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development website.</p> <ul style="list-style-type: none"> • Commonwealth of Australia (2014) <i>Monitoring and management of subsidence induced by coal seam gas extraction</i>, Knowledge report, prepared by Coffey Geotechnics for the Department of the Environment, Commonwealth of Australia, Canberra. <p>http://www.environment.gov.au/water/publications#iesc http://iesc.environment.gov.au/publications</p>
Key personnel	Coffey Geotechnics
Research themes	Disruption of surface water flow pathways, subsidence
Project information source	Survey

Table 4.44 Project 44: Assessing predictive error when up-scaling CSG reservoir models for regional GW model impact assessment

Project characteristics	Details
Project title	Assessing predictive error when up-scaling CSG reservoir models for regional GW model impact assessment
Project location	Australia
Principal investigator	Unknown
Lead institution	CSIRO
Project budget	Unknown
Source of funding	Unknown
Project duration	2014
Current status	In progress
Project summary	Determine the predictive uncertainty associated with predictions of drawdown impacts resulting from CSG extraction, within the regional scale context and the best way to upscale from detailed to regional representations.
Objectives	Unknown
Achievements	Unknown
Outputs	http://research.ccsq.uq.edu.au/projects/assessing-predictive-error-when-scaling-csg-reservoir-models-regional-gw-model-impact
Key personnel	Unknown
Research themes	Surface water
Project information source	UQ CCSG Online Portal

Table 4.45 Project 45: Applications of signal decomposition and surrogate modelling to assist the identification of aquifer stressors and sentinel well selection

Project characteristics	Details
Project title	Applications of signal decomposition and surrogate modelling to assist the identification of aquifer stressors and sentinel well selection
Project location	Australia
Principal investigator	Moore, Catherine
Lead institution	CSIRO
Project budget	Unknown
Source of funding	Unknown
Project duration	Unknown—Literature output 2013
Current status	Unknown—Literature output 2013
Project summary	<p>The impacts of new mining developments, such as coal seam gas projects, upon groundwater resources can be difficult to evaluate. The drawdown time series at a given observation well may reflect the influence of a number of stressors, such as groundwater extractions by various users. Determining the relative influence of each stressor is useful to water users and managers when managing the impacts of additional groundwater use.</p> <p>The first part of this study used signal decomposition techniques such as series and wavelet analysis to separate a ‘mixed’ drawdown time series into orthogonal component series, including mining and irrigation extraction signals, as well as a long-term climate signal. Least squares calibration tools were then used to estimate the contribution of each orthogonal component to the mixed signal. A related problem may occur when the extent of an existing observation well network is not sufficient to identify aquifer impacts from recent development. When attempting to locate additional ‘sentinel’ observation wells, groundwater regulators may face complications arising from complex aquifer geometry, including multiple hydrogeological units, or from the confounding effects of existing groundwater water development. Under this scenario, numerical modelling tools can be used as a test bed to compare the efficacy of various possible sentinel well options; together with signal decomposition and hypothesis testing methods. In this context, well locations and monitoring frequencies are assessed as having greater or lesser value depending on the degree to which they increase the reliability of estimates of relative impact. To facilitate the large computational burden requirements of identifying optimal locations of new sentinel wells, model reduction methods such as Proper Orthogonal Decomposition are being explored. Linear predictive uncertainty measures are being used as the metric for comparison of different reduction methods.</p>
Objectives	To apply signal decomposition and surrogate modelling to assist the identification of aquifer stressors and sentinel well selection.
Achievements	The use of signal decomposition techniques such as series and wavelet analysis to separate a ‘mixed’ drawdown time series into orthogonal component series, including mining and irrigation extraction signals, as well as a long-term climate signal.

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Outputs	https://publications.csiro.au/rpr/pub?list=ASE&pid=csiro:EP133112&expert=false&sb=RECENT&n=20&rpp=50&page=8&tr=451&dr=all&csiro.flagshipOrPortfolio=0000009550 Moore C, Turnadge C and Pagendam D (2013) "Applications of signal decomposition and surrogate modelling to assist the identification of aquifer stressors and sentinel well selection". IAH 2013. Perth, Australia: International Association of Hydrogeologists.
Key personnel	Moore, Catherine; Turnadge, Chris; Pagendam, Dan
Research themes	Surface water
Project information source	Literature

Table 4.46 Project 46: A new subsurface fracture height prediction model for longwall mines in the NSW coalfields

Project characteristics	Details
Project title	A new subsurface fracture height prediction model for longwall mines in the NSW coalfields
Project location	Australia
Principal investigator	Ditton, Steven
Lead institution	Ditton Geotechnical Services Pty Ltd
Project budget	Unknown
Source of funding	Unknown
Project duration	Unknown - July 2014
Current status	Completed
Project summary	<p>Community concerns regarding subsurface groundwater regime impacts and widely varying subsurface fracture height predictions (and groundwater response definitions) at several longwall mine locations in NSW have prompted a review of published mine site data by the authors.</p> <p>The current suite of subsurface fracture height prediction models attempt to define the zone of complete groundwater de-pressurisation and the minimum thickness of overlying rock required to protect highly productive aquifers and permanent waters. Unfortunately, some models developed in one coalfield are not easily transferable for use in other coalfields due to significant variations in mining geometry and geology.</p>
Objectives	<ul style="list-style-type: none"> • Review of the 'state-of-the-art' subsurface fracture zone height prediction models. • Development of a new model based on Buckingham's PI-Term theory and analytical models of strata behaviour during the caving process above longwalls.
Achievements	<ul style="list-style-type: none"> • Review of the 'state-of-the-art' subsurface fracture zone height prediction models. • Development of a new model based on Buckingham's PI-Term theory and analytical models of strata behaviour during the caving process above longwalls. The new model includes the key fracture height driving parameters of panel width (W), cover depth (H), mining height (T) and local geology factors to estimate the A and B zone horizons above a given longwall panel. The potential bias in the regression equations due to geological affects has been addressed by determining the effective thickness (t') of the strata where the A Zone height occurred.
Outputs	Ditton S and Merrick N (2014) "A new subsurface fracture height prediction model for longwall mines in the NSW coalfields". In Geological Society of Australia, 2014 <i>Australian Earth Sciences Convention (AESC), Sustainable Australia. Abstract No 110 of the 22nd Australian Geological Convention</i> , Newcastle City Hall and Civic Theatre, Newcastle, New South Wales. July 7–10.
Key personnel	Ditton, Steven; Merrick, Noel

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Research themes	Surface water; aquifer interconnectivity
Project information source	Conference

Table 4.47 Project 47: Management of mine subsidence impacts beneath the township of Tahmoor

Project characteristics	Details
Project title	Management of mine subsidence impacts beneath the township of Tahmoor
Project location	Australia
Principal investigator	Sheppard, I
Lead institution	Glencore and Mine Subsidence Engineering Consultants
Project budget	Unknown
Source of funding	Private sector funding
Project duration	1 March 2007 to 2014
Current status	Completed
Project summary	<p>Over a period of nine years, Tahmoor Colliery has successfully extracted six longwall panels directly beneath the township of Tahmoor. The seventh and final longwall panel directly beneath the town will be extracted in 2014. The extraction of Longwalls 22 to 27 have affected approximately 1550 houses, a number of public amenities including a shopping centre and places of worship and many commercial establishments including a poultry processing plant. Mining has also affected more than 20 km of local roads, the Main Southern Railway, two road bridges, and many kilometres of potable water, sewerage, gas, electrical and telecommunications infrastructure.</p> <p>Successful management of mine subsidence impacts has been a critical component of Tahmoor Colliery's operations. It has been achieved through extensive engagement, education and consultation with the community and owners of infrastructure; consultation and coordination with the Mine Subsidence Board, the Department of Trade and Investment Resources and Energy and other government departments; and careful planning and diligent execution of subsidence management measures for each item of infrastructure. This paper describes the approach undertaken by Tahmoor Colliery to manage mine subsidence impacts at Tahmoor. It includes a description of how Tahmoor Colliery has consulted with the community and a summary of impacts that have occurred as a result of mining. The experience gained at Tahmoor illustrates that longwall mining beneath urban areas is sustainable and can be successfully managed to mitigate the impacts on surface developments.</p>
Objectives	Manage mine subsidence impacts at Tahmoor. It includes a description of how Tahmoor Colliery has consulted with the community and a summary of impacts that have occurred as a result of mining.
Achievements	The experience gained at Tahmoor illustrates that longwall mining beneath urban areas is sustainable and can be successfully managed to mitigate the impacts on surface developments
Outputs	Sheppard I, Treverrow B, Kay DJ, Bullock DW, Matheson J, Warren G and Dove C (2014) "Management of mine subsidence impacts beneath the township of Tahmoor". 9 th Triennial Conference on Mine Subsidence, 11–13 May 2014, Hunter Valley, NSW. http://www.mstsociety.org/

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Key personnel	Sheppard, I; Treverrow, B; Kay, DJ; Bullock, DW; Matheson, J; Warren, G; Dove, C
Research themes	Cumulative impact assessments, surface water
Project information source	Survey

Table 4.48 Project 48: Walloon connectivity project

Project characteristics	Details
Project title	Walloon connectivity project
Project location	Australia
Principal investigator	Clohessy, Steven
Lead institution	Office of Groundwater Impact Assessment (OGIA), Queensland Department of Natural Resources and Mines
Project budget	Unknown
Source of funding	OGIA through an industry levy
Project duration	2013 – 2015
Current status	In progress
Project summary	<p>As part of its work in gaining a better understanding about groundwater flow systems in the Surat Basin, the Office of Groundwater Impact Assessment (OGIA) is carrying out the Walloon Connectivity Research Project (the WCP). The WCP is part of the implementation of the Surat Underground Water Impact Report (UWIR) which was approved in December 2012.</p> <p>The WCP is improving understanding of the connectivity between the Walloon Coal Measures (WCM) and the underlying Hutton Sandstone and the overlying Springbok Formation. Outcomes from the WCP will be incorporated into the next revision of the regional groundwater flow model that will be used to update the Surat UWIR in late 2015.</p>
Objectives	To improve the understanding of connectivity between the Walloon Coal Measures and underlying and overlying aquifers.
Achievements	<ul style="list-style-type: none"> • Regional desktop investigations (in progress) • Field data collection (in progress) • Mapping of vertical permeability values
Outputs	<p>Assessment of connectivity between Walloon Coal Measures and overlying and underlying aquifers in three focus areas and at a regional scale based on water pressure, hydrochemical data, petrophysical analysis and centrifuge permeameter testing.</p> <p>Project outcomes will be included in the groundwater conceptualisation, regional flow modelling and reporting for the next Surat CMA UWIR (in December 2015)</p> <p>Doherty J, Gallagher M, Herckenrath D, Jolly P and Pandey S (2013) "Towards development of a regional modelling methodology for assessment of impacts from coal seam gas development". 40th IAH Congress on Solving the Groundwater Challenges of the 21st Century, 15–20 September 2013, Perth, Australia.</p>
Key personnel	Clohessy, Steven; Singh, Dhananjay
Research themes	Aquifer interconnectivity, cumulative impacts
Project information source	Survey

Table 4.49 Project 49: Assessment of potential for formation compaction and surface subsidence associated with CSG production in the Surat Basin, Queensland

Project characteristics	Details
Project title	Assessment of potential for formation compaction and surface subsidence associated with CSG production in the Surat Basin, Queensland
Project location	Australia
Principal investigator	Morris, Ryan
Lead institution	QGC; Santos; APLNG; Arrow Energy
Project budget	Unknown
Source of funding	QGC; Santos; APLNG; Arrow Energy
Project duration	2014 – 2015
Current status	In progress
Project summary	<p>In order to extract coal seam gas, reservoir pressures must be reduced to allow the methane to desorb from the coal matrix. The pressure reduction is achieved through the extraction of water, which has the potential to compress the coals and overlying and underlying strata and could result in formation compaction and surface subsidence. This potential is controlled by the degree of compressibility of the material and the magnitude of the pressure change and is greatest when sediments are unconsolidated and pressure declines are large.</p> <p>Although the degree of pressure change associated with CSG productions can be large, the formations are consolidated. Federal Government environmental approvals condition the Australian Pacific LNG Project to undertake subsidence monitoring of its CSG developments in the Surat Basin, Queensland. The Surat Basin is a sub-basin of the Great Artesian Basin. The monitoring program being implemented comprises regional scale Interferometric Synthetic Aperture Radar (InSAR) and traditional geodetic surveying of permanent benchmarks, and local scale focused study sites that include extensometers, arrays of tiltmeters and nested piezometers.</p> <p>This paper discusses the results of a baseline InSAR survey, geomechanical responses at one of the focus sites during water injection trials, and the risk of potential formation compaction and surface subsidence associated with CSG production in the Surat Basin.</p>
Objectives	To use high resolution satellites to evaluate ground motion within QGC tenements. This investigation is part of an industry wide collaborative effort.
Achievements	The completion of a baseline InSAR survey.
Outputs	<p>http://research.ccsq.uq.edu.au/projects/ground-motion-studies-qgc-santos-australia-pacific-lng-arrow-energy</p> <p>Morris R (2013) "Assessment of potential for formation compaction and surface subsidence associated with CSG production in the Surat Basin, Queensland". 40th IAH Congress on Solving the Groundwater Challenges of the 21st Century. Perth, Australia.</p>
Key personnel	Morris, Ryan
Research themes	Disruption of surface flow pathways

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Project information source	40 th IAH Congress, UQ CCSG database

Table 4.50 Project 50: Numerical modeling of mining subsidence in the Southern Coalfield of New South Wales, Australia

Project characteristics	Details
Project title	Numerical modeling of mining subsidence in the Southern Coalfield of New South Wales, Australia
Project location	Australia
Principal investigator	Zhang, C
Lead institution	School of Mining Engineering, University of New South Wales; Metropolitan Coal
Project budget	Unknown
Source of funding	University of New South Wales and Peabody Energy
Project duration	2010 – 2014
Current status	In progress
Project summary	<p>Valley closure and valley floor upsidence occur when mining beneath or in close proximity to valleys and other forms of irregular surface topography. The research aims to conduct comprehensive numerical investigation and calibration studies for a range of parameters, in order to deliver improvement in the understanding of such mechanism. The study will:</p> <ul style="list-style-type: none"> • develop a series of hypothetical mining/surface topography scenarios based on the existing database • conduct comprehensive modelling for each mining/topography scenarios, including a series of parametric analyses • develop recommendations with regard to the underlying geotechnical mechanisms that lead to the observed valley closure subsidence.
Objectives	As above
Achievements	PhD thesis nearing completion.
Outputs	<p>Zhang C, Mitra R, Hebblewhite B and Tarrant G (2014) "Investigation of geological and geotechnical effects on valley closure subsidence behaviour", Mine Subsidence Technological Society 9th Triennial Conference, 11–13 May 2014, Vol 1, pp. 207–220.</p> <p>Zhang C, Mitra R, Hebblewhite B and Tarrant G (2013) "Numerical modeling of mining subsidence in the Southern Coalfield of New South Wales, Australia". Proceedings of the 3rd International FLAC/DEM Symposium-Continuum and Distinct Element Numerical Modeling in Geomechanics – 2013. Hangzhou, China: Itasca International Inc.</p> <p>Ilic J and Hebblewhite B (2013) "Evaluating the prediction of subsidence for multi-seam mines within the Hunter Coalfields", BE Honours Thesis, UNSW Australia School of Mining.</p>
Key personnel	Zhang, C; Mitra, R; Hebblewhite, B; Tarrant, G
Research themes	Surface water
Project information source	Survey

Table 4.51 Project 51: Background review: Subsidence from coal seam gas extraction in Australia

Project characteristics	Details
Project title	Background review: Subsidence from coal seam gas extraction in Australia
Project location	Australia
Principal investigator	Sinclair Knight Merz Pty Ltd
Lead institution	Sinclair Knight Merz Pty Ltd; Australian Government – Department of the Environment
Project budget	Approx. \$52 500 (GST inclusive)
Source of funding	Australian Government – Department of the Environment
Project duration	2012 – 2014
Current status	Completed
Project summary	This report provides an overview of Australian and international experiences of subsidence and other ground-related movements as a result of coal seam gas extraction, including the methods used to predict the magnitude of subsidence and to subsequently measure that subsidence. Where large quantities of groundwater are extracted during the coal seam gas extraction process, one of the possible consequences is compaction caused by de-pressurisation of the coal seam, settlement due to the increased effective stress this generates within the overlying strata and subsidence at the ground surface.
Objectives	<p>The focus of this report is on subsidence issues associated with coal seam gas extraction including:</p> <ul style="list-style-type: none"> • the different causes of subsidence • technology and tools for monitoring, measuring and assessing the extent of subsidence • models to predict the scale and extent of subsidence • remediation options.
Achievements	<p>Key findings are listed below.</p> <ul style="list-style-type: none"> • While there is no confirmed subsidence resulting from coal seam gas development in Australia, the maximum predicted is approximately 280 mm. • This compares with observed subsidence of up to 83 mm over three years in the United States. • The predicted subsidence and hence impacts from coal seam gas development are relatively small compared with long wall coal mining. But small movements can be significant in some circumstances and so need to be assessed on a case-by-case basis. • Predictions are constrained by the absence of observed subsidence and empirical relationships. • Techniques are available to monitor subsidence; a mixture is preferred to capture the effects at different scales. • Effective remediation options are limited.

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Outputs	<p>Published on the Australian Government – Department of the Environment website and the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) website.</p> <ul style="list-style-type: none"> Commonwealth of Australia (2014) <i>Subsidence from coal seam gas extraction in Australia, Background review</i>. Department of the Environment, Canberra. http://www.environment.gov.au/water/publications#iesc
Key personnel	Unknown
Research themes	Disruption of surface water flow pathways, subsidence
Project information source	Survey

Table 4.52 Project 52: Background review: Subsidence from coal mining activities

Project characteristics	Details
Project title	Background review: Subsidence from coal mining activities
Project location	Australia
Principal investigator	Sinclair Knight Merz Pty Ltd
Lead institution	Sinclair Knight Merz Pty Ltd; Australian Government – Department of the Environment
Project budget	Approximately \$52 500 (GST inclusive)
Source of funding	Australian Government – Department of the Environment
Project duration	2012 – 2014
Current status	Completed
Project summary	<p>The subject of this report is subsidence associated with coal mining in Australia, including predicting, monitoring and mitigating subsidence, and application of regulatory requirements. The report focusses on current underground coal mining in the states of New South Wales and Queensland, where most activity occurs. Subsidence risks associated with mining voids that resulted from past mining activities are not the subject of this review.</p> <p>The report has been prepared from information available in the public domain, including:</p> <ul style="list-style-type: none"> • journal articles • conference proceedings • scientific text books • government department reports • industry and consulting reports.
Objectives	<p>The report was commissioned to provide a review of what is known about predicting, monitoring, assessing and remediating subsidence and other movement-related impacts associated with coal mining activities, including:</p> <ul style="list-style-type: none"> • the different causes and expressions of subsidence from coal mining • existing technology and tools for monitoring and assessing the extent of subsidence • models to predict the scale and extent of subsidence • remediation options.
Achievements	This review provides background to Australian underground coal mining practice, impact assessment procedures and regulatory frameworks. It draws largely from New South Wales experience, but also refers to underground mining in Queensland, which is at a comparatively earlier stage.
Outputs	<p>Published on the Australian Government – Department of the Environment website and the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) website.</p> <p>http://www.environment.gov.au/node/37007</p> <ul style="list-style-type: none"> • Commonwealth of Australia (2014) <i>Subsidence from coal mining activities, Background review</i>. Department of the Environment, Canberra. <p>http://www.environment.gov.au/water/publications#iesc</p>

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Key personnel	Unknown
Research themes	Disruption of surface water flow pathways, subsidence
Project information source	Survey

Table 4.53 Project 53: Radon-222 studies in a longwall mining impacted water supply catchment

Project characteristics	Details
Project title	Radon-222 studies in a longwall mining impacted water supply catchment
Project location	Australia
Principal investigator	McLean, Wendy
Lead institution	Sydney Catchment Authority
Project budget	Unknown
Source of funding	Unknown
Project duration	Unknown—Literature output 2013
Current status	Unknown—Literature output 2013
Project summary	<p>The groundwater-surface water interaction in a longwall mining affected reach of the Waratah Rivulet catchment, New South Wales, Australia, was estimated using an applied tracer (salt tracer) as well as a natural tracer (radon-222). The natural tracer (radon-222) has been regularly measured since 2007 along the Waratah Rivulet and its two main tributaries, Tributary D and Forest Gully. Prior longwall panels had been mined at a depth of >400 m below the Waratah Rivulet and the effects of surface subsidence and fracturing were apparent during periods of low flow with loss of surface water flow and decline in natural pool levels.</p> <p>During the study period, the progressive increase in mining occurred in a northwestern direction with 6 panels mined beneath the 2 main tributaries and 2 further panels below the lower reaches of the Waratah Rivulet. These groundwater and surface water resources of the Waratah Rivulet which are part of the Sydney Basin form a critical part of water supply for the Greater Sydney area. However, mine subsidence beneath these water supply catchments can reactivate existing fractures, joints, lineaments and faults, and cause new fractures and fracture zones.</p> <p>The impact of subsidence on surface waterways is characterised by fracturing of riverbeds and rockbars, resulting in the diversion of surface water to subsurface flow, changes to stream alignment, increased interaction between surface water and groundwater and deterioration in water quality. Depending on the vertical extent of cracking, surface water may be lost temporarily, with the possibility of water re-emerging downstream. Background radon-222 values in the shallow groundwater system (un-impacted by mining) were measured to be 17 Bq/L. During the study period, radon-222 values in the shallow groundwater system ranged from 1.80 to 17.0 Bq/L. Values showed a decreasing trend with the progression of mining, that is, radon-222 values in shallow groundwater became progressively lower as longwall mining progressed beneath the tributaries and enhanced groundwater-surface water connections through surface cracking. Mass balance calculations using radon-222 along the 2 km stretch of the Rivulet affected by longwall mining during the study period estimated a net loss of surface water ranging from 0.20 MU day to 0.48 MUday under low flow conditions <12 MUday. Results were compared to the results of applied tracer tests of which the latest tracer test showed a 25% reduction in surface water flow over the 2 km study stretch (including of current mining) (-0.5 to 1.0 MUday). These results will be used in ongoing management of water supply catchments in the Sydney Catchment Authority.</p>

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Objectives	To investigate the groundwater-surface water interaction in a longwall mining affected reach of the Waratah Rivulet catchment.
Achievements	The application of an applied tracer (salt tracer) as well as a natural tracer (radon-222) in the study area.
Outputs	McLean W, Jankowski J, Scarff S and Moran S (2013) "Radon-222 studies in a longwall mining impacted water supply catchment". 40 th IAH Congress on Solving the Groundwater Challenges of the 21 st Century. Perth, Australia.
Key personnel	McLean, Wendy; Jankowski, Jerzy; Scarff, Sarah; Moran, Sean
Research themes	Disruption of surface water flow pathways
Project information source	40 th IAH Congress

Table 4.54 Project 54: Improved methods for predicting mining induced horizontal movements and ground strains caused by longwall mining

Project characteristics	Details
Project title	Improved methods for predicting mining induced horizontal movements and ground strains caused by longwall mining
Project location	Australia
Principal investigator	Barbato, James
Lead institution	University of New South Wales
Project budget	\$530 000
Source of funding	Currently seeking funding to allow full time research.
Project duration	1 August 2013 – 1 August 2017
Current status	In progress
Project summary	<p>The potential for impacts on natural and built features from longwall coal mining are dependent on the differential ground movements, which include both normal and shear strains. There are several well established empirical and numerical/analytical methods used to predict vertical subsidence movements, however, at the moment there are no accurate methods for predicting horizontal movements or strains.</p> <p>The predictive methods for these horizontal components represent a significant knowledge gap in mine subsidence research, principally because accurate 3D horizontal monitoring techniques were not available until more recently. Existing methods for the prediction of horizontal movements and strain are generally based on simple empirical relationships which are not as accurate as the predictive methods for vertical subsidence, or based on statistical analyses for specific mining geometries. There are currently no recognised methods for the prediction of shear strains. Extensive 3D horizontal movement monitoring data and case studies are now available which will assist in the development of much improved methods for the prediction of absolute horizontal movements, normal strains and shear strains.</p> <p>The research includes the:</p> <ul style="list-style-type: none"> • detailed reviews of available monitoring data and case studies from the NSW Coalfields • development of analytical models for each of the known mechanisms which influence mine subsidence • numerical modelling to investigate the mechanisms and factors which influence mine subsidence • statistical analysis of the available monitoring data. <p>The aim is to develop methods which provide the predictions and the confidence intervals for absolute horizontal movement, normal and shear strain.</p>
Objectives	The objective of this research is to improve the reliability of the horizontal movement and strain predictive methods to allow for better assessments of the potential impacts on all types of natural and built features, as well as the more realistic assessments of the potential levels of risk associated with longwall coal mining.
Achievements	Nil to date (research in progress)

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Outputs	Nil to date (research in progress)
Key personnel	Barbato, James
Research themes	Surface water
Project information source	Survey

Table 4.55 Project 55: Subsidence monitoring – technical background paper for NSW Chief Scientist and Engineer

Project characteristics	Details
Project title	Subsidence monitoring – technical background paper for NSW Chief Scientist and Engineer
Project location	Australia
Principal investigator	Tickle, Phil
Lead institution	University of Newcastle, Australia
Project budget	Unknown
Source of funding	New South Wales Government
Project duration	Unknown—Literature output 2014
Current status	Unknown—Literature output 2014
Project summary	The paper discusses the main causes of subsidence with particular emphasis on the effects associated with CSG extraction. An overview of the most common subsidence problems occurring in different engineering scenarios is given in Section 2. The main characteristics of the coal seam gas extraction are described in Section 3, including the most common methods employed for gas extraction, the main mechanisms of subsidence related to CSG extraction, and their potential impacts. The influence of the different extraction configurations, their similarities compared to other mining activities, the potential ‘worst’ case subsidence scenarios and the risk assessment and management are also discussed in Section 3. The key issues and knowledge gaps regarding subsidence caused by CSG extraction are discussed in Section 4, with emphasis on the further research that is needed to improve current practice as well as subsidence prediction and control.
Objectives	To discuss the main causes of subsidence with particular emphasis on the effects associated with CSG extraction.
Achievements	<ul style="list-style-type: none"> • An overview of the most common subsidence problems occurring in different engineering scenarios. • The main characteristics of the coal seam gas extraction, including the most common methods employed for gas extraction, the main mechanisms of subsidence related to CSG extraction, and their potential impacts. • The key issues and knowledge gaps regarding subsidence caused by CSG extraction, with emphasis on the further research that is needed to improve current practice as well as subsidence prediction and control.
Outputs	http://www.chiefscientist.nsw.gov.au/coal-seam-gas-review/csg-background-papers Tickle P (2014) Subsidence causes - technical background paper for NSW Chief Scientist and Engineer. Cooperative Research Centre for Spatial Information.
Key personnel	Tickle, Phil
Research themes	Surface water

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Project information source	Literature

4.2.3 China

Table 4.56 Project 56: Treatment methods of coal mining subsidence area at South Lake in Tangshan city, Hebei province

Project characteristics	Details
Project title	Treatment methods of coal mining subsidence area at South Lake in Tangshan city, Hebei province
Project location	China
Principal investigator	Xu, Chunguang
Lead institution	China University of Mining and Technology, Beijing
Project budget	Unknown
Source of funding	Teachers' Scientific Research Funds of China Earthquake Administration (No. 20110113)
Project duration	Unknown—Literature output 2014
Current status	Unknown—Literature output 2014
Project summary	The mine environmental problems, such as mining collapse, karst collapse, ground cracks, land subsidence and water pollution, are produced by coal exploitation at the south lake of Tangshan city. Considering the species and distribution characteristics, stable subsidence and unstable subsidence, we'll conduct the geological disaster partition. Adopting scientific principles according to local conditions helps to achieve the purposes of management and protection. © 2014 Taylor Francis Group.
Objectives	To investigate the feasibility of treatment methods for subsidence affected areas in Tangshan city.
Achievements	The construction of an ecological city at the south lake of Tangshan city that can make good use of the characteristics of topography and turn the waste into the treasure.
Outputs	http://www.crcnetbase.com/doi/abs/10.1201/b16606-64 Xu C, Chen Y and Li Z (2014) "Treatment methods of coal mining subsidence area at South Lake in Tangshan city, Hebei province". 2nd International Symposium of Mine Safety Science and Engineering, September 21, 2013 - September 23, 2013. Beijing, China: Taylor & Francis - Balkema.
Key personnel	Xu, Chunguang; Chen, Ye; Li, Zhong
Research themes	Surface water
Project information source	Literature

Table 4.57 Project 57: Effect of mining subsidence on soil erosion in mountainous area of the Loess Plateau

Project characteristics	Details
Project title	Effect of mining subsidence on soil erosion in mountainous area of the Loess Plateau
Project location	China
Principal investigator	Huang, Yi
Lead institution	School of Environment and Spatial Information, China University of Mining and Technology, Xuzhou, China
Project budget	Unknown
Source of funding	Unknown
Project duration	Unknown—Literature output 2014
Current status	Unknown—Literature output 2014
Project summary	<p>Mining subsidence reshapes the surface structure and morphology in a mountainous area. However, surface deformation and movement rules in a mountainous area influenced by mining subsidence are quite different from those in a flat area, which result mainly from the superposition of ground subsidence and surface moving caused by slippage. Research about change of the soil erosion caused by the above phenomenon is very necessary.</p> <p>In this paper, based on mining subsidence rules and models, a DEM of the subsidence area was constructed referring to the subsidence parameters in the research area. On this basis, the soil erosion changes of three major factors—slope, slope length factor, and vegetation coverage factor caused by mining subsidence in a revised universal soil loss equation in mountainous area were measured for the first time, and the other three parameters that were not disturbed by mining in a revised universal soil loss equation were calculated according to relevant research studies. Finally, soil erosion quantity in the research area was calculated.</p> <p>The results showed that:</p> <ul style="list-style-type: none"> • From 2001 to 2010, the average slope decreased by 0.025, caused by mining in the study area, average slope length factor decreased by 0.139, the area that soil erosion unchanged, reduced and increased in subsidence area was respectively 3.083, 3.412 and 4.707 km², and the area in which soil erosion reduced and increased out of the subsidence area was respectively 0.143 and 0.023 km², the totally soil erosion amount decreased by 78426.95 t, 689.892 t/km² in average per year, which was mainly caused by the decrease of slope length and slope. • The impact on soil erosion affected by mining subsidence in the upstream area will influence in part the area of the watershed where outside the mining area, and ending in the position where the slope length is ended, because mining subsidence changes the flow direction, and furthermore, flow length is changed as a result. • In the basin of the subsidence area, the subsidence value was basically the same, slope and flow direction doesn't change. Nevertheless, the physical and chemical properties of the soil are changed, the vegetation was injured, and the vegetation cover factor became the main factor influencing soil

Project characteristics	Details
	<p>erosion in this region.</p> <ul style="list-style-type: none"> • Soil erosion affected by mining subsidence in a mountainous area is quite different from flat ground. On flat ground, mining subsidence will absolutely intensify soil erosion except in the subsidence basin, because the slope and slope length are increased, but in a mountainous area, there is no absolute positive or negative influence, and the result is closely related to the original landform, subsidence magnitude, and location.
Objectives	To investigate the effect of mining subsidence on soil erosion in mountainous area of the Loess Plateau.
Achievements	The research conclusions can provide a scientific basis for soil erosion predictions in a mountainous mining area.
Outputs	<p>http://dx.doi.org/10.3969/j.issn.1002-6819.2014.01.029</p> <p>Huang Y, Wang Y, Wang M, Tian F and Ao J (2014) "Effect of mining subsidence on soil erosion in mountainous area of the Loess Plateau". <i>Nongye Gongcheng Xuebao/Transactions of the Chinese Society of Agricultural Engineering</i>, 30 (1). Agricultural Exhibition Road South, Beijing, 100026, China: Chinese Society of Agricultural Engineering.</p>
Key personnel	Huang, Yi; Wang, Yunjia; Wang, Meng; Tian, Feng; Ao, Jianfeng
Research themes	Surface water
Project information source	Literature

4.2.4 United States

Table 4.58 Project 58: Surface water and groundwater interactions in an extensively mined watershed, upper Schuylkill River, Pennsylvania, USA

Project characteristics	Details
Project title	Surface water and groundwater interactions in an extensively mined watershed, upper Schuylkill River, Pennsylvania, USA
Project location	USA
Principal investigator	Cravotta, Charles A
Lead institution	U.S. Geological Survey; US Army Corps Engineers
Project budget	Unknown
Source of funding	U.S. Geological Survey
Project duration	Unknown—Literature output May 2014
Current status	Unknown—Literature output May 2014
Project summary	<p>Streams crossing underground coal mines may lose flow, whereas abandoned mine drainage (AMD) restores flow downstream. During 2005-2012, discharge from the Pine Knot Mine Tunnel, the largest AMD source in the upper Schuylkill River Basin, had near-neutral pH and elevated concentrations of iron, manganese and sulphate. Discharge from the tunnel responded rapidly to recharge but exhibited a prolonged recession compared with nearby streams, consistent with rapid infiltration of surface water and slow release of groundwater from the mine complex. Dissolved iron was attenuated downstream by oxidation and precipitation, whereas dissolved CO₂ degassed and pH increased. During high flow conditions, the AMD and downstream waters exhibited decreased pH, iron and sulphate with increased acidity that were modelled by mixing net-alkaline AMD with recharge or run-off having low ionic strength and low pH. Attenuation of dissolved iron within the river was least effective during high flow conditions because of decreased transport time coupled with inhibitory effects of low pH on oxidation kinetics.</p> <p>A numerical model of groundwater flow was calibrated by using groundwater levels in the Pine Knot Mine and discharge data for the Pine Knot Mine Tunnel and West Branch Schuylkill River during a snowmelt event in January 2012. Although the calibrated model indicated substantial recharge to the mine complex took place away from streams, simulation of rapid changes in mine pool level and tunnel discharge during a high flow event in May 2012 required a source of direct recharge to the Pine Knot Mine. Such recharge produced small changes in mine pool level and rapid changes in tunnel flow rate because of extensive unsaturated storage capacity and high transmissivity within the mine complex. Thus, elimination of stream leakage could have a small effect on the annual discharge from the tunnel, but a large effect on peak discharge and associated water quality downstream.</p> <p>Published 2013. This article is a U.S. Government work and is in the public domain in the USA.</p>
Objectives	To investigate the influence of abandoned mine drainage in the upper Schuylkill River Basin.

Project characteristics	Details
Achievements	<ul style="list-style-type: none"> • A numerical model of groundwater flow calibrated using groundwater levels in the Pine Knot Mine and discharge data for the Pine Knot Mine Tunnel and West Branch Schuylkill River during a snowmelt event in January 2012. • Maps showing the geographic extent and interconnection of underground mines.
Outputs	http://onlinelibrary.wiley.com/doi/10.1002/hyp.9885/abstract Cravotta CA, Goode DJ, Bartles MD, Risser DW and Galeone DG (2014) "Surface water and groundwater interactions in an extensively mined watershed, upper Schuylkill River, Pennsylvania, USA". <i>Hydrological Processes</i> , 28 (10).
Key personnel	Cravotta, Charles A; Goode, DJ; Bartles, MD; Risser, DW; Galeone, DG
Research themes	Surface water, water supplies
Project information source	Literature

4.3 Co-produced water and salt management (CSG) and mine water and salt management (coal mines)

Projects in this category relate to the impacts of water produced during coal seam gas and mining operations and consequently, the need for salt management. This encompasses technologies for water disposal such as aquifer injection or water treatment, and the effects of this water on land, water resources and water-dependent ecosystems due to the selected management method.

A total of 39 projects were collated with the primary theme of co-produced water and salt management (CSG) and mine water and salt management (coal mines) from Australia (27 projects), Canada (1 project), China (2 projects), Russia (1 project), the United Kingdom (1 project) and the United States (7 projects).

4.3.1 Australia

Table 4.59 Project 59: Understanding the salinity issue of coal mine spoils in the context of salt cycle

Project characteristics	Details
Project title	Understanding the salinity issue of coal mine spoils in the context of salt cycle
Project location	Australia
Principal investigator	Li, XF
Lead institution	Centre for Mined Land Rehabilitation, Sustainable Minerals Institution, University of Queensland
Project budget	Unknown
Source of funding	UQ Postdoctoral Research Fund
Project duration	Unknown—Literature output 2014
Current status	Unknown—Literature output 2014
Project summary	<p>Coal mine spoils (CMS), the solid wastes originated from the rock formations and soil cover overlying or interbedded with coal seams, are a worldwide environmental management challenge. Previous studies have shown that salinity is of most concern among the CMSs' environmental impacts, especially in Australia. With increasing concerns from both the governments and communities, there is a real need for the coal mining industry to understand the source, dynamics and management options of CMS salinity.</p> <p>We reviewed the general properties of CMSs from coal mine sites worldwide and the current understanding of the CMS salinity, which are in a limited number of available published reports. Properties (e.g. pH, electrical conductivity and hydraulic conductivity) of studied CMSs varied largely due to its complex lithological origination. A conceptual model was proposed to illustrate the origin, dispersion paths and transformations dynamics of salts in spoils, taking the scenario of a coal mine in Australia as an example. The major factors governing the salt dynamics in CMSs are summarised as mineral weatherability and salt leachability of the spoils. Management of CMS salinity is still a vague area awaiting more extensive studies. Three topics related to the management were explored in the review, which are pre-mining planning, spatial variability of spoil properties and remediation including electrokinetics and phytoremediation.</p>

Project characteristics	Details
	Particularly, based on the geological classification of CMSs and the leachate chemistry of spoils of various sources, a clear relationship between salinity and geounits was established. This association has a potential application in pre-mining planning for the management of salinity from coal mine spoils.
Objectives	To review the general properties of CMSs from coal mine sites worldwide and the current understanding of the CMS salinity.
Achievements	A conceptual model was proposed to illustrate the origin, dispersion paths and transformations dynamics of salts in spoils, taking the scenario of a coal mine in Australia as an example.
Outputs	http://link.springer.com/article/10.1007%2Fs10653-013-9573-4 Li XF, Park JH, Edraki M and Baumgartl T (2014) "Understanding the salinity issue of coal mine spoils in the context of salt cycle". <i>Environmental Geochemistry and Health</i> , 36 (3).
Key personnel	Li, XF; Park, JH; Edraki, M; Baumgartl, T
Research themes	Co-produced/mine water
Project information source	Literature

Table 4.60 Project 60: Assessing environmental safety of in-pit disposal of tailings in coal mines C20027

Project characteristics	Details
Project title	Assessing environmental safety of in-pit disposal of tailings in coal mines C20027
Project location	Australia
Principal investigator	Baumgartl, Thomas
Lead institution	Centre for Mined Land Rehabilitation, University of Queensland, Australia
Project budget	\$260 000
Source of funding	Australian Coal Industry Research Program (ACARP)
Project duration	1 March 2011 – 1 July 2014
Current status	Completed
Project summary	<p>In-pit disposal of tailings can be beneficial because of the stability of tailings storage attained by placing the tailings below the natural ground surface, and by filling final voids, thereby reducing risk of wall failure. However, there is a potential risk of contaminant release into the surrounding environment through groundwater transport.</p> <p>The main objective of the project is to examine the potential environmental issues arising from the in-pit disposal of coal tailings through a multidisciplinary approach and to suggest a framework to assess in-pit tailings. The assessment of tailings includes physical, hydrological and geochemical techniques. Several coal mines in New South Wales and Queensland with in pit tailings were visited and relevant site information was collated. To cover a wide spectrum of physical and geochemical properties of tailings, Burton, Mt Arthur and Wambo coal mines were selected for further field measurements and geochemical sampling. The project involved three main parts:</p> <ul style="list-style-type: none"> • hydrological and geochemical characterisation of tailings • long-term behaviour, attenuation and management scenarios of co-disposed reject and tailings • statistical analysis and modelling. <p>Hydrological and geochemical characterisation results were used to better define potential release, reactivity and mobility of contaminants from tailings. Possible contaminants from coal tailings include acids, salts and heavy metals. Long-term behaviour, attenuation and management scenarios of co-disposed reject and tailings accounted for different properties of co-disposed tailings. Therefore, it is important to characterise these factors to determine geochemical consequences of alternative tailings disposal options and to guide tailings management.</p> <p>Statistical analysis of data can alleviate the need for extensive sampling and chemical analysis of tailings to perform a risk assessment, and the modelling approach predicts hydro-geochemical processes controlling the chemistry of seepages from in-pit tailings. A consistent approach suggested by this study for the assessment of in-pit tailings enables the stakeholders to more easily communicate data and provides necessary information for better management of tailings and planning for mine closure. This study recommends collection of long-term groundwater monitoring data to validate the result of hydrogeochemical models and reduce uncertainty of long-term consequences of in-pit disposal of</p>

Project characteristics	Details
	tailings.
Objectives	The aim of this project was to develop a knowledge base of potential environmental issues arising from the in-pit disposal of coal tailings, particularly salinity, in the Bowen Basin and Hunter Valley coal mines, through collection of physical, hydrological and geochemical data for selected sites based on a staged methodology for the assessment of tailings.
Achievements	<p>A conceptual model was presented to discuss the hydrogeochemical processes controlling the chemistry of seepages from in-pit tailings namely oxidation, reduction, precipitation- dissolution, and adsorption-desorption. Based on the conceptual model, a decision making chart was developed and followed for minimum tests required to characterise and predict contaminant release from in-pit tailings. While each site may have a different type of tailings, resulting from different geology and processing practices, there are a minimum set of test procedures that can be followed for tailings assessment.</p> <p>Such a consistent approach would make the communication of data with the stakeholders much easier. Furthermore, over years a useful database could be generated across a variety of mine sites to inform planning on how to deal with associated hazards, particularly for mine closure planning. It is a common practice to use limited geochemical parameters available, for example, conductivity values in hydrological models. The current study suggests a set of parameters that can be applied in hydrological models. Besides, at some sites the interaction of rainwater with surrounding natural geology produces geogenic salts and other contaminants, and there are uncertainties with the extension of impact. The suggested procedures will help to better characterise and classify tailings and identify the sources of contaminants.</p>
Outputs	Unknown
Key personnel	Baumgartl, Thomas; Edraki, Mansour; Park, Jinhee
Research themes	Co-produced/mine water
Project information source	Survey

Table 4.61 Project 61: Managed aquifer recharge and re-injection of aquifers

Project characteristics	Details
Project title	Managed aquifer recharge and re-injection of aquifers
Project location	Australia
Principal investigator	Unknown
Lead institution	CSIRO
Project budget	Unknown
Source of funding	Unknown
Project duration	2013 - Unknown
Current status	In progress
Project summary	Evaluating the feasibility of using managed aquifer recharge re-use to treat the produced water from CSG production and re-injecting it into the aquifers beneath Roma in Queensland's Western Downs. If successful, this project will be Australia's largest potable water managed aquifer recharge (MAR) project. The MAR project aims to re-inject over 30 000 ML of treated water to re-pressurise the Gubberamunda Aquifer, part of the Great Artesian Basin.
Objectives	Unknown
Achievements	Unknown
Outputs	http://research.ccsq.uq.edu.au/projects/managed-aquifer-recharge-and-reinjection-aquifers
Key personnel	Unknown
Research themes	Co-produced/mine water
Project information source	UQ CCSG Online Portal

Table 4.62 Project 62: Pilot scale integrated forward and reverse osmosis system for mine water reuse C23031

Project characteristics	Details
Project title	Pilot scale integrated forward and reverse osmosis system for mine water reuse C23031
Project location	Australia
Principal investigator	Thiruvengkatachari, Ramesh
Lead institution	CSIRO
Project budget	\$258 237
Source of funding	Australian Coal Association Research Program (ACARP)
Project duration	July 2014 - January 2016
Current status	In progress
Project summary	This project offers the coal industry a novel, cost effective desalination technology that produces higher water recovery and reduction in mine site brine storage volumes. A laboratory scale, osmotically driven process (the driving force for water transfer across a membrane is osmotic instead of hydraulic pressure) has been integrated with a reverse osmosis unit to treat mine affected water, producing a steady stream of reusable quality water, thereby eliminating extensive pre-treatment steps that are generally required for reverse osmosis. This project will develop a pilot scale, integrated treatment system that can process 1 m ³ of water per day and will complete a preliminary technical and economic assessment of the technology.
Objectives	The main project objective is to develop a 1 m ³ /day capacity pilot scale novel integrated forward and reverse osmosis (FO_RO) system to treat coal mine impacted water.
Achievements	Demonstration of proof-of-concept of the integrated FO-RO system for the treatment of mine impacted water.
Outputs	http://www.acarp.com.au/abstracts.aspx?repId=C21043 http://www.acarp.com.au/Media/ACARPCurrentProjectsReport.pdf Thiruvengkatachari R (2013) "Pilot scale integrated forward and reverse osmosis system for mine water reuse". (C23031).
Key personnel	Thiruvengkatachari, Ramesh
Research themes	Co-produced/mine water
Project information source	ACARP website

Table 4.63 Project 63: Enhancing ecological values of coal pit lakes with simple nutrient additions and bankside vegetation C21038

Project characteristics	Details
Project title	Enhancing ecological values of coal pit lakes with simple nutrient additions and bankside vegetation C21038
Project location	Australia
Principal investigator	Lund, Mark
Lead institution	Edith Cowan University
Project budget	\$182 575
Source of funding	Australian Coal Association Research Program (ACARP)
Project duration	Unknown - March 2014
Current status	Completed
Project summary	<p>This project builds upon the previous ACARP project (C19018) undertaken by the Mine Water and Environment Research Centre (MiWER) at study sites in Collie (Western Australia). Project C19018 identified that nutrients were limiting algal productivity, water quality improvements, and the development of ecosystem values in coal pit lakes. We also found that simple additions of nutrients (carbon, nitrogen and phosphorus), resulted in significant increases in algae. Algae form the base of natural lake aquatic food chains as food for macroinvertebrates (such as aquatic insects and zooplankton), with subsequent nutrient transfer to higher consumers such as fish and water birds. Algae also offer a number of 'phytoremediation' processes that may improve pit lake water quality impacted by acid and metalliferous drainage (AMD) that impedes mine closure.</p> <p>Developing environmental values could be a valid alternative for pit lake closure criteria, rather than simply meeting (often difficult) water quality guideline closure criteria as the principle focus for relinquishment. Pit lakes showing particular environmental values could also provide opportunities to improve regional biodiversity. In turn, these opportunities will reduce environmental and social risk of these landforms at closure, facilitating a faster and easier relinquishment back to the state.</p> <p>This ACARP project (C21038) focusses on the importance of the pit lake catchment at mine closure in supplying nutrients and organic matter to pit lakes. Essentially, we aim to determine how maximising use of this catchment material can help the coal industry meet biodiversity objectives at closure.</p> <p>Experimental nutrient and bulk organic matter additions were evaluated to examine the potential of these materials to improve biodiversity in coal pit lakes across a range of water qualities; from acidic to neutral.</p>
Objectives	<p>Specifically, the project sought to:</p> <ul style="list-style-type: none"> • determine which nutrient(s) is/are limiting in at least two contrasting coal pit lake types (acidic to neutral), and identify nutrient concentration thresholds for increased algal growth • test whether additions of C, N and P prior to closure can significantly improve ecosystem values in pit lakes of differing acidities • quantify the role of bankside revegetation in providing nutrient inputs and aquatic habitat post-closure for increasing pit lake environmental values (e.g. aquatic biodiversity).

Project characteristics	Details
Achievements	<p>A survey across a range of Collie pit lakes of differing acidities to determine the importance of catchment organic material to lake food webs. This survey allowed assessment of how the historic absence of rehabilitation versus current revegetation strategies and catchment designs provide opportunities for pit lake aquatic ecological restoration through organic matter accumulation in the lakes.</p> <p>A survey of the macroinvertebrate communities of five Collie pit lakes has been completed, using a very high sampling intensity to ensure a robust estimate of total species present in each lake. The study relates the presence and abundance of these key aquatic ecosystem indicators to habitat and water quality variables. Of particular interest, is the apparent differences between taxa found in litter bags versus those caught around the edge.</p> <p>Key recommendations from the project relate to maximising the value of the catchment to provide long-term improvements in pit lake water quality. This approach contrasts with current practices which seek to minimise pit lake catchment areas. Catchments supply pit lakes with nutrients, particularly bulk organic carbon (leaves and branches). The research suggests that enhancement of lakes with this type of material will increase biodiversity and abundance of macroinvertebrates regardless of the water quality. We believe that these positive changes will occur until the water quality becomes the predominant factor controlling the populations. We therefore recommend:</p> <ul style="list-style-type: none"> • pit lakes are planted with riparian and aquatic plant species as part of revegetation • littoral margins are redesigned to be better habitats for aquatic biota • organic materials are added to the lakes, when available, both pre- and post-filling.
Outputs	http://www.acarp.com.au/abstracts.aspx?repld=C21038
Key personnel	Lund, Mark; Blanchette, Melanie
Research themes	Co-produced/mine water
Project information source	ACARP website

Table 4.64 Project 64: Understanding and quantifying clogging and its management during re-injection of CSG water permeates, brines and blends

Project characteristics	Details
Project title	Understanding and quantifying clogging and its management during re-injection of CSG water permeates, brines and blends
Project location	Australia
Principal investigator	Dillon, Peter
Lead institution	GISERA (CSIRO)
Project budget	\$1 039 989
Source of funding	APLNG, CSIRO
Project duration	December 2011 - June 2014
Current status	Complete
Project summary	Understand, quantify and manage clogging of injection wells during re-injection of CSG water permeates, brines and blends. Outcome: strategies to manage clogging of re-injection wells to maximise re-injection volumes.
Objectives	Project objectives and outputs include: <ul style="list-style-type: none"> • preliminary predictions of clogging for different waters at pilot re-injection site • evaluation of prediction methodology • tested diagnostics for clogging at pilot re-injection site • Australia Pacific LNG staff trained to use the newly developed model for sites similar to that tested.
Achievements	<ul style="list-style-type: none"> • Scoping meeting and research plan. • Lab study-aquifer hydraulic characterisation.
Outputs	<ul style="list-style-type: none"> • Task 1. Report on aquifers that were selected for testing, likely candidate for field testing of injection, and an outline of the proposed lab test methodology. • Task 2. Report on aquifer core hydraulic testing giving comparisons with traditional tests and field data (pumping tests, down-hole flow meter and geophysical logs) and discussion on how to deal with dual porosity in a systematic framework. • Task 3. Report that includes a literature review, basis for model, model description and its ability to predict at core scale. The report will also include description of injection trials undertaken, which provides field data on near-well permeability declines and increases. • Task 4. Report on application of model to field trial with at least two water qualities. Other outputs include two journal papers on methodology and model, training materials for Australia Pacific LNG and documented progress meetings with the project reference panel each year. <p>http://www.gisera.org.au/research/waterprojects/water-project-2-reinjection.pdf Dillon P, Miontinski K, Barry K, Gregg G, Vanderzalm J and Wolf L (2014) "Understanding and quantifying clogging and its management during re-injection of CSG water permeates, brines and blends (Re-injection of CSG water)".</p>
Key personnel	Dillon, Peter; Miontinski, Konrad; Barry, Karen; Gregg, Gupta; Vanderzalm, Joanne; Wolf, Leif

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Research themes	Co-produced/mine water
Project information source	GISERA website

Table 4.65 Project 65: Understanding and quantifying the geochemical response to re-injection of CSG water permeates, brines and blends

Project characteristics	Details
Project title	Understanding and quantifying the geochemical response to re-injection of CSG water permeates, brines and blends
Project location	Australia
Principal investigator	Prommer, Henning
Lead institution	GISERA (CSIRO)
Project budget	\$881 242
Source of funding	APLNG, CSIRO
Project duration	July 2011 - June 2014
Current status	Completed
Project summary	<p>Injection of reverse osmosis treated production water from coal seams into surrounding aquifers may provide the most viable measure to dispose of production water. The geochemical dis-equilibrium between the injectant water composition and the prevailing mineral inventory will drive a range of mineral reactions that must be clearly understood and quantified in order to anticipate and manage future water quality changes at both the local and the regional scale. This project is aimed at:</p> <ul style="list-style-type: none"> • data analysis and experimental work that provides an advanced characterisation of the reactivity of the sediment material of aquifers targeted for re-injection • the development of a reactive transport modelling framework that will allow the analysis and prediction of water quality changes resulting from re-injection of treated CGS waters • the evaluation and improvement of the reactive transport modelling framework during analysis of laboratory and field-trial data from selected target aquifers.
Objectives	The key objective of this project is to develop methodologies that allow the assessment and quantification of the extent of the geochemical changes that may be triggered by the re-injection of treated CSG waters.
Achievements	For more details, see http://www.gisera.org.au/research/waterprojects/water-project-1-response-reinjection.pdf
Outputs	<p>A 3-day workshop was held in February 2013 and a second workshop was held during the field site visit (27/28th May). In February 2014 a third workshop was held from 5–9 February between CSIRO Team members and Origin.</p> <p>http://www.gisera.org.au/research/waterprojects/water-project-1-response-reinjection.pdf</p>
Key personnel	Prommer, Henning; Martens, Evelien; Patterson, Bradley; Furness, Andrew
Research themes	Co-produced/mine water, water-dependent ecosystems
Project information source	GISERA website

Table 4.66 Project 66: High performance groundwater modelling for risk assessment and management option analysis of large-scale injection schemes

Project characteristics	Details
Project title	High performance groundwater modelling for risk assessment and management option analysis of large-scale injection schemes
Project location	Australia
Principal investigator	Moore, Catherine
Lead institution	GISERA (CSIRO)
Project budget	\$928 215
Source of funding	APLNG, CSIRO
Project duration	July 2011 - June 2014
Current status	Complete
Project summary	Determine the feasibility of large-scale re-injection schemes. Outcomes: models that assess the feasibility of large re injection schemes and predict how re injection may reduce impacts from CSG development.
Objectives	<p>Upscaling and synthesis of findings from (a) geochemical modelling (b) managed aquifer recharge (MAR) operational modelling and clogging studies (c) isotope monitoring & hydrochemical baseline study. Upscaling will account for data scarcity and the degree to which such data impacts on predictive reliability. The focus of the synthesis will be on communication, and improvement of, the reliability of model scenarios underpinning decisions on CSG production water re-injection.</p> <p>Identify information support needed for modelling framework and evaluate available data for which parametric statistical distributions can be derived to constrain model characteristics and enhance predictive reliability.</p> <p>For selected scenarios quantitatively evaluate the value of investment in data acquisition in relation to model predictive uncertainty and identify priorities for future data acquisition.</p> <p>Predict cumulative impacts of injection strategies in the Surat & Bowen Basins.</p> <p>Predictions of short- and long-term changes to groundwater quality, both the areal extent of possible changes and the time to equilibrium in terms of general impacts within the basin.</p> <p>Predictions of short- and long-term pressure changes and their areal extent and the time frame over which they would occur in terms of general impacts within the basin.</p> <p>Improving MAR risk assessment procedures for cumulative impacts on hydraulic heads and travel times to extraction wells through the use of probability based modelling.</p> <p>Model the performance of different layout options for large scale injection to identify suitable well locations/spacing.</p> <p>Optimum target aquifers in recognition of risk/benefit.</p> <p>Demonstrate state of the art uncertainty modelling.</p> <p>Demonstrating methodologies for fact based decision making in context with data uncertainty, e.g. via exploring whether the hypothesis of contamination of a potable water supply well can be rejected at a 99% confidence level, and if not,</p>

Project characteristics	Details
	exploring which alternative management option will allow such confidence.
Achievements	<ul style="list-style-type: none"> • Project set up and management. • Risk assessment framework. • Model basis and local and regional scale model development.
Outputs	<p>http://www.gisera.org.au/research/waterprojects/water-project-3-groundwater-modelling.pdf</p> <p>Moore C, Wolf L, Hodgen M, Page D, Doherty J and Prommer H (2014) "High performance groundwater modelling for risk assessment and management option analysis of large scale injection schemes".</p>
Key personnel	Moore, Catherine; Wolf, Leif; Hodgen, Malcolm; Page, Declan; Doherty, John; Prommer, Henning
Research themes	Co-produced/mine water, water-dependent ecosystems
Project information source	GISERA website

Table 4.67 Project 67: Background paper on produced water and solids in relation to coal seam gas production

Project characteristics	Details
Project title	Background paper on produced water and solids in relation to coal seam gas production
Project location	Australia
Principal investigator	Davies, Peter
Lead institution	Macquarie University
Project budget	\$50 000
Source of funding	NSW Office of the Chief Scientist and Engineer
Project duration	1 June 2013 – 31 October 2013
Current status	Completed
Project summary	The purpose of this report is to review the issues, management practices, impacts and risks related to produced water and solids generated by the coal seam gas (CSG) industry. The report has been commissioned by the NSW Office of the Chief Scientist and Engineer as one of a number of independent studies to inform the NSW Government about the potential impacts of CSG exploration, extraction and related activities on human health and the environment. The content and recommendations of this report are based largely on publicly available, independent peer-reviewed literature and reports by and for government agencies.
Objectives	<ol style="list-style-type: none"> 1. To characterise produced water in the context of CSG in Australia. 2. To identify potential issues with produced water. 3. Identify technologies for treatment and potential uses of produced water. 4. Identify risks and risk management approaches for the management of produced water. 5. Identity knowledge gaps.
Achievements	Report to the NSW Chief Scientist and Engineer. This is being used to inform evidenced based policy on the future policy, regulation and management of this sector by the NSW Government.
Outputs	http://www.chiefscientist.nsw.gov.au/__data/assets/pdf_file/0003/34779/Produced-water-_Gore_Davies_MQU.pdf
Key personnel	Davies, Peter; Gore, Damian
Research themes	Co-produced/mine water, hydraulic fracturing, water supplies
Project information source	Survey

Table 4.68 Project 68: Development of a management tool to support the beneficial use of treated coal seam gas water for irrigation in eastern Australia

Project characteristics	Details
Project title	Development of a management tool to support the beneficial use of treated coal seam gas water for irrigation in eastern Australia
Project location	Australia
Principal investigator	Jakubowski, R
Lead institution	MWH Global
Project budget	Unknown
Source of funding	Unknown
Project duration	Unknown—Literature output June 2014
Current status	Unknown—Literature output June 2014
Project summary	<p>An infiltration and salinity transport model (ISTM) based on the HYDRUS modeling platform was developed to support the beneficial use of treated coal seam gas (CSG) water to irrigate perennial forage plots in eastern Australia. The ISTM was used to support the expansion of irrigated areas under the CSG industry's first specific irrigation beneficial use approval issued by the Queensland environmental regulatory administering authorities in March 2009. To support meeting regulatory requirements for expansion beyond the original irrigation area, forward modelling within the vadose zone was used to evaluate the fate and transport of the irrigation water as it migrates through the shallow soils and unsaturated bedrock toward the saturated zone; simulations beneath three agricultural systems with contrasting infiltration capacities were assessed. The model simulation results were used to guide irrigation activities to maximise water use in the readily available soil water capacity range for these agroecosystems, without detrimental impacts to plant growth or surface water/groundwater and soil resources.</p> <p>In this paper, a practical irrigation and rainfall systems-driven hydrogeochemical conceptual model is presented to identify processes that are likely to govern infiltration from the land surface, root water uptake, and solute transport into, and potentially through, the unsaturated zone. A numerical model is then parameterised to represent the primary processes hypothesized to affect water and salinity movement in the vadose zone. Finally, a series of simulations, conducted to identify the key parameters and processes governing the potential movement of water and salt through the root zone and into the bedrock vadose zone, are discussed.</p> <p>The simulations are used to support continuous improvement in modeling approaches for sustainably managing treated CSG extraction water allocated to irrigation.</p>
Objectives	To develop an infiltration and salinity transport model (ISTM) based on the HYDRUS modeling platform to support the beneficial use of treated coal seam gas (CSG) water to irrigate perennial forage plots in eastern Australia.

Project characteristics	Details
Achievements	<ul style="list-style-type: none"> • Forward modelling within the vadose zone to evaluate the fate and transport of the irrigation water as it migrates through the shallow soils and unsaturated bedrock toward the saturated zone. • Simulation modeling beneath three agricultural systems with contrasting infiltration capacities. • The development of a practical irrigation and rainfall systems-driven hydrogeochemical conceptual model to identify processes that are likely to govern infiltration from the land surface. • A numerical model parameterised to represent the primary processes hypothesised to affect water and salinity movement in the vadose zone.
Outputs	<p>http://link.springer.com/article/10.1007%2Fs10230-013-0246-4 Jakubowski R, Haws N, Ellerbroek D, Murtagh J and Macfarlane D (2014). "Development of a management tool to support the beneficial use of treated coal seam gas water for irrigation in Eastern Australia". <i>Mine Water and the Environment</i>, 33 (2).</p>
Key personnel	Jakubowski, R; Haws, N; Ellerbroek, D; Murtagh, J; Macfarlane, D
Research themes	Co-produced/mine water, aquifer interconnectivity, water supplies
Project information source	Literature

Table 4.69 Project 69: Growing algae using water from coal seam gas industry and harvesting using an innovative technique: A review and a potential

Project characteristics	Details
Project title	Growing algae using water from coal seam gas industry and harvesting using an innovative technique: A review and a potential
Project location	Australia
Principal investigator	Hamawand, Ihsan
Lead institution	National Centre for Engineering in Agriculture, University of Southern Queensland
Project budget	Unknown
Source of funding	National Centre for Engineering in Agriculture
Project duration	1 January 2013 - Unknown
Current status	Completed
Project summary	<p>The aim of this project was to carry a literature review in order to address many aspects regarding the coal seam gas industry. These involve:</p> <ul style="list-style-type: none"> • First stage: addressed CSG production worldwide, and CSG water impact on the environment, its benefit and management. This paper also addresses the different methods that have been applied to control the negative impact of the produced water when used for irrigation. • Second stage: in this stage amended water from the coal seam gas industry was studied and suggested for growing micro-algae to achieve two aims; produce suitable water for irrigation from the CSG water and renewable energy from algae cells. • Third stage: studied the potential of using CSG as alternative for diesel in agriculture.
Objectives	<p>The objective was to provide a better understanding of this industry and its associated water. The objective was to provide/show the following:</p> <ol style="list-style-type: none"> 1. The importance of CSG for the Australian economy. 2. CSG can be alternative for diesel in agriculture. 3. Conventional and innovative methods for treatment of the associated water. 4. Impact of the treated water on agriculture and energy sectors.
Achievements	<p>Three papers published in peer reviewed journals:</p> <p>Hamawand I, Yusaf T, Hamawand S (2013) Coal seam gas and associated water, A review paper. <i>Renewable & Sustainable Energy Reviews</i> 2013; 22: 550–560 (IF 5.627).</p> <p>Hamawand I, Yusaf T, Hamawand S (2014) Growing algae using water from coal seam gas industry and harvesting using an innovative technique: A review and a potential. <i>Fuel Journal</i> 2014; 117 (A): 422–430.</p> <p>Talal Yusaf, Ihsan Hamawand, Erik Schmidt, James Binnie, Steven Rees, Sayan Chakrabarty. Coals Seam Gas (CSG) in Agriculture “ A Review: Technical and Market Analysis for Australia. <i>Journal of Sustainable Energy Technologies and Assessments</i>, accepted.</p>

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Outputs	First paper: http://www.sciencedirect.com/science/article/pii/S1364032113001329 Second paper: http://www.sciencedirect.com/science/article/pii/S0016236113008831 Third paper: In Press
Key personnel	Hamawand, Ihsan; Yusaf, Talal; Hamawand, Sara
Research themes	Co-produced/mine water
Project information source	Survey

Table 4.70 Project 70: Gloucester NSW Camden NSW Narrabri NSW

Project characteristics	Details
Project title	Gloucester NSW Camden NSW Narrabri NSW
Project location	Australia
Principal investigator	Pells, Philip
Lead institution	Pells Consulting
Project budget	\$200 000
Source of funding	Communities
Project duration	10 January 2012 - Unknown
Current status	In progress
Project summary	Preparation of hydrogeological models and completion of 2D and 3D groundwater analyses for three substantially different geological environments.
Objectives	Impacts of CSG extraction on groundwater systems and base flows to surface waters. Disposal of saline produced water.
Achievements	Presentations at multiple public meetings in Gloucester, Picton, Wollongong and Newcastle. Provision of advice to community groups in Scotland. Workshop with NSW Chief Scientist on produced water.
Outputs	The following can be downloaded from www.pellsconsulting.com.au <ul style="list-style-type: none"> • Impacts of longwall mining and coal seam gas extraction on groundwater regimes in the Sydney Basin Part 1 – Theory. SE Pells and PJN Pells • Impacts of longwall mining and coal seam gas extraction on groundwater regimes in the Sydney Basin Part 2 - Practical Applications. SE Pells and PJN Pells • On the cynicism of the public to information provided regarding coal seam gas operations - Gloucester, NSW example. Short paper presented after a public meeting at Gloucester on 16 May 2013. PJN Pells • On the absence of quantitative criteria for stop-go assessment of coal seam gas projects in NSW using Gloucester Stage 1 as a case study. Short paper presented after a public meeting at Gloucester on 16 May 2013. PJN Pells • CSG101. Memo prepared covering basics of CSG in New South Wales. Pells Consulting • Three dimensional groundwater model of Hume Coal Prospect, Southern Highlands NSW. SE Pells and PJN Pells • Some notes on disposal of produce water by irrigation. PJN Pells • CSG - some knowns and unknowns - Science Forum, State Parliament House, 25 March 2014. PJN Pells • The blowout of well LMG03 (Stratford 3) at Gloucester September 2004. PJN Pells
Key personnel	Pells, Philip; Pells, Steven
Research themes	Aquifer interconnectivity, surface water, co-produced/mine water

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Project information source	Survey

Table 4.71 Project 71: Mount Hope Station pilot project

Project characteristics	Details
Project title	Mount Hope Station pilot project
Project location	Australia
Principal investigator	Unknown
Lead institution	Santos
Project budget	Unknown
Source of funding	Unknown
Project duration	2014
Current status	Unknown
Project summary	Several key areas of Santos' Roma CSG field are located on Mount Hope Station, a family-owned agribusiness. Since mid-2009, Santos and the landholder have worked closely to develop a plan to use water from the Roma CSG field to benefit the farm business and allow field development to continue. At the end of the pilot project, the landholder will have a sustainable pasture that exceeds current best practice. Santos will have addressed the challenge of water management in critical areas of its operation and ensured the beneficial use of water produced during its gas operations. The four-year project involves the construction of water treatment facilities and associated water infrastructure. In keeping with the GLNG project's water management strategy, two treatment processes will be adopted.
Objectives	Unknown
Achievements	Unknown
Outputs	http://www.santos.com/coal-seam-gas/coal-seam-gas-water.aspx
Key personnel	Unknown
Research themes	Co-produced/mine water
Project information source	UQ CCSG Online Portal

Table 4.72 Project 72: Investigation of the plant production and water use of forages irrigated with CSG water

Project characteristics	Details
Project title	Investigation of the plant production and water use of forages irrigated with CSG water
Project location	Australia
Principal investigator	Shelton, Max
Lead institution	School of Agriculture and Food Sciences, University of Queensland
Project budget	Unknown
Source of funding	UniQuest Pty Ltd
Project duration	2011 – 2014
Current status	Unknown—Literature output 2014
Project summary	Not available
Objectives	Unknown
Achievements	Unknown
Outputs	http://research.ccsq.uq.edu.au/projects/investigation-plant-production-and-water-use-forages-irrigated-csg-water
Key personnel	Shelton, Max; Fukai, Shu; Lambrides, Christopher
Research themes	Co-produced/mine water
Project information source	UQ CCSG Online Portal

Table 4.73 Project 73: Biological silica removal to aid coal seam gas (CSG) water management

Project characteristics	Details
Project title	Biological silica removal to aid coal seam gas (CSG) water management
Project location	Australia
Principal investigator	Bin, Tengku
Lead institution	School of Chemical Engineering, University of Queensland
Project budget	Unknown
Source of funding	Unknown
Project duration	April 2013 - Unknown
Current status	Unknown—Literature output 2014
Project summary	No summary available.
Objectives	No objectives available.
Achievements	No achievements available.
Outputs	PhD Thesis http://research.ccsq.uq.edu.au/projects/biological-silica-removal-aid-coal-seam-gas-csg-water-management
Key personnel	Bin, Tengku; Pratt, Steven
Research themes	Co-produced/mine water
Project information source	UQ CCSG Online Portal

Table 4.74 Project 74: Adsorption on activated alumina: mitigating fouling of water treatment processes caused by deposition of silica, organics and hardness ions

Project characteristics	Details
Project title	Adsorption on activated alumina: mitigating fouling of water treatment processes caused by deposition of silica, organics and hardness ions
Project location	Australia
Principal investigator	Lant, Paul
Lead institution	School of Chemical Engineering, University of Queensland
Project budget	\$166 953
Source of funding	Australian Research Council
Project duration	2012 – 2015
Current status	In progress
Project summary	It is highly desirable to reduce the volume of saline CSG water, but the technologies available to achieve this are severely impacted on by fouling and mineral scaling. Of concern are the build up of organics, formation of mineral scales and silicate deposition. This fundamental research will enable the CSG industry to reduce saline volumes and potentially recover salt from saline streams.
Objectives	The aim of this work is understand removal of silica and organics by activated alumina, along with the potential for incidental removal of hardness ions.
Achievements	Unknown
Outputs	http://researchers.uq.edu.au/research-project/13452 Lant P and Pratt S (2014) "Adsorption on activated alumina: mitigating fouling of water treatment processes caused by deposition of silica, organics and hardness ions". School of Chemical Engineering (University of Queensland).
Key personnel	Lant, Paul; Pratt, Steven
Research themes	Co-produced/mine water
Project information source	UQ and ARC Website

Table 4.75 Project 75: Treatment of coal seam gas (CSG) co-produced water using natural and modified zeolite

Project characteristics	Details
Project title	Treatment of coal seam gas (CSG) co-produced water using natural and modified zeolite
Project location	Australia
Principal investigator	Wang, Xiaoyu
Lead institution	School of Chemical Engineering, University of Queensland
Project budget	Unknown
Source of funding	Unknown
Project duration	September 2009 – Unknown
Current status	In progress
Project summary	<p>PhD project entitled <i>Investigation of the potential of natural and modified zeolite for the treatment of CSG co-produced water</i>.</p> <p>This project uses low cost material, such as natural zeolite, to desalt coal seam gas co-produced water.</p> <p>Zeolite surface property investigation is another main area of my thesis. A series of surface properties studies such as using X-Ray Photoelectron Spectroscopy and Zeta Potential analysis on natural and acid modified zeolite have been completed so far. A simplified electrical double layer model has been also developed to explain the surface charge properties of natural and the sulphuric acid modified zeolite.</p>
Objectives	<p>Use low cost material, e.g. natural zeolite, to desalt CSG co-produced water.</p> <p>Zeolite surface property investigation.</p>
Achievements	<p>A series of surface properties studies such as using X-Ray Photoelectron Spectroscopy and Zeta Potential analysis on natural and acid modified zeolite.</p> <p>A simplified electrical double layer model has been also developed to explain the surface charge properties of natural and the sulphuric acid modified zeolite.</p> <p>The results demonstrate that acid activated zeolite at 30%wt solid ratio can reduce the sodium content from 563.0 to 182.7 ppm; the pH from 8.74 to 6.95; and SAR from 70.3 to 18.5. Based on the results of the batch experiments, the sodium adsorption capacity of the acid-treated zeolite is three times greater than that of the untreated zeolite.</p>
Outputs	<p>Wang X, Ozdemir O, Hampton MA, Nguyen AV and Do DD (2012) "The effect of zeolite treatment by acids on sodium adsorption ratio of coal seam gas water". <i>Water Research</i>, 46 (16), pp.5247–5254.</p> <p>PhD thesis</p> <p>http://research.ccsq.uq.edu.au/projects/treatment-coal-seam-gas-csg-co-produced-water-using-natural-and-modified-zeolite</p>
Key personnel	Wang, Xiaoyu; Nguyen, Anh
Research themes	Co-produced/mine water

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Project information source	UQ CCSG Online Portal, literature

Table 4.76 Project 76: Smart Futures Fellowship (Early): Inorganic membranes of CSG water and brine treatment

Project characteristics	Details
Project title	Smart Futures Fellowship (Early): Inorganic membranes of CSG water and brine treatment
Project location	Australia
Principal investigator	Smart, Simon
Lead institution	School of Chemical Engineering, University of Queensland
Project budget	Unknown
Source of funding	Queensland Government
Project duration	2012 – 2016
Current status	In progress
Project summary	The key concept of this research is an inorganic membrane with an intelligent, hierarchical and highly percolative structure that can recover fresh water from either CSG water or the highly concentrated brine waste streams through the process of membrane distillation. The key requirements for desalination via membrane distillation are high water flux, high salt rejection, robust membranes and minimal energy consumption. If successful this project will provide enabling materials and technologies that will greatly reduce the volume of brine waste to be disposed of and increase the water recovery from the CSG industry which could prove crucial for inland water supply security.
Objectives	This project aims to produce a new generation of high flux, inorganic membranes for desalination in the coal seam gas (CSG) industry.
Achievements	Unknown
Outputs	http://researchers.uq.edu.au/research-project/14120
Key personnel	Smart, Simon
Research themes	Co-produced/mine water, water supplies, water-dependent ecosystems
Project information source	UQ CCSG Online Portal

Table 4.77 Project 77: Produced water and solids – technical background paper for NSW Chief Scientist and Engineer

Project characteristics	Details
Project title	Produced water and solids – technical background paper for NSW Chief Scientist and Engineer
Project location	Australia
Principal investigator	Kahn, Stuart
Lead institution	School of Civil and Environmental Engineering, University of New South Wales
Project budget	Unknown
Source of funding	New South Wales Government
Project duration	Unknown—Literature output 2014
Current status	Unknown—Literature output 2014
Project summary	This background paper was prepared for the Office of the NSW Chief Scientist and Engineer (OCSE) to provide information and a discussion about produced water in relation to coal seam gas (CSG) activities.
Objectives	The purpose is to provide an overview of the key issues associated with produced water and solids in relation to CSG activities.
Achievements	A number of examples of incidents related to produced water are described in this report. A number of knowledge gaps are identified towards the end of the report.
Outputs	http://www.chiefscientist.nsw.gov.au/coal-seam-gas-review/csg-background-papers Gore, D. and Davies, P. (2013). "Produced Water - technical background paper for NSW Chief Scientist and Engineer". Macquarie University
Key personnel	Kahn, Stuart; Kordek, Geena
Research themes	Co-produced/mine water
Project information source	Literature

Table 4.78 Project 78: Engineering design of low permeability barriers between open pit mine sites and surface waters

Project characteristics	Details
Project title	Engineering design of low permeability barriers between open pit mine sites and surface waters
Project location	Australia
Principal investigator	Timms, W
Lead institution	School of Mining Engineering, University of New South Wales
Project budget	Unfunded
Source of funding	Unfunded
Project duration	2011 – 2014
Current status	In progress
Project summary	<p>A low permeability barrier (LPB) can be constructed to limit inflow to a mine, control horizontal seepage and/or process water with potential contaminants, and discharge to surface water sources. In this study, optimum soil-bentonite mixtures were determined based on compaction, geotechnical centrifuge testing and numerical flow modeling of LPB scenarios between an open cut mine and a river. Results indicate that target permeability (i.e. K of 10^{-8} m/s) could be achieved with appropriate soil compaction mixed with as little as 2% bentonite. This can significantly reduce cost by more than \$1 million if the bentonite content of an LPB was reduced from 8% to 2%. Geotechnical centrifuge testing proved to be more reliable and rapid than standard column permeameter methods.</p> <p>A model was developed in HYDRUS-2D to represent an open cut mine near a river. The model was run over 365 days at daily steps with river level and rainfall-evaporation boundary conditions, pre-LPB, and with a 1 m wide LPB constructed across the aquifer. Prior to any mining activity, the lateral flux through the aquifer was <0.5 m²/year, increasing to ~ 66 m²/year after the open cut construction without an LPB, and reducing to between 1 and ~ 27 m²/year with an LPB with K of 10^{-10} m/s and 10^{-8} m/s, respectively. The variably saturated model indicated that lateral flux towards the pit was sourced from de-watering near the pit, rather than from induced leakage from the river. Further work is in progress to verify the long-term performance of this soil bentonite mixture and the risk of LPB failure if permeated with poor quality water.</p>
Objectives	Improve methods for engineering design and construction of reliable low permeability barriers (vertical compacted earth walls) at mine sites.
Achievements	Critique of current construction guidelines for LPB, identification of common failure mechanisms, development of guide for bentonite mixing with local soil and numerical model.
Outputs	<p>Bouzalakos S, Crane R, Liu H and Timms WA (2014) Geotechnical and modelling studies of low permeability barriers to limit subsurface mine water seepage. Presented at 4th International Conference on Water Management in Mining, Vina del Mar, Chile, 28–30 May 2014.</p> <p>Timms W, Liu H and Laurence D (2013) Design of a Low Permeability Barrier (LPB) to limit seepage between a mine and a river. AusIMM Water in Mining, Brisbane, 26–28 November.</p> <p>Liu H and Timms W (2013) Design of a Low Permeability Barrier (LPB) to Limit</p>

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
	seepage between an open pit mine and a river. BE Honours Thesis, UNSW Australia School of Mining.
Key personnel	Timms, W
Research themes	Water supplies, co-produced/mine water, water-dependent resources
Project information source	Survey

Table 4.79 Project 79: Interactions between agriculture and coal seam gas development

Project characteristics	Details
Project title	Interactions between agriculture and coal seam gas development
Project location	Australia
Principal investigator	Cavaye, Jim
Lead institution	The University of Queensland
Project budget	\$840 000
Source of funding	Centre for Coal Seam Gas The University of Queensland
Project duration	20 November 2013 - Unknown
Current status	In progress
Project summary	<p>The project will investigate and help improve strategies for how CSG development and agriculture can be best managed in key farm production systems in southern Queensland whilst maintaining agricultural assets and the long term productivity and sustainability of both agricultural enterprises and CSG operations. This involves consolidating an evidence-base for interactions between agriculture and CSG that allows the CSG industry and agricultural producers to better co-exist.</p> <p>The project will address the following research questions:</p> <ul style="list-style-type: none"> • What are the implications of CSG development for agricultural production and profitability in key farm production systems in southern Queensland? • What are the current and key management strategies to best manage CSG development and agriculture on-farm so that agricultural assets and productivity are maintained together with a sustainable CSG industry? • What are the best quantifiable measures to assess the interaction between CSG and agriculture? • What information do landholders and other stakeholders want, how would they like to access and consider information and how would they like to be engaged in considering interactions with CSG and possible co-existence? <p>The project consists of two sub-projects:</p> <ol style="list-style-type: none"> 1. Quantifying effects on production and profitability on the development and use of quantifiable measures to understand the effects of CSG development on agricultural production and profitability on-farm. 2. Strategies for co-existence understanding the factors that support or inhibit co-existence between CSG and agriculture and assessing and developing strategies that enhance co-existence. <p>The research will involve: interviews and discussions with carefully selected primary producers and other stakeholders, the development of detailed case studies of production systems on the properties of co-operating producers, the development and application of objective measures of impacts on production and profitability, documentation and assessment of existing and emerging co-existence strategies developed by primary producers, peak bodies and CSG companies, analysis of remote sensing and mapping data, workshops and forums to extend research results and engage stakeholders in progressing strategies to better manage agriculture and CSG issues, ongoing reports and forums to discuss progress in each step with a range of project stakeholders.</p>

Project characteristics	Details
Objectives	<ol style="list-style-type: none"> 1. To scope quantifiable measures of the interaction between agriculture and CSG and methodologies for measuring impacts on farm production and profitability. 2. To describe and quantify the effects of CSG development on agricultural production and profitability in production systems in southern Queensland. 3. To describe and define co-existence between agriculture and CSG. 4. To describe examples of co-existence being achieved in key farm production systems and to understand the factors that facilitate co-existence and the barriers to it. 5. To develop methodologies and tools to assess co-existence strategies and the factors that encourage co-existence. 6. To identify and provide evidence of the most appropriate strategies and approaches to better manage co-existence in key agricultural production systems. 7. To understand stakeholder information needs and inform other projects aimed at making existing research more accessible to more people.
Achievements	<ul style="list-style-type: none"> • Working paper on Quantifiable Measures is open for comment. • Working paper on Strategies for Co-existence is open for comment. • A scoping paper on agriculture and CSG is in final editing. • Measures and instruments for assessing interactions between agriculture and CSG have been finalised. • Two rounds of meeting with stakeholders have been completed. • Pilot interviews with landholders have been completed. • Twenty-five farm visits and interviews with landholders have been held. • Six monitoring sites have been identified.
Outputs	Working paper on Quantifiable Measures; Working paper on Strategies for Co-existence; Scoping Paper on agriculture and CSG (was in final editing).
Key personnel	Cavaye, Jim; Kelly, Lisa; Baldwin, Shelley; Cameron, Don; Martin, Mal; Everingham, Jo-Anne
Research themes	Co-produced/mine water
Project information source	Survey

Table 4.80 Project 80: Salinity tolerance of freshwater organisms from the Southern and Western Coalfields C23010

Project characteristics	Details
Project title	Salinity tolerance of freshwater organisms from the Southern and Western Coalfields C23010
Project location	Australia
Principal investigator	Vink, Sue
Lead institution	University of Queensland
Project budget	\$177 000
Source of funding	Australian Coal Association Research Program (ACARP)
Project duration	2013 - Unknown
Current status	In progress
Project summary	Mine water releases are regulated by salinity (measured as electrical conductivity), pH and concentration limits for a number of other constituents, including heavy metals. Local guidelines should be developed from tests conducted using locally collected organisms and tests solutions that have a composition similar to natural stream waters. The work will be conducted using field caught and laboratory reared organisms tested with artificial mine water solutions diluted with artificial creek waters. This method will remove the confounding effects of other constituents that may be toxic and present in mine water solutions.
Objectives	The overall objective of this work is to produce toxicity datasets for the Southern and Western coalfields in New South Wales that can be used to develop local salinity guidelines.
Achievements	Unknown
Outputs	http://www.acarp.com.au/Media/ACARP2013PeopleAndProjectsReport.pdf Vink S (2013) "Salinity Tolerance of Freshwater Organisms from the Southern and Western Coalfields". (C23010). UQ
Key personnel	Vink, Sue
Research themes	Co-produced/mine water, water-dependent ecosystems
Project information source	ACARP website

Table 4.81 Project 81: Stabilisation of algal biomass harvested from coal seam gas associated water to generate a renewable, high nutrient resource

Project characteristics	Details
Project title	Stabilisation of algal biomass harvested from coal seam gas associated water to generate a renewable, high nutrient resource
Project location	Australia
Principal investigator	Pratt, Steven
Lead institution	University of Queensland; APLNG
Project budget	\$118 700
Source of funding	Australian Research Council and APLNG
Project duration	2012 – 2015
Current status	In progress
Project summary	This project will develop composting technology to stabilise the biomass harvested from coal seam gas ponds. A feature of the project is consideration of toxic algal metabolites, and the potential for the release and degradation of these compounds during stabilisation.
Objectives	To develop composting technology to stabilise the biomass harvested from coal seam gas ponds.
Achievements	Unknown
Outputs	http://researchers.uq.edu.au/research-project/13451 Pratt S, Slater F, Lant P and Schenk P (2014) " <i>Stabilisation of algal biomass harvested from coal seam gas associated water to generate a renewable, high nutrient resource</i> ". School of Chemical Engineering (University of Queensland).
Key personnel	Pratt, Steven; Slater, Frances; Lant, Paul; Schenk, Peer
Research themes	Co-produced/mine water
Project information source	ARC website

Table 4.82 Project 82: Coal seam gas water as a medium to grow *Dunalliella tertiolecta* for lipid extraction

Project characteristics	Details
Project title	Coal seam gas water as a medium to grow <i>Dunalliella tertiolecta</i> for lipid extraction
Project location	Australia
Principal investigator	Aravinthan, Vasantha
Lead institution	University of Southern Queensland
Project budget	Unknown
Source of funding	Internal funding
Project duration	11 March 2011 – 28 February 2014
Current status	On hold
Project summary	<p>The coal seam gas (CSG) industry in Queensland, Australia is expected to produce about 300 GL of CSG water annually as a by-product of its methane extraction processes. Surat Basin aquifers typically produce sodium bicarbonate-chloride type water, having high concentration of salts making it unfit for direct beneficial use. The objective of this bench-scale investigation is to assess the potential of using bicarbonate-rich CSG water as a medium for growing <i>Dunalliella tertiolecta</i> for biofuel production.</p> <p>The rates of microalgal growth and carbon sequestration were found to be 49.7 mg SS/L/d and 29 mg C/L/d, respectively, with an average total lipid content of 22% in CSG medium enriched with nutrients and amended for a salinity concentration of 10 gNaCl/L and 200 mg carbon/L in non-aerated batch reactor.</p> <p>In summary, the brine resulting from reverse osmosis treated CSG water could be trialled as an ideal medium to grow the microalgae <i>Dunalliella tertiolecta</i>.</p>
Objectives	The objective of this bench-scale investigation is to assess the potential of using bicarbonate-rich CSG water as a medium for growing <i>Dunalliella tertiolecta</i> for biofuel production.
Achievements	Unknown
Outputs	http://www.tandfonline.com/doi/full/10.1080/19443994.2013.827295#.VC4GvvmSx8E
Key personnel	Aravinthan, Vasantha; Harrington, Daniel
Research themes	Co-produced/mine water, water supplies
Project information source	Survey

Table 4.83 Project 83: Salty gas: the ecological risk of saline effluents from coal seam gas and other hydrocarbon resources

Project characteristics	Details
Project title	Salty gas: the ecological risk of saline effluents from coal seam gas and other hydrocarbon resources
Project location	Australia
Principal investigator	Kefford, Ben
Lead institution	University of Technology Sydney; NSW Office of Environment and Heritage
Project budget	\$180 754
Source of funding	ARC Linkage Project
Project duration	2013 – 2016
Current status	In progress
Project summary	The objective of this project is to predict the effect of saline water produced from coal and coal seam gas extraction activities on freshwater systems. The findings will assist decisions on whether to permit discharge of such waste water, and if permitted under what conditions (e.g. water quality criteria) so as to prevent environment damage.
Objectives	The objective of this project is to predict the effect of saline water produced from coal and coal seam gas extraction activities on freshwater systems.
Achievements	Unknown
Outputs	http://www.arc.gov.au/pdf/LP13/LP13%20Listing%20by%20all%20State%20and%20Organisation_web%20version.pdf Kefford B, Lim R and Hyne R (2013) "Salty gas: the ecological risk of saline effluents from coal seam gas and other hydrocarbon resources". (LP130100100).
Key personnel	Kefford, Ben; Lim, Richard; Hyne, Ross
Research themes	Water supplies, co-produced/mine water
Project information source	ARC website

Table 4.84 Project 84: Silica scale mitigation for high recovery reverse osmosis of groundwater for a mining process

Project characteristics	Details
Project title	Silica scale mitigation for high recovery reverse osmosis of groundwater for a mining process
Project location	Australia
Principal investigator	Sanciolo, P
Lead institution	Victoria University, Melbourne, Australia
Project budget	Unknown
Source of funding	The National Centre of Excellence in Desalination Australia, which is funded by the Australian Government through the Water for the Future initiative, and the collaboration of Hatch Associates.
Project duration	Unknown—Literature output 2014
Current status	Unknown—Literature output 2014
Project summary	The feasibility of silica removal in RO treatment of groundwater from a Western Australian mining and processing operation to prevent scaling and enhance water recovery was investigated. This study has shown that it is possible to decrease the silica concentration in RO concentrate to levels that would allow an overall water recovery of 90% to 95% using 10 g/L of regenerable activated alumina adsorbent. Regeneration of the adsorbent using 2% NaOH was found to be effective for at least three regeneration cycles. A preliminary costing of the high water recovery RO process using silica removal by adsorption indicated product water (permeate) costs of \$5.60 per kL and savings due to a reduction in brine volume from the current 40% of feed volume to 5–10% of feed volume. It also allows better utilisation of a scarce groundwater resource, allowing the production of up to 1.6 times more low salt water from a given volume of groundwater. These results warrant larger scale investigation of silica removal and adsorbent regeneration for high recovery RO processing for mining operations, and application of silica removal to RO treatment of other silica laden waters such as coal seam gas produced water.
Objectives	To investigate the feasibility of silica removal in RO treatment of groundwater from a Western Australian mining and processing operation to prevent scaling and enhance water recovery.
Achievements	<ul style="list-style-type: none"> • System water recoveries between 90% and 95% are predicted. • Brine volume reductions between $\frac{1}{4}$ and $\frac{1}{8}$ of the current volume are predicted. • Regeneration of the activated alumina increased its adsorption capacity. • Silica can be removed from groundwater RO concentrate using activated alumina. • The silica-loaded activated alumina can be regenerated using 2% NaOH.
Outputs	http://www.sciencedirect.com/science/article/pii/S0011916414000897 Sanciolo P, Milne N, Taylor K, Mullet M and Gray S (2014) "Silica scale mitigation for high recovery reverse osmosis of groundwater for a mining process". <i>Desalination</i> , 340 (0).
Key personnel	Sanciolo, P; Milne, N; Taylor, K; Mullet, M; Gray, S

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Research themes	Co-produced/mine water, water-dependent ecosystems
Project information source	Literature

4.3.2 Canada

Table 4.85 Project 85: Speciation and toxicity of arsenic in mining-affected lake sediments in the Quinsam watershed, British Columbia

Project characteristics	Details
Project title	Speciation and toxicity of arsenic in mining-affected lake sediments in the Quinsam watershed, British Columbia
Project location	Canada
Principal investigator	Moriarty, MM
Lead institution	Royal Military College of Canada, University of British Columbia
Project budget	Unknown
Source of funding	The US Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract DE-AC02-06CH11357
Project duration	Unknown—Literature output 2014
Current status	Unknown—Literature output 2014
Project summary	<p>Anthropogenic arsenic inputs into fresh water lakes in the Quinsam watershed, British Columbia, were probed by using multiple methods of inquiry including sediment coring combined with ^{210}Pb dating, a principal components analysis of elemental composition of sediments, arsenic speciation, bioaccessibility, and toxicity testing. The quantification of arsenic inputs from anthropogenic sources was not trivial because a variety of processes redistribute the element throughout lakes. However, elevated arsenic and sulfate concentrations in Long Lake, a lake that receives arsenic from a seep, suggest that this lake is influenced by mine operations. X-ray absorption near edge structure (XANES) spectra reveal similar arsenic speciation for all sediments within the studied lakes. Bioaccessibility tests, which in this study were used to approximate the solubility and availability of arsenic to benthic organisms, indicate moderate bioaccessibility of arsenic in sediments (7.9-35%). Toxicity testing indicates that not all benthic organisms should be used for evaluating arsenic toxicity, and suggests that the amphipod, <i>Corophium volutator</i>, shows promise as a candidate for widespread use for arsenic sediment toxicity testing.</p>
Objectives	<p>The objectives of the present study were to determine whether quantification of anthropogenic inputs is possible in the studied lakes through a combination of coring, surficial sediment sampling and analysis; to determine the chemical nature of elevated arsenic in sediments near mining activities through the use of solid-state speciation X-ray absorption spectroscopic (XAS) methods; and to establish a method for evaluating the toxicity of the arsenic within these sediments, through the use of an amphipod <i>Corophium volutator</i>.</p>
Achievements	<ul style="list-style-type: none"> • Chemical analysis combined with PCA that confirms that the elemental compositions of samples from a mine impacted lake (Long Lake) are unique to that lake. • Dating of sediment cores in Long Lake which revealed an increase of arsenic around the time mining operations began. • The conclusion that evidences indicates a mainly anthropogenic origin for the arsenic with a seep from abandoned underground workings being one of the sources.

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Outputs	http://www.sciencedirect.com/science/article/pii/S0048969713007730 Moriarty MM, Lai VWM, Koch I, Cui L, Combs C, Krupp EM, Feldmann J, Cullen WR and Reimer KJ (2014) "Speciation and toxicity of arsenic in mining-affected lake sediments in the Quinsam watershed, British Columbia". <i>Science of the Total Environment</i> , 466–467.
Key personnel	Moriarty, MM; Lai, VWM; Koch, I; Cui, L; Combs, C; Krupp, EM; Feldmann, J; Cullen, WR; Reimer, KJ
Research themes	Co-produced/mine water
Project information source	Literature

4.3.3 China

Table 4.86 Project 86: Influences of coal mining water irrigation on the maize losses in the Xingdong Mine area, China

Project characteristics	Details
Project title	Influences of coal mining water irrigation on the maize losses in the Xingdong Mine area, China
Project location	China
Principal investigator	Sun, YuZhuang
Lead institution	Key Laboratory of Hebei Province for Resource Exploration Research, Hebei University of Engineering, Handan, Hebei, China.
Project budget	Unknown
Source of funding	This study was financially supported by the Hebei Science Funding (D2006000625, D2011402034).
Project duration	Unknown—Literature output 2014
Current status	Unknown—Literature output 2014
Project summary	In 2008, a maize underproduction disaster occurred in the Xianyu village after irrigation using the coal mining water from the Xingdong Mine, China. This disaster resulted in about 40 hectare maize underproduction and 20 hectare total loss of the maize yields. In order to study the reason, a total of 25 soil, water and plant samples were taken from the study area. These samples were analysed by inductively coupled plasma mass spectrometry and ion chromatography. The results indicate that the contents of both water-soluble fluorine and total fluorine are very high and resulting of maize underproduction and total loss of production. The possible pollution sources of fluorine in the study area could be from the coal mine water used for irrigation and glass chemical factory near the study area.
Objectives	To determine the contents of some heavy metals, pH values and fluorine of the samples from the Xianyu village.
Achievements	The contents of some heavy metals, pH values and fluorine of the samples from the Xianyu village were determined. The results indicate that the heavy metal contents and pH values are not high, but the contents of both water-soluble fluorine and total fluorine are very high. The high fluorine contents should be the reason of maize underproduction and total loss of production. The possible pollution sources of fluorine in the study area could be from the coal mine and glass chemical factory
Outputs	http://link.springer.com/article/10.1007%2Fs10653-013-9521-3 Sun, Y., Ling, P., Li, Y., Li, Q., Sun, Q. and Wang, J. (2014). "Influences of coal mining water irrigation on the maize losses in the Xingdong Mine area, China". <i>Environmental Geochemistry and Health</i> , 36 (1).
Key personnel	Sun, YuZhuang; Ling, Pei; Li, YanHeng; Li, QingXue; Sun, QuanDe; Wang, JinXi
Research themes	Co-produced/mine water
Project information source	Literature

Table 4.87 Project 87: Treatment of the produced water of coalbed methane using artificial wetland in Qinshui Basin, China

Project characteristics	Details
Project title	Treatment of the produced water of coalbed methane using artificial wetland in Qinshui Basin, China
Project location	China
Principal investigator	YU, Zhisheng
Lead institution	University of Chinese Academy of Sciences
Project budget	Unknown
Source of funding	NSF, China
Project duration	1 March 2014 - Unknown
Current status	On hold
Project summary	Construct an artificial wetland for treating formation water of coalbed methane.
Objectives	Try to use wetland to treat abundant formation water of coalbed methane.
Achievements	Scientific articles and a wetland plant for treating the produced water of coalbed methane
Outputs	Unknown
Key personnel	YU, Zhisheng
Research themes	Co-produced/mine water
Project information source	Survey

4.3.5 Russia

Table 4.88 Project 88: Using modified perlites to treat mine water of abandoned coal mines in Partizansk city, Primorskiy Krai

Project characteristics	Details
Project title	Using modified perlites to treat mine water of abandoned coal mines in Partizansk city, Primorskiy Krai
Project location	Russia
Principal investigator	Arefieva, OD
Lead institution	Far East Federal University
Project budget	Unknown
Source of funding	The study was supported by The Ministry of education and science of Russian Federation, project 14.A18.21.1896.
Project duration	Unknown—Literature output 2013
Current status	Unknown—Literature output 2013
Project summary	So far, various methods and schemes for mine water treatment are available. Finding new filtering materials capable for physical holding of solid particles and possessing sorption features is of great concern. This paper studies the adsorption capacity of modified perlite (Nachikinsk deposit, Kamchatka peninsula) of various size distribution to treat mine water of the abandoned Nagomaya mine, Partizansk city (Primorskiy Krai). Basic hydrochemical parameters of mine water when filtering through expanded water-repelling perlite.
Objectives	The objective of this paper is to find the specifics of the chemical composition of mine water out of abandoned mines in Partizansk coal basin and to study the possibility to treat mine water using various size modified perlite.
Achievements	The successful treatment of mine water using of local perlite as a sorbent after modification through expanding and hydrophobization treatment.
Outputs	http://www.scientific.net/AMR.726-731.4041 Arefieva OD, Perfilov AV, Nazarkina AV, Ksenik TV, Yudakov AA and Kondratyeva AA (2013) "Using modified perlites to treat mine water of abandoned coal mines in Partizansk city, Primorskiy Krai". In: Zhao, J., Iranpour, R., Li, X. and Jin, B. (eds.) <i>Advances in Environmental Technologies, Pts 1-6</i> , 726-731. Stafa-Zurich: Trans Tech Publications Ltd
Key personnel	Arefieva, OD; Perfilov, AV; Nazarkina, AV; Ksenik, TV; Yudakov, AA; Kondratyeva, AA
Research themes	Co-produced/mine water
Project information source	Literature

4.3.6 United Kingdom

Table 4.89 Project 89: Hydraulic performance and iron removal in wetlands and lagoons treating ferruginous coal mine waters

Project characteristics	Details
Project title	Hydraulic performance and iron removal in wetlands and lagoons treating ferruginous coal mine waters
Project location	United Kingdom
Principal investigator	Kusin, FM
Lead institution	University of Newcastle; Putra University Malaysia
Project budget	Unknown
Source of funding	Newcastle University; partly sponsored by the Ministry of Higher Education Malaysia
Project duration	Unknown—Literature output June 2014
Current status	Unknown—Literature output June 2014
Project summary	A study of hydraulic residence time has been conducted for several UK Coal Authority mine water treatment systems to evaluate the impact of residence time on the overall hydraulic performance and iron removal within the systems. A series of tracer tests were conducted within the Coal Authority mine water treatment wetlands and lagoons to measure actual hydraulic residence time. The tracer residence time distributions (RTDs) were analysed based on a tanks-in-series (TIS) model to yield the mean residence time and corresponding hydraulic characteristics of the systems. The relationship between iron retention and residence time was tested against a first-order removal model. The mean hydraulic efficiency is 69% for the wetlands compared to 24% for the lagoons, mainly attributable to comparatively greater volumetric efficiency within the wetland systems. The mean number of TIS, n , is 3.9 for the wetlands and 2.1 for the lagoons, illustrating considerably different flow patterns between wetlands and lagoons. There is also a notable difference of treatment efficiency for iron; mean of 81% and 47% for wetlands and lagoons, respectively. Generally, it appears that system hydraulic efficiency (derived from the principle of TIS model) corresponds with iron retention in the treatment systems.
Objectives	The aim of this study is to assess the effect of residence time on the overall system hydraulic performance and removal of iron as a consequence.
Achievements	<ul style="list-style-type: none"> Established that residence time is an important influence on hydraulic efficiency and on iron removal. Found that no relationship exists between residence time and iron removal when using a first-order removal model. Tentatively concluded that improvement of treatment system performance may be achieved by maximising hydraulic efficiency, i.e. greater residence time and a more uniform flow movement.
Outputs	http://link.springer.com/article/10.1007%2Fs13157-014-0523-4 Kusin FM, Jarvis AP and Gandy CJ (2014) "Hydraulic performance and iron removal in wetlands and lagoons treating ferruginous coal mine waters". <i>Wetlands</i> , 34 (3).
Key personnel	Kusin, FM; Jarvis, AP; Gandy, CJ

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Research themes	Co-produced/mine water
Project information source	Literature

4.3.7 United States

Table 4.90 Project 90: Investigating the unpublished EPA results for Pavilion, Wyoming

Project characteristics	Details
Project title	Investigating the unpublished EPA results for Pavilion, Wyoming
Project location	USA
Principal investigator	Garnett, Andrew
Lead institution	Centre for Coal Seam Gas (University of Queensland); Bureau of Economic Geology, University of Texas at Austin
Project budget	\$51 480
Source of funding	University of Queensland, Santos, QGC, Arrow Energy
Project duration	November 2013 – May 2014
Current status	Data collection and analysis are underway.
Project summary	Groundwater contamination in the Pavilion area of Wyoming, USA was investigated by the USA Environmental Protection Agency (EPA) to determine if natural gas wells and fracking had adversely influenced groundwater quality. The preliminary report from this EPA study indicated that fracturing chemicals had contaminated groundwater and this outcome has been regularly used as an example of the negative fracking impacts. However, the methodology used and the outcomes obtained have been the subject of scientific dispute. Further analysis of both the EPA report and subsequent USGS investigation is required to clarify if fracking chemicals have been found in groundwater or if the contamination is due to chemicals from other human activities. This project will conduct a review of all scientific information related to the Pavilion groundwater investigations to produce a complete assessment of the incident and its causes.
Objectives	This project will conduct a review of all scientific information related to the Pavilion groundwater investigations to produce a complete assessment of the incident and its causes.
Achievements	Unknown
Outputs	<ol style="list-style-type: none"> 1. Report documenting the investigations and analysis. 2. Information materials for community education. http://research.ccsq.uq.edu.au/projects/investigating-unpublished-epa-results-pavillion-wyoming Garnett A and Duncan I (2014) "Investigating the unpublished EPA results for Pavilion, Wyoming". Centre for Coal Seam Gas (University of Queensland), Bureau of Economic Geology (University of Texas at Austin). Garnett A and Duncan I (2014) "Lessons and comparisons between US CBM and Australian CSG industries". Centre for Coal Seam Gas (University of Queensland), Bureau of Economic Geology (University of Texas at Austin).
Key personnel	Garnett, Andrew; Duncan, Ian
Research themes	Hydraulic fracturing, co-produced/mine water, water-dependent ecosystems
Project information source	Literature

Table 4.91 Project 91: Coal and coalbed gas

Project characteristics	Details
Project title	Coal and coalbed gas
Project location	USA
Principal investigator	Flores, Romeo M.
Lead institution	Cipher Coal Consulting Limited
Project budget	Unknown
Source of funding	Unknown
Project duration	Unknown—Literature output 2014
Current status	Unknown—Literature output 2014
Project summary	Co-produced water is extracted from groundwater aquifers during coalbed gas production. Coalbed gas held by hydrostatic pressure from overlying groundwater requires large amounts of co-produced water for initial gas desorption decreasing over time. Origin of co-produced water is internal (endogenous) and external (exogenous) confined in groundwater aquifers by impermeable rocks (aquitards/aquicludes). Aquifers are basinal hydrogeologic or macro and regional hydrostratigraphic or micro units. Composition of co-produced water is grouped into dominantly sodium bicarbonate and sodium chloride related to calcium, magnesium, and sulfate including radionuclide, organic, and inorganic parameters. Composition and volume of co-produced water influence management practices (e.g. disposal, treatment, and beneficial use). Co-produced water disposal requires aeration/chemical precipitation, reverse osmosis, ion exchange, and electrodialysis treatments. Benefits of co-produced water include surface water augmentation, aquifer recharges, storage, and recovery for domestic/municipal, agricultural, environmental restoration/remediation, and industrial uses. Management practices for co-produced water are similar worldwide but no universal solution.
Objectives	This chapter of the book seeks to describe the topic of: Co-Produced Water Management and Environmental Impacts
Achievements	Unknown
Outputs	http://www.sciencedirect.com/science/article/pii/B9780123969729000082 Flores RM (2014) " <i>Coal and Coalbed Gas</i> ". Elsevier.
Key personnel	Flores, Romeo M.
Research themes	Co-produced/mine water
Project information source	Literature

Table 4.92 Project 92: Coalbed methane produced water screening tool for treatment technology and beneficial use

Project characteristics	Details
Project title	Coalbed methane produced water screening tool for treatment technology and beneficial use
Project location	USA
Principal investigator	Plumlee, Megan H
Lead institution	Kennedy/Jenks Consultants
Project budget	Unknown
Source of funding	The Ultra-Deepwater and Unconventional Natural Gas and Other Petroleum Resources Research and Development Program (Grant #07122-12)
Project duration	Unknown—Literature output 2014
Current status	Unknown—Literature output 2014
Project summary	<p>Produced water is a byproduct of oil and gas production and represents the largest volume waste stream in the oil and gas industry. Due to the high demand for water and the costs associated with current produced water disposal practices, energy companies and local water users are interested in cost-effective alternatives for beneficial use of produced water. The main objective of this study was to apply a previously developed and publicly available coalbed methane produced water screening tool to two simulated case studies to determine site-specific produced water treatment technologies and beneficial use options, as well as costs, using realistic conditions and assumptions. Case studies were located in the Powder River (Wyoming) and San Juan (New Mexico) Basins. Potential beneficial uses evaluated include crop irrigation, on-site use, potable use, and instream flow augmentation. The screening tool recommended treatment trains capable of generating the water quality required for beneficial use at overall project costs that were comparable to or less than existing produced water disposal costs, given site-specific conditions and source (raw produced) water quality. In this way, the tool may be used to perform a screening-level cost estimate for a particular site to determine whether the costs per barrel for beneficial use are more or less than site-specific disposal costs. The demonstrated technical and economic feasibility provide incentives to address the institutional and legal challenges associated with beneficial use of produced water.</p>
Objectives	The main objective of this study was to apply a previously developed and publicly available coalbed methane produced water screening tool to two simulated case studies to determine site-specific produced water treatment technologies and beneficial use options, as well as costs, using realistic conditions and assumptions.
Achievements	<ul style="list-style-type: none"> • Produced water is a large volume waste stream of the oil and gas industry. • We used an available screening tool to evaluate two produced water case studies. • The tool outputs treatment technologies and costs for beneficial water reuse. • Beneficial uses included crop irrigation, on-site use, potable use, and others. • Project costs were similar to or less than existing produced water disposal costs.

Project characteristics	Details
Outputs	http://www.sciencedirect.com/science/article/pii/S2213397613000372 Plumlee MH, Debroux J-F, Taffler D, Graydon JW, Mayer X, Dahm KG, Hancock NT, Guerra KL, Xu P, Drewes JE and Cath TY (2014) "Coalbed methane produced water screening tool for treatment technology and beneficial use". <i>Journal of Unconventional Oil and Gas Resources</i> , 5. Langford Lane, Kidlington, Oxford, OX5 1GB, United Kingdom: Elsevier Ltd
Key personnel	Plumlee, Megan H; Debroux, Jean-Francois; Taffler, Dawn; Graydon, James W; Mayer, Xanthe; Dahm, Katharine G; Hancock, Nathan T; Guerra, Katie L; Xu, Pei; Drewes, Jorg E; Cath, TY
Research themes	Co-produced/mine water
Project information source	Literature

Table 4.93 Project 93: Energy resources: environmental geochemistry and health

Project characteristics	Details
Project title	Energy resources: environmental geochemistry and health
Project location	USA
Principal investigator	Orem, William H
Lead institution	U.S. Geological Survey
Project budget	US \$250 000
Source of funding	USGS and some other funding
Project duration	2013 to 2018
Current status	In progress
Project summary	Examines contaminants in water, air, and soil from energy resources. Focus on produced water from coalbed methane and shale gas; especially contaminants from hydraulic fracturing. Effects of contaminants from these sources on environmental quality and human health is the focus. Organic and inorganic substances are examined. Also conduct toxicological studies of natural samples on human cell line cultures.
Objectives	Determine the chemicals present in produced water from coalbed methane and shale gas/oil extraction activities. Determine if any substances from the produced water are present in the environment, and determine if they pose an environmental or health issue. Examine potential exposure pathways for human exposures. Work with biomedical collaborators to determine toxicological impacts and to relate geochemical investigations to human disease occurrences.
Achievements	First publications on organics in produced water from coalbed methane extraction. First publication on organics in produced water from shale gas extraction in the Marcellus Shale.
Outputs	<p>Orem W, Tatu C, Varonka M, Lerch H, Bates A, Engle M, Crosby L and McIntosh J (2014) Organic substances in produced and formation water from unconventional natural gas extraction in coal and shale. <i>Int. J. Coal Geol.</i> 126: 20–31.</p> <p>Pashin JC, McIntyre MR, Mann SD, Varonka M, and Orem W (2014) Interrelationships between water and gas chemistry in mature coalbed methane reservoirs of the Black Warrior Basin. <i>Int. J. Coal Geol.</i> 126: 92–105.</p> <p>Schlegel ME, JC McIntosh, ST Petsch, WH Orem, EJP Jones and AM Martini (2013) Extent and limits of biodegradation by in situ methanogenic consortia in shale and formation fluids. <i>Appl. Geochem.</i> 28:172–184.</p> <p>Orem WH, Voytek MA, Jones EJ, Lerch HE, Bates AL, Corum MD, Warwick PD and Clark AC (2010) Organic intermediates in the anaerobic biodegradation of coal to methane under laboratory conditions. <i>Org. Geochem.</i> 41: 997–1000.</p> <p>Haider R, Ghauri MA, Sanfilipo JR, Jones EJ, Orem WH, Tatu CA, Akhtar K and Akhtar N (2013) Fungal degradation of coal as a pretreatment for methane production. <i>Fuel</i> 104: 717–725.</p> <p>Jones EJP, Voytek MA, Corum MD and Orem WH (2010) Stimulation of methane generation from a non-productive coal by addition of nutrients or a microbial consortium. <i>Applied and Environmental Microbiology</i> 76: 7013–7022.</p> <p>Orem W, Tatu C, Pavlovic N, Bunnell J, Kolker A and Engle M (2010) Health effects of energy resources. Fact Sheet, U.S. Geological Survey, 4 pp.</p>

Project characteristics	Details
	<p>Jones EJP, Voytek MA, Warwick PD, Corum MD, Cohn A, Bunnell JE, Clark AC and Orem WH (2008) Evaluating coal for biogenic methane generation potential using a bioassay to assess coal bioavailability. <i>International Journal of Coal Geology</i> 76: 138–150.</p> <p>Bunnell JE, Tatu CA, Lerch HE, Orem WH and Pavlovic N (2007) Evaluating nephrotoxicity of high-molecular-weight organic compounds in drinking water from lignite aquifers. <i>J. of Toxicology and Environ. Health, Part A</i> 70: 2089–2091.</p> <p>Orem WH, Tatu CA, Lerch HE, Rice CA, Bartos TT, Bates AL, Tewalt S and Corum MD (2007) Organic compounds in produced waters from coalbed natural gas wells in the Powder River Basin, Wyoming, USA. <i>Applied Geochemistry</i> 22: 2240–2256.</p>
Key personnel	Orem, William H
Research themes	Co-produced/mine water, water supplies
Project information source	Survey

Table 4.94 Project 94: Impacts from beneficial use of produced waters

Project characteristics	Details
Project title	Impacts from beneficial use of produced waters
Project location	USA
Principal investigator	Engle, Mark
Lead institution	U.S. Geological Survey
Project budget	Unknown
Source of funding	U.S. Geological Survey Energy Resources Program
Project duration	1 October 2009 – 30 September 2013
Current status	Completed
Project summary	This activity focused on examining the impacts from beneficial use of produced waters. For purposes of this inquiry, part of this investigation focused on identifying impacts from agricultural use of coalbed methane waters via subsurface drip irrigation systems.
Objectives	To examine the impacts from beneficial use of produced waters.
Achievements	Unknown
Outputs	<p>Engle MA, Bern CR, Healy RW, Sams JI, Zupancic JW, Schroeder KT (2011) Tracking solutes and water from subsurface drip irrigation application of coalbed methane produced waters, Powder River Basin, Wyoming, <i>Environmental Geosciences</i>, 18, 169–187.</p> <p>Bern CR, Breit GN, Healy RW, Zupancic J, Hammack R (2013a) Deep subsurface drip irrigation using coal-bed sodic water: Part I. Water and solute movement: <i>Agricultural Water Management</i> 118: 122–134.</p> <p>Bern CR, Breit GN, Healy RW, Zupancic J, Hammack R (2013b) Deep subsurface drip irrigation using coal-bed sodic water: Part II. <i>Geochemistry: Agricultural Water Management</i> 118: 135–149.</p> <p>Bern CR, Engle MA, Boehlke AR, Zupancic JW (2013) Low salinity hydrocarbon water disposal through deep subsurface drip irrigation: Leaching of native selenium, in the proceedings for the 2013 International Mine Water Association Annual Conference, Brown, A, Figueroa, L, Wolkersdorfer Ch. (eds.), <i>Reliable Mine Water Technology (Vol II)</i>, Golden, Colorado, 1187–1192.</p> <p>Bern CR, Boehlke AR, Engle MA, Geboy NJ, Schroeder KT, Zupancic JW (2013) Shallow groundwater and soil chemistry response to 3 years of subsurface drip irrigation using coalbed natural gas produced water, <i>Hydrogeology Journal</i>, 21: 1803–1820.</p> <p>Sams JI, Veloski G, Smith BD, Minsley BJ, Engle MA, Hammack R, Zupancic JW (2014) Application of near-surface geophysics as part of a hydrologic study of a sub-surface drip irrigation system along the Powder River floodplain near Arvada, Wyoming. <i>International Journal of Coal Geology</i> 126, 128–139.</p> <p>Engle MA, Gallo M, Schroeder KT, Geboy NJ, Zupancic JW (2014) Three-way compositional analysis of water quality monitoring data, <i>Environmental and Ecological Statistics</i> 21, 565–581, DOI 10.1007/s10651-013-0268-x.</p>
Key personnel	Engle, Mark; Bern, Carleton
Research themes	Co-produced/mine water, hydraulic fracturing

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Project information source	Survey

Table 4.95 Project 95: Carbon isotope characterization of Powder River Basin Coal Bed Waters: Key to minimizing unnecessary water production and implications for exploration and timing of biogenic gas

Project characteristics	Details
Project title	Carbon isotope characterization of Powder River Basin Coal Bed Waters: Key to minimizing unnecessary water production and implications for exploration and timing of biogenic gas
Project location	USA
Principal investigator	Frost, Carol
Lead institution	University of Wyoming
Project budget	\$100 000
Source of funding	Wyoming State Geological Survey
Project duration	Unknown – 1 March 2014
Current status	Completed
Project summary	<p>Compared to other natural waters, water associated with biogenic natural gas is enriched in $^{13}\text{-carbon}$. Shallow coal seams regularly contain abundant resources of biogenic gas; as such water associated with biogenic gas in these coal beds is isotopically distinct from other waters. The production of gas from coal beds requires the removal of large volumes of produced water. Thus, a method of discerning coalbed reservoir water from other natural waters (surface and groundwater) is important to both the coalbed natural gas (CBNG) industry and associated environmental and regulatory agencies. Although isotopic tracers have been employed to identify coalbed natural gas produced waters, the isotopic variability within the reservoir has not been documented and explained.</p> <p>In this study, we present the isotopic compositions of dissolved inorganic carbon, oxygen and hydrogen for water produced from 197 CBNG wells in the Powder River Basin of Wyoming and Montana. This extensive database allows us to distinguish variations in isotopic compositions that may occur by multiple processes. These include variations that identify efficient de-watering of coal beds, variations characterizing incomplete hydraulic isolation of coal beds from adjacent strata and the subsequent mixing of groundwaters, variations related to well completion design, and variations associated with geochemical and biogenic processes that occur along groundwater flow paths. These data suggest that little change in $\delta^{13}\text{CDIC}$ occurs within the reservoir as a result of water and gas production; thus, the carbon isotopic composition informs other processes within the reservoir unrelated to coalbed natural gas recovery. The $\delta^{13}\text{CDIC}$ and $\delta^2\text{D}$ of groundwater vary along flow-path across the basin, reflecting different methanogenic pathways that are associated with different isotopic fractionations, and the pathways that dominate in different areas within the basin. In areas where several producing coal seams are present, the $\delta^{13}\text{CDIC}$ and $\delta^2\text{D}$ of produced waters from each seam are distinct. Therefore, on a local scale, the isotopic composition of produced water can identify the particular coal seam from which water and gas are withdrawn. The methods and results presented in this case study provide examples that illustrate how water quality and isotopic data can be used to determine the hydraulic connectivity between coal and non-coal strata, identify and quantify water from individual coal horizons, as well as predict and understand the isotopic variability of the reservoir.</p>

Project characteristics	Details
Objectives	This study seeks to understand both the natural isotopic variations of water within a biogenic natural gas reservoir along with any that are induced as a result of gas production. We have selected the Powder River Basin (PRB) of Montana and Wyoming for our study, a mature and well-studied biogenic coalbed natural gas (CBNG) field, which contain thousands of producing CBNG wells.
Achievements	Our stable isotopic investigation of produced waters associated with coalbed natural gas in the Powder River Basin of Wyoming and Montana has shown that $\delta^{13}\text{CDIC}$ compositions of +10 to +25‰ identify produced water that is associated with methanogenesis. This is the range of isotopic compositions of produced water from most PRB CBNG reservoirs. Our analyses of water collected from wells that have been pumping for between 1 and 15 years show no correlation between the amount of water that has been withdrawn from the well and the $\delta^{13}\text{CDIC}$ of the water now being produced. Most importantly, coal bed produced water is isotopically distinct from non-coal bed waters. Regardless of how long the well has been in production, coal bed waters have positive $\delta^{13}\text{CDIC}$, whereas non-coal bed waters are negative.
Outputs	Quillinan S and Frost CD (2014) Carbon isotope characterization of Powder River Basin Coal Bed Waters: Key to minimizing unnecessary water production and implications for exploration and timing of biogenic gas. <i>International Journal of Coal Geology</i> , 126,106–119, doi:10.1016/j.coal.2013.10.006. http://www.sciencedirect.com/science/article/pii/S0166516213002383
Key personnel	Frost, Carol; Quillinan, Scott
Research themes	Co-produced/mine water
Project information source	Survey

Table 4.96 Project 96: Mountaintop removal mining and catchment hydrology

Project characteristics	Details
Project title	Mountaintop removal mining and catchment hydrology
Project location	USA
Principal investigator	Miller, AJ
Lead institution	West Virginia University
Project budget	Unknown
Source of funding	Funding for this research was provided in part by NSF EAR Award 1042683; Oak Ridge Associated University (ORAU) Ralph E. Powe Junior Faculty Enhancement Award; West Virginia University Senate Research Award; and Hatch Act Formula Fund.
Project duration	Unknown—Literature output March 2014
Current status	Unknown—Literature output March 2014
Project summary	Mountaintop mining and valley fill (MTM/VF) coal extraction, practiced in the Central Appalachian region, represents a dramatic landscape-scale disturbance. MTM operations remove as much as 300 m of rock, soil, and vegetation from ridge tops to access deep coal seams and much of this material is placed in adjacent headwater streams altering landcover, drainage network, and topography. In spite of its scale, extent, and potential for continued use, the effects MTM/VF on catchment hydrology is poorly understood. Previous reviews focus on water quality and ecosystem health impacts, but little is known about how MTM/VF affects hydrology, particularly the movement and storage of water, hence the hydrologic processes that ultimately control flood generation, water chemistry, and biology. This paper aggregates the existing knowledge about the hydrologic impacts of MTM/VF to identify areas where further scientific investigation is needed. While contemporary surface mining generally increases peak and total runoff, the limited MTM/VF studies reveal significant variability in hydrologic response. Significant knowledge gaps relate to limited understanding of hydrologic processes in these systems. Until the hydrologic impact of this practice is better understood, efforts to reduce water quantity and quality problems and ecosystem degradation will be difficult to achieve.
Objectives	To investigate the effects of mountaintop mining (MTM) and valley fill on catchment hydrology with a particular focus on the movement and storage of water.
Achievements	Literature review of studies investigating the hydrological impacts of MTM. Highlighted present knowledge gaps regarding understanding of the hydrological impacts of MTM.
Outputs	http://www.mdpi.com/2073-4441/6/3/472 Miller AJ and Zegre NP (2014) "Mountaintop removal mining and catchment hydrology". <i>Water</i> , 6 (3).
Key personnel	Miller, AJ; Zegre, NP
Research themes	Surface water, co-produced/mine water
Project information source	Literature

Table 4.97 Project 97: Reference list for water-related coal seam gas and coal mining research – Australia, Canada, China, India, Russia, United Kingdom and United States of America (January 2000 to September 2014)

Project characteristics	Details
Project title	Reference list for water-related coal seam gas and coal mining research – Australia, Canada, China, India, Russia, United Kingdom and United States of America (January 2000 to September 2014)
Project location	Worldwide
Principal investigator	Badenhop, Alexandra (Water Research Laboratory), and SMEC
Lead institution	Snowy Mountains Engineering Corporation (SMEC) – Report 1 School of Civil and Environmental Engineering, Water Research Laboratory, University of New South Wales – Reports 2 – 4 Funded by the Australian Government – Department of the Environment
Project budget	\$151 860
Source of funding	Australian Government – Department of the Environment
Project duration	February 2014 – 2015
Current status	Completed
Project summary	Series of reports commissioned by the Australian Government – Department of the Environment on the advice of the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC). The series includes summaries of research projects relating to the impacts of coal seam gas and coal mining developments on water resources, currently being undertaken or completed, in Australia, Canada, China, Russia, India, United Kingdom (UK) and United States of America (US) during the period January 2000 to September 2014.
Objectives	The objective of the reference list series is to identify relevant research projects to: <ul style="list-style-type: none"> • support targeted approaches to future research – that address critical gaps in the scientific understanding of water-related impacts associated with coal seam gas and large coal mining activities • enable the Department of the Environment to effectively support the IESC as it provides advice to regulators on the water impacts of coal seam gas and large coal mining.
Achievements	These reports profile research projects relating to the water-related impacts of coal seam gas and coal mining activities. The number of research projects profiled were: <ul style="list-style-type: none"> • Report 1 – 55 projects profiled • Report 2 – 80 projects profiled • Report 3 – 210 projects profiled • Report 4 – 187 projects profiled (this report)

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Outputs	<p>Published on the Australian Government – Department of the Environment website and the IESC website.</p> <p>http://www.environment.gov.au/water/publications#iesc http://iesc.environment.gov.au/publications</p> <ul style="list-style-type: none"> • Commonwealth of Australia (2014) <i>Reference list for water-related coal seam gas and coal mining research, Report 1: Australia, Canada and the United States, January 2000 to June 2012</i>, prepared by the Snowy Mountains Engineering Corporation (SMEC) for the Department of the Environment, Commonwealth of Australia. • Commonwealth of Australia (2014) <i>Reference list for water-related coal seam gas and coal mining research, Report 2: United Kingdom, China, Russia and India, January 2000 to June 2012</i>, prepared by the Water Research Laboratory of the School of Civil and Environmental Engineering at UNSW Australia for the Department of the Environment, Commonwealth of Australia. • Commonwealth of Australia (2014) <i>Reference list for water-related coal seam gas and coal mining research, Report 3: Australia, Canada, China, India, Russia, United Kingdom and United States of America, July 2012 to September 2013</i>, prepared by the Water Research Laboratory of the School of Civil and Environmental Engineering at UNSW Australia for the Department of the Environment, Commonwealth of Australia. • Report 4 to be published in 2015 (this report).
Key personnel	Badenhop, Alexandra; Drummond, Chris; Glamore, Will; Anderson, Doug; SMEC
Research themes	Aquifer interconnectivity, surface water, co-produced/mine water, seismicity, well integrity, hydraulic fracturing, water supplies, water-dependent ecosystems, cumulative impact assessment
Project information source	Literature

4.4 Seismicity

Projects in this category investigate the impacts of seismic events caused by coal seam gas and coal mining operations on water resources and water-dependent ecosystems. All of the current research into seismicity within the scope of this report relates to North America.

Nine projects were collated with the primary theme of seismicity from Canada (1 project) and the United States (8 projects). Note that it is not clear from these projects whether the injected water is specifically from coal seam gas operations.

4.4.1 Canada

Table 4.98 Project 98: An investigation of seismicity clustered near the Cordel Field, west central Alberta, and its relation to a nearby disposal well

Project characteristics	Details
Project title	An investigation of seismicity clustered near the Cordel Field, west central Alberta, and its relation to a nearby disposal well
Project location	Canada
Principal investigator	Schultz, Ryan
Lead institution	Alberta Geological Survey
Project budget	Unknown
Source of funding	Unknown
Project duration	Unknown—Literature output April 2014
Current status	Unknown—Literature output April 2014
Project summary	<p>Historically, seismicity documented in the Western Canada Sedimentary Basin has been relatively quiescent and earthquakes are usually restricted to the foreland belt of the Rocky Mountains. However, exceptional clusters of events, which have remained active for decades, are recognized in Alberta. In this study we investigate the seismicity in this region using data obtained from recently established regional arrays, emphasizing the relationship between a disposal well in the Cordel Field and a nearby cluster of previously reported earthquakes. We explore temporal correlations of wastewater pumping rates and local seismic activity dating back to 1960. We find that the first statistically significant increase in seismicity lags the onset of wastewater injection (October 1991) by ~3.33 years. In particular, the waveform similarity of 32 events are analyzed from continuous data recorded at NOR, a nearby (~30 km) station operated by the University of Alberta starting in September of 2006.</p> <p>Results from this analysis suggest that many events are well correlated in the characteristics of the waveforms and thus are likely to share a similar origin and source mechanism. The most prolific of these multiplets repeats more than 10 times sporadically throughout the entire duration of recorded data from October 2006 to March 2012. Despite the limited availability of nearby stations, which adversely affects the resolution of our analysis, hypocenter depths could be relatively accurately determined from waveform synthesis and double difference methods. The results of our analysis provide first-order evidence that the seismicity is consistent with fluid injection-induced events.</p>

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Objectives	To explore the temporal correlation of events at the Brazeau cluster and to determine their relevance to disposal activities.
Achievements	A cluster of events is investigated and found to be induced
Outputs	http://onlinelibrary.wiley.com/doi/10.1002/2013JB010836/abstract Schultz R, Stern V and Gu YJ (2014) "An investigation of seismicity clustered near the Cordel Field, west central Alberta, and its relation to a nearby disposal well". <i>Journal of Geophysical Research: Solid Earth</i> , 119 (4).
Key personnel	Schultz, Ryan; Stern, Virginia; Gu, Yu Jeffrey
Research themes	Seismicity, co-produced water, re-injection
Project information source	Literature

4.4.3 United States

Table 4.99 Project 99: Induced seismicity associated with fluid injection into a deep well in Youngstown, Ohio

Project characteristics	Details
Project title	Induced seismicity associated with fluid injection into a deep well in Youngstown, Ohio
Project location	USA
Principal investigator	Kim, Won-Young
Lead institution	Columbia University
Project budget	Unknown
Source of funding	The U.S. Geological Survey has provided partial support for this study under contract G10AC00094
Project duration	Unknown—Literature output July 2013
Current status	Unknown—Literature output July 2013
Project summary	<p>Over 109 small earthquakes (Mw 0.4–3.9) were detected during January 2011 to February 2012 in the Youngstown, Ohio area, where there were no known earthquakes in the past. These shocks were close to a deep fluid injection well. The 14 month seismicity included six felt earthquakes and culminated with a Mw 3.9 shock on 31 December 2011. Among the 109 shocks, 12 events greater than Mw 1.8 were detected by regional network and accurately relocated, whereas 97 small earthquakes ($0.4 < \text{Mw} < 1.8$) were detected by the waveform correlation detector. Accurately located earthquakes were along a subsurface fault trending ENE-WSW—consistent with the focal mechanism of the main shock and occurred at depths 3.5–4.0 km in the Precambrian basement.</p> <p>We conclude that the recent earthquakes in Youngstown, Ohio were induced by the fluid injection at a deep injection well due to increased pore pressure along the pre-existing subsurface faults located close to the wellbore. We found that the seismicity initiated at the eastern end of the subsurface fault—close to the injection point, and migrated toward the west—away from the wellbore, indicating that the expanding high fluid pressure front increased the pore pressure along its path and progressively triggered the earthquakes. We observe that several periods of quiescence of seismicity follow the minima in injection volumes and pressure, which may indicate that the earthquakes were directly caused by the pressure build-up and stopped when pressure dropped.</p>
Objectives	To investigate injection-induced seismicity in Youngstown, USA.
Achievements	The authors conclude that the recent 2011 to 2012 earthquakes in Youngstown, Ohio were induced by the fluid injection at Northstar 1 deep injection well due to increased pore pressure along the pre-existing (ENE-WSW trending) faults located close to the wellbore in the Precambrian basement.
Outputs	<p>http://onlinelibrary.wiley.com/doi/10.1002/jgrb.50247/abstract</p> <p>Kim W-Y (2013) "Induced seismicity associated with fluid injection into a deep well in Youngstown, Ohio". <i>Journal of Geophysical Research: Solid Earth</i>, 118 (7).</p>
Key personnel	Kim, Won-Young

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Research themes	Seismicity, co-produced water, re-injection
Project information source	Literature

Table 4.100 Project 100: Analysis of the Cleburne, Texas, earthquake sequence from June 2009 to June 2010

Project characteristics	Details
Project title	Analysis of the Cleburne, Texas, earthquake sequence from June 2009 to June 2010
Project location	USA
Principal investigator	Justinic, Ashley Howe
Lead institution	Southern Methodist University
Project budget	Unknown
Source of funding	Southern Methodist University
Project duration	Unknown—Literature output December 2013
Current status	Unknown—Literature output December 2013
Project summary	<p>On 9 June 2009, an 2.8 earthquake shook Cleburne, Texas, a community not known to have previously experienced earthquakes. Over 50 small earthquakes followed by the end of December 2009. A temporary network of four and then five IRIS-Passcal broadband systems was deployed from June 2009 to June 2010, recording data that were used to locate 38 events with the most confident P- and S-arrival picks. Event locations were distributed along a 2 km long north-northeast trend. This location is approximately 1.3 km from a saltwater disposal well that began injection in October 2007 and 3.2 km away from a second injection well that was active from September 2005 to late July 2009.</p> <p>Focal mechanisms estimated for the best-recorded events suggest a north-northeast–south-southwest-trending normal fault with a dip of $\sim 50^\circ$ and a component of oblique motion (rake of $\sim -80^\circ$). This average solution is generally consistent with the north-northeast-trending extensional faults that are prevalent across parts of Texas, Oklahoma, Louisiana, and Arkansas. Stress drops calculated from P and S spectra for seven different events ranged from 3.9 to 90 bars, with most estimates between 40 and 50 bars, typical values for intraplate earthquakes. Because there were no known previous earthquakes, and the located events were close to the two injection wells and near the injection depth, the possibility exists that earthquakes may be related to fluid injection.</p>
Objectives	Investigate the Cleburne seismicity and its relationship to nearby injection wells.
Achievements	Application of the seven Davis and Frohlich (1993) criteria to assess whether fluid injection may have caused earthquake activity. Answers for the Cleburne sequence are “yes” to four of the seven questions based on the analysis.
Outputs	http://bssa.geoscienceworld.org/content/103/6/3083.full.pdf+html Justinic AH, Stump B, Hayward C and Frohlich C (2013) "Analysis of the Cleburne, Texas, Earthquake Sequence from June 2009 to June 2010". <i>Bulletin of the Seismological Society of America</i> , 103 (6).
Key personnel	Justinic, Ashley Howe; Stump, Brian; Hayward, Chris; Frohlich, Cliff
Research themes	Seismicity, co-produced water, re-injection

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Project information source	Literature

Table 4.101 Project 101: Modelling earthquake rate changes in Oklahoma and Arkansas: Possible signatures of induced seismicity

Project characteristics	Details
Project title	Modelling earthquake rate changes in Oklahoma and Arkansas: Possible signatures of induced seismicity
Project location	USA
Principal investigator	Llenos, Andrea L
Lead institution	U.S. Geological Survey
Project budget	Unknown
Source of funding	Unknown
Project duration	Unknown—Literature output 2013
Current status	Unknown—Literature output 2013
Project summary	<p>The rate of $ML \geq 3$ earthquakes in the central and eastern United States increased beginning in 2009, particularly in Oklahoma and central Arkansas, where fluid injection has occurred. We find evidence that suggests these rate increases are man-made by examining the rate changes in a catalog of $ML \geq 3$ earthquakes in Oklahoma, which had a low background seismicity rate before 2009, as well as rate changes in a catalog of $ML \geq 2.2$ earthquakes in central Arkansas, which had a history of earthquake swarms prior to the start of injection in 2009. In both cases, stochastic epidemic-type aftershock sequence models and statistical tests demonstrate that the earthquake rate change is statistically significant, and both the background rate of independent earthquakes and the aftershock productivity must increase in 2009 to explain the observed increase in seismicity. This suggests that a significant change in the underlying triggering process occurred.</p> <p>Both parameters vary, even when comparing natural to potentially induced swarms in Arkansas, which suggests that changes in both the background rate and the aftershock productivity may provide a way to distinguish man-made from natural earthquake rate changes. In Arkansas we also compare earthquake and injection well locations, finding that earthquakes within 6 km of an active injection well tend to occur closer together than those that occur before, after, or far from active injection. Thus, a change in interevent distance distribution may also be an indicator of induced seismicity.</p>
Objectives	To investigate the link between increased earthquake rates and induced seismicity in areas of central and eastern US.
Achievements	Providing evidence that that increases in earthquake events are man-made.
Outputs	http://www.bssaonline.org/content/103/5/2850.abstract Llenos AL and Michael AJ (2013) "Modeling earthquake rate changes in Oklahoma and Arkansas: Possible signatures of induced seismicity". <i>Bulletin of the Seismological Society of America</i> , 103 (5).
Key personnel	Llenos, Andrea L; Michael, Andrew J
Research themes	Seismicity, co-produced water, re-injection

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Project information source	Literature

Table 4.102 Project 102: Maximum magnitude earthquakes induced by fluid injection

Project characteristics	Details
Project title	Maximum magnitude earthquakes induced by fluid injection
Project location	USA
Principal investigator	McGarr, A
Lead institution	U.S. Geological Survey
Project budget	Unknown
Source of funding	Unknown
Project duration	Unknown—Literature output February 2014
Current status	Unknown—Literature output February 2014
Project summary	<p>Analysis of numerous case histories of earthquake sequences induced by fluid injection at depth reveals that the maximum magnitude appears to be limited according to the total volume of fluid injected. Similarly, the maximum seismic moment seems to have an upper bound proportional to the total volume of injected fluid.</p> <p>Activities involving fluid injection include:</p> <ul style="list-style-type: none"> • hydraulic fracturing of shale formations or coal seams to extract gas and oil • disposal of wastewater from these gas and oil activities by injection into deep aquifers • the development of enhanced geothermal systems by injecting water into hot, low-permeability rock. <p>Of these three operations, wastewater disposal is observed to be associated with the largest earthquakes, with maximum magnitudes sometimes exceeding 5. To estimate the maximum earthquake that could be induced by a given fluid injection project, the rock mass is assumed to be fully saturated, brittle, to respond to injection with a sequence of earthquakes localized to the region weakened by the pore pressure increase of the injection operation and to have a Gutenberg-Richter magnitude distribution with a b value of 1.</p> <p>If these assumptions correctly describe the circumstances of the largest earthquake, then the maximum seismic moment is limited to the volume of injected liquid times the modulus of rigidity. Observations from the available case histories of earthquakes induced by fluid injection are consistent with this bound on seismic moment. In view of the uncertainties in this analysis, however, this should not be regarded as an absolute physical limit.</p>
Objectives	To investigate fluid injection induced earthquakes.
Achievements	<p>The following conclusions have been made:</p> <ul style="list-style-type: none"> • The maximum seismic moment is limited to the volume of injected liquid times the modulus of rigidity. • The upper-bound seismic moment is proportional to the injected volume. • Deep injection of wastewater causes the largest fluid-induced earthquakes.
Outputs	<p>http://onlinelibrary.wiley.com/doi/10.1002/2013JB010597/abstract</p> <p>McGarr A (2014) "Maximum magnitude earthquakes induced by fluid injection". <i>Journal of Geophysical Research: Solid Earth</i>, 119 (2).</p>
Key personnel	McGarr, A

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Research themes	Seismicity, co-produced water, injection
Project information source	Literature

Table 4.103 Project 103: Sharp increase in central Oklahoma seismicity since 2008 induced by massive wastewater injection

Project characteristics	Details
Project title	Sharp increase in central Oklahoma seismicity since 2008 induced by massive wastewater injection
Project location	USA
Principal investigator	Keranen, KM
Lead institution	University of Cornell
Project budget	Unknown
Source of funding	USGS National Earthquake Hazards Reduction Program (NEHRP) grant G13AP00025, M.W. was partially supported by the USGS Powell Center grant G13AC00023, and G.A.A. was partially supported by NEHRP grant G13AP00024.
Project duration	Unknown–Literature output July 2014
Current status	Unknown–Literature output July 2014
Project summary	Unconventional oil and gas production provides a rapidly growing energy source; however, high-production states in the United States, such as Oklahoma, face sharply rising numbers of earthquakes. Subsurface pressure data required to unequivocally link earthquakes to injection are rarely accessible. Here we use seismicity and hydrogeological models to show that fluid migration from high-rate disposal wells in Oklahoma is potentially responsible for the largest swarm. Earthquake hypocenters occur within disposal formations and upper-basement, between 2-5 km depth. The modeled fluid pressure perturbation propagates throughout the same depth range and tracks earthquakes to distances of 35 km, with a triggering threshold of ~0.07 MPa. Although thousands of disposal wells operate aseismically, four of the highest-rate wells are capable of inducing 20% of 2008 to 2013 central US seismicity.
Objectives	To investigate links between fluid migration from high-rate disposal wells in Oklahoma to rising numbers of earthquakes using seismicity and hydrogeological models.
Achievements	Our earthquake relocations and pore pressure modelling showed that four high-rate disposal wells are capable of increasing pore pressure above the reported triggering threshold throughout the Jones swarm and thus are capable of triggering ~20% of 2008 to 2013 central and eastern U.S. seismicity.
Outputs	http://www.sciencemag.org/content/345/6195/448.abstract Keranen KM, Weingarten M, Abers GA, Bekins BA and Ge S (2014) "Sharp increase in central Oklahoma seismicity since 2008 induced by massive wastewater injection". <i>Science</i> 345: 448–451.
Key personnel	Keranen, KM; Weingarten, M; Abers, GA; Bekins, BA; Ge, S
Research themes	Seismicity, co-produced water, re-injection
Project information source	Literature

Table 4.104 Project 104: The 17 May 2012 M4.8 earthquake near Timpson, East Texas: An event possibly triggered by fluid injection

Project characteristics	Details
Project title	The 17 May 2012 M4.8 earthquake near Timpson, East Texas: An event possibly triggered by fluid injection
Project location	USA
Principal investigator	Frohlich, Cliff
Lead institution	University of Texas
Project budget	Unknown
Source of funding	Unknown
Project duration	Unknown—Literature output January 2014
Current status	Unknown—Literature output January 2014
Project summary	<p>This study summarizes our investigation of the 17 May 2012 MW-RMT4.8 earthquake near Timpson, Texas, the largest earthquake recorded historically in eastern Texas. To identify preshocks and aftershocks of the 17 May event we examined the arrivals recorded at Nacogdoches (NATX) 30 km from the 17 May epicenter, at nearby USArray Transportable Array stations, and at eight temporary stations deployed between 26 May 2012 and mid-2013.</p> <p>At NATX we identified seven preshocks, the earliest occurring in April 2008. Reliably located aftershocks recorded by the temporary stations lie along a 6 km long NW-SE linear trend corresponding to a previously mapped basement fault that extends across the highest-intensity (MMI VII) region of the 17 May main shock. Earthquakes in this sequence are relatively shallow—with focal depths ranging from 1.6 to 4.6 km. Evidence supporting these depths include: hypocentral locations of exceptionally well-recorded aftershocks, S-P intervals at the nearest stations, and comparisons of synthetics and observed seismograms.</p> <p>Within 3 km of the linear trend of aftershock activity there are two Class II injection disposal wells injecting at 1.9 km depth beginning in August 2006 and February 2007, with injection rates averaging 42 750 m³/mo and 15 600 m³/mo, respectively. Several observations support the hypothesis that fluid injection triggered the Timpson sequence: well-located epicenters are situated near a mapped basement fault and near high-volume injection wells, focal depths are at or below the depths of injection, and the earliest preshock (April 2008) occurred after the onset of injection in 2006.</p>
Objectives	To investigate links between an earthquake in Timpson, Texas with injection disposal wells situated near the epicentral area.
Achievements	<p>Present results from a felt report survey for the 17 May 2012 earthquake:</p> <ul style="list-style-type: none"> • summarize an analysis of seismograms to identify and locate earthquakes in the sequence • describe the injection disposal wells situated near the epicentral area and discuss their possible relationship with seismicity.
Outputs	<p>http://onlinelibrary.wiley.com/doi/10.1002/2013JB010755/abstract</p> <p>Frohlich C, Ellsworth W, Brown WA, Brunt M, Luetgert J, MacDonald T and Walter S (2014) "The 17 May 2012 M4.8 earthquake near Timpson, East Texas: An event possibly triggered by fluid injection". <i>Journal of Geophysical Research: Solid Earth</i>, 119 (1).</p>

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Key personnel	Frohlich, Cliff; Ellsworth, William; Brown, Wesley A; Brunt, Michael; Luetgert, Jim; MacDonald, Tim; Walter, Steve
Research themes	Seismicity, co-produced water, re-injection
Project information source	Literature

Table 4.105 Project 105: Correlations between formation properties and induced seismicity during high pressure injection into granitic rock

Project characteristics	Details
Project title	Correlations between formation properties and induced seismicity during high pressure injection into granitic rock
Project location	USA
Principal investigator	McClure, Mark
Lead institution	University of Texas
Project budget	Unknown
Source of funding	Part of this work was performed with support from the Precourt Institute for Energy at Stanford University
Project duration	Unknown—Literature output June 2014
Current status	Unknown—Literature output June 2014
Project summary	<p>We reviewed published results from six projects where hydraulic stimulation was performed in granitic rock. At each project, fractures in the formation were well-oriented to slip at the injection pressures used during stimulation. In all but one case, thousands of cubic meters of water were injected, and in every case, flow rates on the order of tens of liters per second were used. Despite these similarities, there was a large variation in the severity of induced seismicity that occurred in response to injection. At the three projects where induced seismicity was significant, observations at the wellbore showed evidence of well-developed brittle fault zones. At the three projects where induced seismicity was less significant, observations at the wellbore indicated only crack-like features and did not suggest significant fault development. These results suggest that assessments of the degree of fault development at the wellbore may be useful for predicting induced seismicity hazard.</p> <p>We cannot rule out that the differences were caused by variations in frictional properties that were unrelated to the degree of fault development (and it is possible that there is a relationship between these two parameters). The projects with more significant seismicity tended to be deeper, and if this is a meaningful correlation, it is unclear whether depth influenced seismic hazard through the degree of fault development, frictional properties, or some other variable. The results of this paper indicate that there may be significant opportunity for future research on identifying geological conditions that increase induced seismicity hazard.</p>
Objectives	To investigate correlations between formation properties and induced seismicity during high pressure injection into granitic rock.
Achievements	Review of published results from six projects where hydraulic stimulation was performed in granitic rock
Outputs	http://www.sciencedirect.com/science/article/pii/S0013795214000684 McClure M and Horne R (2014) "Correlations between formation properties and induced seismicity during high pressure injection into granitic rock". <i>Engineering Geology</i> , 175 (0).
Key personnel	McClure, Mark; Horne, Roland
Research themes	Seismicity, co-produced water, re-injection

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Project information source	Literature

Table 4.106 Project 106: The 24 January 2013 ML 4.4 earthquake near Paradox, Colorado, and its relation to deep well injection

Project characteristics	Details
Project title	The 24 January 2013 ML 4.4 earthquake near Paradox, Colorado, and its relation to deep well injection
Project location	USA
Principal investigator	Block, Lisa V
Lead institution	US Bureau of Reclamation
Project budget	Unknown
Source of funding	Unknown
Project duration	Unknown—Literature output May 2014
Current status	Unknown—Literature output May 2014
Project summary	A local magnitude (ML) 4.4 earthquake occurred near the town of Paradox, in western Colorado, on 24 January 2013, at 4:46:39 UTC time (23 January 2013, at 9:46:39 p.m. local time) and was strongly felt in nearby communities. Earthquakes this large are infrequent in the region. A search of regional earthquake databases yields just nine previous earthquakes of magnitude 3.5 or larger recorded since 1985, and occurring within 200 km of the January 2013 earthquake epicenter. Of these nine earthquakes, the epicenters of four are within several kilometers of an active brine deep injection well, and, based on their timing and location, we interpret them to be induced by injection operations.
Objectives	To investigate links between the 24 January 2013 earthquake near Paradox, Colorado to deep well injection.
Achievements	<ul style="list-style-type: none"> • Comparison of the event to earthquakes recorded previously in the area. • Comparison of recorded ground motions to estimates calculated using empirical ground-motion equations.
Outputs	http://srl.geoscienceworld.org/content/85/3/609.extract Block LV, Wood CK, Yeck WL and King VM (2014) The 24 January 2013 ML 4.4 Earthquake near Paradox, Colorado, and Its Relation to Deep Well Injection. <i>Seismological Research Letters</i> , 85 (3).
Key personnel	Block, Lisa V; Wood, Christopher K; Yeck, William L; King, Vanessa M
Research themes	Seismicity, co-produced water, re-injection
Project information source	Literature

4.5 Integrity of wells – installation, operation and decommissioning

The integrity of wells during all coal seam gas phases of installation, operation and decommissioning may impact on water resources and water-dependent ecosystems.

Nine projects were collated with the primary theme of the integrity of coal seam gas wells, from Australia (4 projects), Canada (2 projects), China (2 projects) and the United Kingdom (1 project). Note that there is currently a lot of research being conducted into shale gas well bore integrity in Canada. While beyond the scope of this project, there may be research outcomes applicable to the coal seam gas industry.

4.5.1 Australia

Table 4.107 Project 107: Investigation of borehole stability in poorly cemented granular formations by discrete element method

Project characteristics	Details
Project title	Investigation of borehole stability in poorly cemented granular formations by discrete element method
Project location	Australia
Principal investigator	Hashemi, SS
Lead institution	Deep Exploration Technology CRC, University of Adelaide
Project budget	Unknown
Source of funding	The Deep Exploration technologies Cooperative Research Centre whose activities are funded by the Australian Government's Research Programme. This is DET CRC Document 2012/064
Project duration	Unknown—Literature output January 2014
Current status	Unknown—Literature output January 2014
Project summary	<p>Behaviour of poorly cemented formations in case of drilling a vertical exploration borehole will be studied to achieve an in-depth understanding of borehole stability problem. Analysis of the granular formation behaviour has a significant importance in identifying stability issues, designing adequate borehole supports and choosing an efficient drilling method. This paper presents numerical investigations on the behaviour of poorly cemented formations in the vicinity of an unsupported vertical cylindrical borehole.</p> <p>Due to poor cementation and therefore granular behaviour of these formations, Discrete Element Method (DEM) was identified as being well suited for developing realistic models. To conduct the numerical studies a cube of 8 m(3) made up of spherical particles with diameters ranging from 5 to 70 mm was constructed and analysed in three-dimensional Particle Flow Code (PFC 3D). It is a discontinuum code used in analysis of the granular materials where the interaction of discrete grains is considered. A cylindrical opening with the diameter of 0.3 m runs along the central vertical axis of the cube simulating the presence of a borehole. The stresses applied to the cube simulate the underground conditions around an exploration borehole at the depth of 80 m.</p> <p>The effects of <i>in situ</i> stresses around the borehole, strength of particle bonding and fluid flow pressure on the stability of the formation around the borehole have been investigated. It has been shown that the development of <i>in situ</i> stresses in</p>

Project characteristics	Details
	the ground due to drilling a borehole results in the formation of a plastic zone around that borehole. When there is lack of sufficient bonding between the sand grains, the interaction between them results in their movement towards the borehole opening and thus eventuates the collapse of the borehole wall. Furthermore, the presence of high pressure water flow expedites the process of the borehole collapse.
Objectives	To present numerical investigations on the behaviour of poorly cemented formations in the vicinity of an unsupported vertical cylindrical borehole.
Achievements	<ul style="list-style-type: none"> • We simulate the borehole in poorly cemented formation by discrete element method. • Borehole stability has been investigated under in-situ underground stresses. • We study the effect of different bondings between particles on borehole stability. • The effect of confined aquifer on borehole instability has been studied.
Outputs	http://www.sciencedirect.com/science/article/pii/S0920410513003483 Hashemi SS, Momeni AA and Melkounian N (2014) "Investigation of borehole stability in poorly cemented granular formations by discrete element method". <i>Journal of Petroleum Science and Engineering</i> , 113.
Key personnel	Hashemi, SS; Momeni, AA; Melkounian, N
Research themes	Well integrity
Project information source	Literature

Table 4.108 Project 108: Coal-seam-gas reservoir surveillance – Extracting value from suspended coreholes, Surat Basin, Queensland, Australia

Project characteristics	Details
Project title	Coal-seam-gas reservoir surveillance – Extracting value from suspended coreholes, Surat Basin, Queensland, Australia
Project location	Australia
Principal investigator	Young, SR
Lead institution	QGC – A BG Group Business
Project budget	Unknown
Source of funding	QGC – A BG Group Business
Project duration	Unknown—Literature output 2014
Current status	Unknown—Literature output 2014
Project summary	<p>In 2009, QGC (a BG Group company) began developing coal seam gas (CSG) feedstock for its new liquefied natural gas (LNG) plant and required a subsurface model and field-development plan to underpin the investment case for the project. Fundamental to the modeling process was acquiring appropriate data to calibrate subsurface models and enhance confidence in their predictive quality. As part of an integrated reservoir-surveillance strategy, specific pressure- and temperature-monitoring wells were required. This paper describes the successful laboratory and field implementation of an innovative completion technique that converts suspended coreholes into reservoir- and aquifer-monitoring wells.</p> <p>The coreholes are re-entered, and vibrating wire piezometers attached to capillary coiled tubing are positioned and cemented in place alongside selected reservoir intervals. The well is then "plugged and abandoned," and the lease is remediated to leave only a small surface footprint for the data logger and telemetry. The cement is effectively impermeable to fluid movement, but possesses sufficient permeability to transmit reservoir pore pressure to an adjacent piezometer. Recompletion of coreholes provides a cost-effective means of acquiring valuable downhole data while eliminating the need to drill a well specifically for monitoring in the same vicinity.</p> <p>Data gathered over the reservoir interval (the Walloon Coal Measures) can inform and help resolve reservoir properties on a regional scale, enhance understanding of the contribution to flow, and provide data points to pressure match a reservoir model. Data gathered over the aquifers within Springbok sandstone and Gubbermunda sandstone enable estimates of any CSG-production effects on groundwater.</p>
Objectives	To implement an innovative completion technique that converts suspended coreholes into reservoir and aquifer monitoring wells.
Achievements	Successfully used recompletion of a corehole to provide a cost effective means of acquiring valuable downhole data and eliminating the potential requirement to drill a for purpose monitoring well in the same vicinity.
Outputs	<p>https://www.onepetro.org/journal-paper/SPE-167050-PA</p> <p>Young SR, Norton GFC and Foo KJ (2014) "Coal-seam-gas reservoir surveillance - Extracting value from suspended coreholes, Surat Basin, Queensland, Australia". <i>SPE Production and Operations</i>, 29 (2). Society of Petroleum Engineers</p>

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Key personnel	Young, SR; Norton, GFC; Foo, KJ
Research themes	Well integrity
Project information source	Literature

Table 4.109 Project 109: Background review: bore integrity

Project characteristics	Details
Project title	Background review: bore integrity
Project location	Australia
Principal investigator	Sinclair Knight Merz Pty Ltd
Lead institution	Australian Government – Department of the Environment (Office of Water Science)
Project budget	\$98 201.40 (GST inclusive)
Source of funding	Australian Government – Department of the Environment
Project duration	2012 – 2014
Current status	Completed
Project summary	<p>The subject of this report is bore integrity, which is the “instantaneous state of a well, irrespective of the purpose, value or age, which ensure the veracity and reliability of the barriers necessary to safely contain and control the flow of all fluids within or connected to the well” (Manifold 2010). A failure of bore integrity is a failure to prevent fluid flow between aquifers and between the surface and the aquifer.</p> <p>Bore integrity is fundamental to protect the target aquifer and surrounding aquifers for the full life cycle of the bore (or well). Hundreds of thousands of bores have been drilled and constructed across Australia and many of these are located in key groundwater resources. If bore integrity is not maintained, or bores are not decommissioned appropriately, there is the potential to cause significant impacts to regional groundwater resources which can affect existing and future users as well as the environment.</p> <p>The report focusses on bore integrity issues as they relate to coal seam gas extraction in Australia, and is informed by the international context and relevant experience in other sectors. It examines issues associated with bore construction, integrity, monitoring and reporting, decommissioning, and legacy issues. Bores constructed for water supply, coal mining exploration, and coal seam gas exploration and production are considered, whilst other onshore and offshore petroleum, oil, and gas wells are not.</p> <p>It provides a summary and synthesis of the relevant and available literature without focussing on the results of any specific study or research project. The report was prepared from information available in the public domain, and discussions with industry representatives.</p>
Objectives	<p>This review is one of a number commissioned by the Department of the Environment on the advice of the Interim Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining (IESC). These reviews aim to capture knowledge on the water-related impacts of coal seam gas extraction and large coal mining, but do not aim to provide detailed analysis and evaluation of methods for identifying and managing impacts, or to develop such methods.</p> <p>The focus of this report is bore integrity.</p>

Project characteristics	Details
Achievements	<p>Key points identified within this project include:</p> <ul style="list-style-type: none"> • bore integrity failure can cause adverse changes in groundwater levels, flow rates and flow directions and can also lead to changes in groundwater quality • bore integrity depends on good bore design, appropriate selection of construction materials and a high standard of cementing • in Australia, different types of bores are regulated under different legislation. Existing guidelines and regulations provide frameworks to establish bore integrity; driller and operator compliance is essential • opportunities for future research include more detailed assessments of the frequency of, mechanisms for and consequences of bore integrity failure • monitoring and reporting of bore and well integrity across all industries will be important to provide information needed to assess bore integrity and to act if there are issues.
Outputs	<p>Published on the Australian Government – Department of the Environment website and the IESC website.</p> <ul style="list-style-type: none"> • Commonwealth of Australia (2014) <i>Bore integrity: Background review</i>. Department of the Environment, Canberra. http://www.environment.gov.au/water/publications/background-review-bore-integrity
Key personnel	Sinclair Knight Merz Pty Ltd
Research themes	Integrity of wells/bores, decommissioning wells/bores
Project information source	Survey

Table 4.110 Project 110: Environmental impacts of coal seam gas activities on water resources

Project characteristics	Details
Project title	Environmental impacts of coal seam gas activities on water resources
Project location	Australia
Principal investigator	Willgoose, Garry
Lead institution	University of Newcastle, Australia
Project budget	\$95 000
Source of funding	Newcastle Innovation
Project duration	2012 – 2015
Current status	In progress
Project summary	This project is to better understand water-related impacts of potential CSG activities in the Broke region of the Hunter Valley and develop estimates of reliability using quantitative risk assessment of groundwater impacts.
Objectives	<p>To estimate hydraulic parameters for a fracked well using data from a pump test. Monte Carlo GLUE assessment of the reliability of estimation of aquifer parameters from the flow test. Assessment of the benefit of using a water only ground water code (MODFLOW) relative to a 2 phase gas (water and methane) model (TOUGH2) for interpretation of flow test data.</p> <p>To use the parameter reliability from the above assessment to develop probability measures of the likelihood of failure of any CSG project and design a monitoring system that will provide forewarning in the event of well field failure.</p>
Achievements	<ul style="list-style-type: none"> • Risk assessment of the Broke site completed using accepted screening models for groundwater pollution risk. • TOUGH2 GLUE analysis of the well testing underway.
Outputs	<p>Askarimarnani S, GR Willgoose and SG Fityus (2014) Using the Integral Finite Difference Method (IFDM) to improve design and generation of numerical grid in complex geologic systems, in 8th European Conference on Numerical Methods in Geotechnical Engineering, 18–20 June 2014, edited, p. in prep, Delft.</p> <p>Askarimarnani S and GR Willgoose (2014) Using the DRASTIC model for determination of groundwater vulnerability in a shallow aquifer in Broke, NSW, Australia, in HWRS Hydrology Symposium 2014, edited, p. in prep, IEAust, Perth.</p> <p>Morgan H and GR Willgoose (2013) A case study to test the suitability of modflow for interpreting pump tests in a hydraulically fractured well, in Groundwater Management in the Resources Industry 2013, edited, p. in press, ICN, Brisbane, 14–15 March.</p> <p>Morgan H and GR Willgoose (2012) Testing the suitability of modflow for interpreting pump tests in a hydraulically fractured well, in Hydrology and Water Resources Symposium, Institution of Engineers (Australia), Sydney.</p>
Key personnel	Willgoose, Garry
Research themes	Aquifer interconnectivity, disruption of surface water flow pathways, co-produced water and salt management (CSG) and mine water, Integrity of wells, hydraulic fracturing, quality and reliability of water supplies including environmental health, cumulative impact assessments

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Project information source	Survey

4.5.2 Canada

Table 4.111 Project 111: Seepage pathway assessment for natural gas to shallow groundwater during well stimulation, in production, and after abandonment

Project characteristics	Details
Project title	Seepage pathway assessment for natural gas to shallow groundwater during well stimulation, in production, and after abandonment
Project location	Canada
Principal investigator	Dusseault, Maurice
Lead institution	University of Waterloo; Geofirma Engineering
Project budget	Unknown
Source of funding	Alberta Department of Energy; Geofirma Engineering Ltd
Project duration	Unknown—Literature output September 2014
Current status	Unknown—Literature output September 2014
Project summary	<p>Hydraulic fracture stimulation (HFS) of unconventional oil and gas reservoirs is of public concern with respect to fugitive gas emissions, fracture height growth, induced seismicity, and groundwater quality changes. We evaluate the potential pathways of fugitive gas seepage during stimulation, in production, and after abandonment; we conclude that the quality of the casing installations is the major concern with respect to future gas migration.</p> <p>The pathway outside the casing is of particular concern as it likely leads to many wells leaking natural gas from thin intermediate-depth gas zones rather than from the deeper target reservoirs. These paths must be understood, likely cases identified, and the probability of leakage mitigated by methods such as casing perforation and squeeze, expanding packers of long life, and induced leakoff into saline aquifers.</p> <p>HFS itself appears not to be a significant risk, with two exceptions. These occur during the high-pressure stage of HFS when:</p> <ul style="list-style-type: none"> • legacy well casings are intersected by fracturing fluids, and • when these fluids pressurize nearby offset wells that have not been shut in, particularly offset wells in the same formation that are surrounded by a region of pressure depletion in which the horizontal stresses are also diminished. <p>This paper focuses on the issue of gas migration from deeper than the surface casing that occurs outside the casing caused by geomechanical processes associated with cement shrinkage, and we review the origin of the gas pulses recorded in noise logs, landowner wells, and surface-casing vents.</p>
Objectives	To investigate natural gas seepage pathways to shallow groundwater during resource extraction.
Achievements	Evaluation of the potential pathways of fugitive gas seepage during stimulation, in production, and after abandonment.
Outputs	http://archives.datapages.com/data/deg/2014/EG0314/EG14004/EG14004.html
Key personnel	Dusseault, Maurice; Jackson, Richard
Research themes	Well integrity

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Project information source	Literature

Table 4.112 Project 112: Towards a road map for mitigating the rates and occurrences of long-term wellbore leakage

Project characteristics	Details
Project title	Towards a road map for mitigating the rates and occurrences of long-term wellbore leakage
Project location	Canada
Principal investigator	Dusseault, Maurice B
Lead institution	University of Waterloo; Geofirma Engineering
Project budget	Unknown
Source of funding	Unknown
Project duration	Unknown—Literature output 2014
Current status	Unknown—Literature output 2014
Project summary	<p>Wellbore leakage, the seepage of natural gas through cement channels, casing annuli and behind the outermost casing string, is a problem reported across Canada. Wellbore leakage is a threat to the environment and public safety because of potential groundwater quality deterioration, contributions to greenhouse gas emissions and explosion risks if methane gas accumulates in inadequately ventilated areas. Leakage rates remain poorly quantified and remedial workovers are often challenging. Subsequent costs attributed to remedial workovers are often significant and present an economic strain on the industry as well as lost profit, reduced exploration and production and, therefore, foregone royalties.</p> <p>The purpose of this report has been to:</p> <ul style="list-style-type: none"> • identify persistent problems that result in wellbore leakage • discuss potential approaches that appear to reduce the rates and occurrences of wellbore leakage • describe methods for detecting and monitoring for wellbore leakage • discuss methods that have improved the efficiency of remedial workovers. <p>Our motivation has been to outline the need for a Canadian Road Map for Wellbore Integrity that identifies future research and development (R&D) needs and identifies where the resources for such R&D might be found.</p> <p>Several key processes were identified that lead to the potential development of a leakage problem, working to either prevent the initial creation of an adequate cement seal or compromising the integrity of the cement sheath over time. The pathways produced by these processes include microannuli, channels and fractures due to poor mud removal, invasion by fluids during setting, stresses imposed by operations, cement shrinkage and casing corrosion.</p> <p>Intermediate-depth formations, i.e. non-commercial gas zones, are often found to be the source of the buoyant fugitive gases that migrate up these pathways. ‘Doing it right the first time’ – i.e. creating a robust seal during primary cementation – was uniformly agreed by industry and regulators to be the best approach for reducing leakage development over the operational and post-operational lifetime of a well. Even if an adequately sealed wellbore was achieved during primary cementation, there remains the possibility that a leakage problem may develop due to corrosion or cement shrinkage. Therefore, in addition to ‘doing it right the first time’, new cement formulations, wellbore designs and abandonment approaches are needed.</p>

Project characteristics	Details
	<p>Wellbore monitoring needs to be improved by adopting the use of newer technologies and undergoing more thorough subsurface monitoring. Remedial workovers require advances in source identification (such as enhanced acoustic logging technology and isotopic fingerprinting) and alternative-sealing materials. Wellbore leakage will likely only become worse with time as new wells are completed and old wells are abandoned. We recommend that a Canadian working group be established to develop a Road Map for Wellbore Integrity R&D to improve long-term wellbore integrity. Hydraulic fracturing is perceived as a threat by many in the public, however, we believe that this concern is misplaced. Because of the real issues associated with greenhouse gas emissions and possible groundwater quality deterioration, we believe the more significant issue affecting the social license of the oil and gas industry is long-term wellbore integrity.</p>
Objectives	<p>The purpose of this report has been to:</p> <ul style="list-style-type: none"> • identify persistent problems that result in wellbore leakage • discuss potential approaches that appear to reduce the rates and occurrences of wellbore leakage • describe methods for detecting and monitoring for wellbore leakage • discuss methods that have improved the efficiency of remedial workovers. <p>These issues outline the need for a Canadian Road Map for Wellbore Integrity that identifies future research and development (R&D) needs and identifies where the resources for such R&D might be found.</p>
Achievements	<p>The following conclusions were reached.</p> <ul style="list-style-type: none"> • It is commonplace for wells to slowly seep gas upwards outside the casing because of inadequate primary cementation. • Slow seepage can develop many years after a successful well abandonment procedure. • The seepage gas is usually close to 100% – methane. • The issue of leaking wells appears to be a moderate public health issue. • The magnitude of the GHG emissions and the amount entering shallow aquifers are not known.
Outputs	<p>http://www.geofirma.com/Research_Main.html Dusseault MB, Jackson RE and Macdonald D (2014) <i>"Towards a road map for mitigating the rates and occurrences of long-term wellbore leakage"</i>. University of Waterloo, Department of Earth and Environmental Sciences</p>
Key personnel	Dusseault, Maurice B; Jackson, Richard E; Macdonald, Daniel
Research themes	Well integrity, co-produced/mine water
Project information source	Website

4.5.3 China

Table 4.113 Project 113: Integrity analysis of gas field water re-injection well wellbore

Project characteristics	Details
Project title	Integrity analysis of gas field water re-injection well wellbore
Project location	China
Principal investigator	Xu, C
Lead institution	Chongqing University of Science & Technology
Project budget	Unknown
Source of funding	Research Foundation of Chongqing University of Science & Technology(CK2010Z11 and CK2010Z15).
Project duration	Unknown—Literature output 2014
Current status	Unknown—Literature output 2014
Project summary	Finding the right abandoned well (or new drilling) leakage layer re-injection into the ground is the most effective, the most mature, the most commonly used method in the gas field water treatment. By simplifying assumptions and the establishment of mathematical model and FEM, simulation and calculation of stress status of the tubing and casing, analysis of wellbore integrity, for the analysis of the wellbore risk of gas field water re-injection wells and re-injection wells safety operation provide important theoretical support.
Objectives	To calculate the stress status of well bore tubing and casing to assess wellbore integrity.
Achievements	The integrity of the gas field re-injection well wellbore gas was calculated using theoretical calculation and finite element analysis.
Outputs	http://www.scientific.net/AMM.121-126.2799 Xu C, Liu J, Xu L, Kuang X and Wang J (2012) "Integrity analysis of gas field water reinjection well wellbore". <i>Applied Mechanics and Materials</i> , 121–126.
Key personnel	Xu, C; Liu, J; Xu, Li; Kuang, X; Wang, J
Research themes	Well integrity
Project information source	Literature

Table 4.114 Project 114: Calculation model for borehole collapse volume in horizontal openhole in formation with multiple weak planes

Project characteristics	Details
Project title	Calculation model for borehole collapse volume in horizontal openhole in formation with multiple weak planes
Project location	China
Principal investigator	Liu, ZY
Lead institution	College of Petroleum Engineering, State Key Lab Petroleum Resources & Prospecting, China University of Petroleum, Beijing
Project budget	Unknown
Source of funding	Supported by the National Science and Technology Major Project (2011ZX05046).
Project duration	Unknown—Literature output 2014
Current status	Unknown—Literature output 2014
Project summary	In view of borehole collapse in testing of horizontal wells, a calculation model for borehole collapse volume of horizontal open-hole in multiple-weak-plane formation was set up to analyze the factors affecting collapse volume. It was compared with the single- weak-plane model by field application. The influences of fracture occurrence, well-bore azimuth, in-situ stress anisotropy, number of weak planes and fluid density on well-bore collapse volume was analyzed.
Objectives	To setup a calculation model for borehole collapse volume of horizontal open-hole in multiple-weak-plane formation to analyze the factors affecting collapse volume.
Achievements	<p>This study reveals:</p> <ul style="list-style-type: none"> • when the fracture dip is small, the volume of well-bore collapse is big and the well-bore stability is poor • when the fracture dip is big, the collapse volume varies greatly with the change of well-bore azimuth and fracture trend • the maximum collapse volume appears with different well-bore azimuth if fracture trend is different • the greater the in-situ stress difference is, the greater the well-bore collapse volume will be • the collapse volume decreases with the increase of borehole fluid density, and is more sensitive to the change of fluid density when fluid density is near the equivalent density of pore pressure. Field application results show that, compared with the single-weak-plane model, the multiple-weakplane model gets big collapse volume in most cases so it can assess the collapse risk more reliably.
Outputs	http://www.sciencedirect.com/science/article/pii/S1876380414600136 Liu ZY, Chen M, Jin Y, Yang XT, Lu YH and Xiong QQ (2014) "Calculation model for borehole collapse volume in horizontal openhole in formation with multiple weak planes". <i>Petroleum Exploration and Development</i> , 41 (1).
Key personnel	Liu, ZY; Chen, M; Jin, Y; Yang, XT; Lu, YH; Xiong, QQ
Research themes	Well integrity

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Project characteristics	Details
Project information source	Literature

4.5.5 United Kingdom

Table 4.115 Project 115: Oil and gas wells and their integrity: Implications for shale and unconventional resource exploitation

Project characteristics	Details
Project title	Oil and gas wells and their integrity: Implications for shale and unconventional resource exploitation
Project location	United Kingdom
Principal investigator	Davies, RJ
Lead institution	Durham University; British Geological Survey
Project budget	Unknown
Source of funding	Natural Environment Research Council (UK), Total, Shell and Chevron
Project duration	Unknown—Literature output September 2014
Current status	Unknown—Literature output September 2014
Project summary	<p>Data from around the world (Australia, Austria, Bahrain, Brazil, Canada, the Netherlands, Poland, the UK and the USA) show that more than four million onshore hydrocarbon wells have been drilled globally. Here we assess all the reliable datasets (25) on well barrier and integrity failure in the published literature and online. These datasets include production, injection, idle and abandoned wells, both onshore and offshore, exploiting both conventional and unconventional reservoirs. The datasets vary considerably in terms of the number of wells examined, their age and their designs. Therefore, the percentage of wells that have had some form of well barrier or integrity failure is highly variable (1.9%–75%).</p> <p>Of the 8030 wells targeting the Marcellus shale inspected in Pennsylvania between 2005 and 2013, 6.3% of these have been reported to the authorities for infringements related to well barrier or integrity failure. In a separate study of 3533 Pennsylvanian wells monitored between 2008 and 2011, there were 85 examples of cement or casing failures, four blowouts and two examples of gas venting. In the UK, 2152 hydrocarbon wells were drilled onshore between 1902 and 2013 mainly targeting conventional reservoirs. UK regulations, like those of other jurisdictions, include reclamation of the well site after well abandonment.</p> <p>As such, there is no visible evidence of 65.2% of these well sites on the land surface today and monitoring is not carried out. The ownership of up to 53% of wells in the UK is unclear; we estimate that between 50 and 100 are orphaned. Of 143 active UK wells that were producing at the end of 2000, one has evidence of a well integrity failure.</p>
Objectives	To investigate the integrity of oil and gas wells in shale and unconventional resource exploitation.
Achievements	<p>The following conclusions were reached.</p> <ul style="list-style-type: none"> • Oil and gas well barrier elements can fail. • The percentage of wells with barrier element failure is between 1.9% and 75%. • Pennsylvanian shale wells have well barrier and failures rates of 6.3% or less.

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Project characteristics	Details
Outputs	http://www.sciencedirect.com/science/article/pii/S0264817214000609# Davies, RJ, Almond, S, Ward, RS, Jackson, RB, Adams, C, Worrall, F, Herringshaw, LG, Gluyas, JG and Whitehead, MA (2014) "Oil and gas wells and their integrity: Implications for shale and unconventional resource exploitation". <i>Marine and Petroleum Geology</i> , 56.
Key personnel	Davies, RJ; Almond, S; Ward, RS; Jackson, RB; Adams, C; Worrall, F; Herringshaw, LG; Gluyas, JG; Whitehead, MA
Research themes	Well integrity
Project information source	Literature

4.6 Hydraulic fracturing

Hydraulic fracturing during coal seam gas operations may impact water resources and water-dependent ecosystems. Research in this area includes the effects of hydraulic fracturing chemicals on surface and groundwater quality, and the physical impacts of hydraulic fracturing such as aquitard disruption and borehole collapse.

Ten projects were collated with the primary theme of hydraulic fracturing from Australia (6 projects), Canada (1 project) and China (3 projects).

4.6.1 Australia

Table 4.116 Project 116: Fault seal characterisation for CSG–aquifer interaction

Project characteristics	Details
Project title	Fault seal characterisation for CSG–aquifer interaction
Project location	Australia
Principal investigator	Undershultz, Jim
Lead institution	Centre for Coal Seam Gas, The University of Queensland
Project budget	Unknown
Source of funding	Unknown
Project duration	Unknown—presentation July 2014
Current status	Unknown
Project summary	<p>When forecasting the potential for interaction between coal seam gas (CSG) development and adjacent aquifer systems at regional scale, an important consideration is to adequately characterise the seal potential of faults. A number of fault seal analysis techniques applied in conventional hydrocarbon exploration can be augmented with hydrodynamic data to make fault seal interpretation more robust.</p> <p>Across-fault seal potential is normally assessed first by juxtaposition analysis using Allan diagrams. Across fault membrane seal capacity has been shown to effectively be estimated using shale gouge ratio analysis that generates a permeability forecast given the observed fault throw distribution and the nature of shale volume fraction that has been in contact with the slip surface. Upfault leakage potential can be estimated by examining the fault zone architecture in conjunction with the in-situ stress regime.</p> <p>All of these methods can be enhanced with standard hydrodynamic analysis of the pressure, salinity and temperature data. An approach to integrated fault seal analysis is presented that can be used to estimate fault seal properties relevant to dynamic simulation aquifer response to CSG development.</p>
Objectives	Present an approach to integrated fault seal analysis that can be used to estimate fault seal properties relevant to dynamic simulation aquifer response to CSG development.
Achievements	Determined an approach to integrated fault seal analysis that can be used to estimate fault seal properties relevant to dynamic simulation aquifer response to CSG development.

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Project characteristics	Details
Outputs	Underschultz J (2014) Fault seal characterisation for CSG–aquifer interaction. Geological Society of Australia, 2014 Australian Earth Sciences Convention (AESC), Sustainable Australia. Abstract No 110 of the 22nd Australian Geological Convention, Newcastle City Hall and Civic Theatre, Newcastle, New South Wales. July 7–10.
Key personnel	Underschultz, Jim
Research themes	Hydraulic fracturing, aquifer interconnectivity
Project information source	Conference

Table 4.117 Project 117: Independent review of tight gas stimulation 2014 Environmental Plan (TGS 14 EP) for Nyanba Buru Yawuru Ltd

Project characteristics	Details
Project title	Independent review of tight gas stimulation 2014 Environmental Plan (TGS 14 EP) for Nyanba Buru Yawuru Ltd
Project location	Australia
Principal investigator	Evans, Brian
Lead institution	Curtin University
Project budget	\$30 000
Source of funding	Nyanba Buru Yawuru Ltd
Project duration	2014
Current status	Completed
Project summary	Independent review of tight gas stimulation plans for Yulleroo wells by Buru, and their effects on local seismicity and ground water contamination. Ground water was specifically studied by a separate groundwater consultancy and our brief was just to review the efficacy of the fracture stimulation process and well completion both finished and proposed.
Objectives	Provide an independent, unbiased assessment of the petroleum engineering and geological aspects of all studies and plans to date.
Achievements	Completed
Outputs	Reports to Nyamba Buru Yawuru Ltd
Key personnel	Evans, Brian
Research themes	Co-produced water and salt management (CSG) and mine water & salt management (coal mines), aquifer injection and/or water treatment (technologies, relative cost benefit), seismicity, integrity of wells – installation, operation, decommissioning, hydraulic fracturing, chemical - surface and groundwater quality, physical - aquitard disruption, borehole collapse
Project information source	Survey

Table 4.118 Project 118: National assessment of chemicals associated with coal seam gas extraction in Australia

Project characteristics	Details
Project title	National assessment of chemicals associated with coal seam gas extraction in Australia
Project location	Australia
Principal investigator	NICNAS, CSIRO, Australian Government – Department of the Environment
Lead institution	Australian Government – Department of the Environment (Office of Water Science)
Project budget	\$4.2 Million
Source of funding	Australian Government – Department of the Environment
Project duration	July 2012 – 2015
Current status	In progress
Project summary	The assessment will examine human health and environmental risks from chemicals used in drilling and hydraulic fracturing for coal seam gas extraction in Australia. It will inform the Australian Government, the IESC, industry and the public about the use and potential risks of these chemicals. The assessment is a collaboration between the National Industrial Chemicals Notification and Assessment Scheme (NICNAS), the Commonwealth Scientific and Industrial Research Organisation (CSIRO), the Department of the Environment and, in an advisory role, Geoscience Australia.
Objectives	To inform the Australian Government, the IESC, industry and the public about the use and potential risks of these chemicals.
Achievements	The National Assessment will: <ul style="list-style-type: none"> • develop an understanding among stakeholders of the public, occupational and environmental risks arising from chemicals used in drilling and hydraulic fracturing for coal seam gas extraction in Australia, thereby addressing some existing scientific gaps and stakeholder concerns • provide an evidence base for the appropriate management of chemicals as part of the broader management of coal seam gas activities • improve public access to information about chemicals used in hydraulic fracturing operations.
Outputs	Reports to be published on the NICNAS website. http://www.nicnas.gov.au/communications/issues/fracking-hydraulic-fracturing-coal-seam-gas-extraction/information-sheet
Key personnel	Dr Rob Jeffrey (CSIRO), Dr Simon Apte (CSIRO), Dr Dirk Mallants (CSIRO), NICNAS, Office of Water Science, Chemical Assessment Section (CAS)
Research themes	Hydraulic fracturing, chemicals, hydraulic fracturing related impacts
Project information source	Survey

Table 4.119 Project 119: Hydraulic fracturing risk assessment – review and experience with the Queensland regulatory framework

Project characteristics	Details
Project title	Hydraulic fracturing risk assessment – review and experience with the Queensland regulatory framework
Project location	Australia
Principal investigator	Jorstad, Lange
Lead institution	Golder Associates Pty Ltd
Project budget	Unknown
Source of funding	Unknown
Project duration	Unknown—Literature output 2013
Current status	Unknown—Literature output 2013
Project summary	<p>Hydraulic fracturing has enabled the economic development of oil and gas reserves that were previously considered to be unattainable, providing the catalyst for a booming unconventional oil and gas industry. The Australian context includes several major coal seam gas developments in Queensland and New South Wales, and more recent exploration of shale reserves.</p> <p>Hydraulic fracturing has recently received close scrutiny in the regulation of unconventional oil and gas projects, as there is a widespread perception that the activity presents a high risk to groundwater and surface water resources and their environmental values. The primary risks are considered to be unintended releases of fracturing fluids into water supply aquifers, and release of residual fluids from storage dams on the surface. This perception is exacerbated in part by the proprietary nature of some of the chemical additives used in fracturing fluids.</p> <p>In Australia, Queensland currently has the most advanced hydraulic fracturing regulation. This was driven by CSG developments targeting resources within the Great Artesian Basin, located in stratigraphic succession with highly productive groundwater resources. Proponents are required to prepare hydraulic fracturing risk assessments prior to the issue of Environmental Authorities for their projects. While the risk assessment conditions continually evolve, they generally focus on the following aspects: environmental setting and values, hydrogeological conceptual model, fracturing process description, exposure pathway analysis, toxicological assessment of chemical additives, and management measures to mitigate impacts.</p> <p>The international experience suggests that surface management of residual fluids presents the highest risk to local receiving environments. Queensland has implemented strict guidelines for surface water dams, and has regulated the use of certain chemicals to mitigate this risk. The key risk assessment challenges include assessing the potential for inter-aquifer connectivity with fractured formations, assessing the toxicity of fluid mixtures, and assessing the cumulative impact of multiple fracturing events. These are compared and contrasted in the context of oil and gas reserves in Southeast and Southwest Queensland to assess their different risk profiles.</p>
Objectives	To compare and contrast issues pertinent to hydraulic fracturing in the context of oil and gas reserves in Southeast and Southwest Queensland to assess their different risk profiles.

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Project characteristics	Details
Achievements	Unknown
Outputs	Jorstad L, Broadgate K and Turczynowicz L (2013) "Hydraulic fracturing risk assessment - review and experience with the Queensland regulatory framework". 40 th IAH Congress on Solving the Groundwater Challenges of the 21 st Century. Perth, Australia.
Key personnel	Jorstad, Lange; Broadgate, Kirsten; Turczynowicz, Leonard
Research themes	Hydraulic fracturing, quality and reliability of water supplies
Project information source	40 th IAH Congress

Table 4.120 Project 120: Qualitative and quantitative modelling of hydraulic fracturing of brittle materials

Project characteristics	Details
Project title	Qualitative and quantitative modelling of hydraulic fracturing of brittle materials
Project location	Australia
Principal investigator	Li, Ling
Lead institution	School of Mechanical and Mining Engineering, University of Queensland
Project budget	\$660 000
Source of funding	Australian Research Council
Project duration	2013 – 2016
Current status	In progress
Project summary	Few technologies have caused more concern in the general population than the so called hydraulic fracturing technique, applied to enhance the hydraulic conductivity of resource-bearing rocks by injecting high pressure fluids. The concern revolves around uncertainty with leakage of used chemicals to overlying aquifers, unwanted seismic events and surface subsidence. Our research, combining experimental and computational investigations, aims to establish fundamental understanding of key processes controlling fracture formation in brittle materials (coal seams and porous rocks) under the action of hydraulic fracturing. The research outcomes will help to assess and minimise the risks associated with the hydraulic fracturing technology.
Objectives	This work aims to establish fundamental understanding of key processes controlling fracture formation in brittle materials (coal seams and porous rocks) under the action of hydraulic fracturing.
Achievements	Unknown
Outputs	http://researchers.uq.edu.au/research-project/21125 Li L, Scheuermann A, Pedroso D and Torres SG (2014) "Qualitative and quantitative modelling of hydraulic fracturing of brittle materials". School of Mechanical and Mining Engineering (University of Queensland)
Key personnel	Li, Ling; Scheuermann, Alexander; Pedroso, Dorival; Torres, Sergio Gilando
Research themes	Hydraulic fracturing
Project information source	UQ and ARC Website

Table 4.121 Project 121: Background review: Hydraulic fracturing ('fracking') techniques, including reporting requirements and governance arrangements

Project characteristics	Details
Project title	Background review: Hydraulic fracturing ('fracking') techniques, including reporting requirements and governance arrangements
Project location	Australia
Principal investigator	URS Australia Pty Ltd
Lead institution	URS Australia Pty Ltd; Australian Government – Department of the Environment
Project budget	\$92 351 (GST inclusive)
Source of funding	Australian Government – Department of the Environment
Project duration	2012 – 2014
Current status	Completed
Project summary	<p>The report provides a summary and synthesis of the relevant and available literature and the expert opinions of the authors, and does not describe the results of a specific study or research project. The focus is primarily on hydraulic fracturing in Australia, although the review includes an international context. Reference is also made to other forms of unconventional gas such as shale gas to illustrate where the fracturing processes and impacts differ. This review is limited to information available in the public domain. Industry operators and government regulators were invited to provide information for this review. The list of source materials include:</p> <ul style="list-style-type: none"> • journal articles • conference proceedings • scientific text books • government department reports • industry and consulting reports.
Objectives	<p>The focus of this report is hydraulic fracturing issues associated with coal seam gas extraction, including the techniques involved, the risks and how they are managed, and the regulatory environment. While hydraulic fracturing is used in a number of industries, including shale gas, conventional gas, ore mining, coal mining and geothermal energy, the scope of this review is limited to hydraulic fracturing in the coal seam gas industry in Australia.</p>
Achievements	<p>Key points identified by the background review include:</p> <ul style="list-style-type: none"> • Of the 1844 coal seam gas wells drilled in Australia over 15 months during 2012 and 2013, 6% were hydraulically fractured. • The composition of fluids used in hydraulic fracturing activities vary depending on site requirements. Benzene, toluene, ethyl-benzene and xylenes (BTEX chemicals) are banned from use in hydraulic fracturing in New South Wales and Queensland. • The main potential environmental concerns are surface and subsurface contamination, induced seismicity and water consumption. • Fracture growth caused by hydraulic fracturing can increase connection between coal seams and aquifers – the magnitude and extent of this growth is dependent on local factors. • Hydraulic fracturing programs are designed to suit local conditions, and to

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Project characteristics	Details
	monitor and control fracture growth during operations.
Outputs	<p>Published on the Australian Government – Department of the Environment website and the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) website.</p> <ul style="list-style-type: none"> Commonwealth of Australia (2014) Hydraulic fracturing ('fracking') techniques, including reporting requirements and governance arrangements, Background review. Department of the Environment, Canberra. http://www.environment.gov.au/water/publications/background-review-hydraulic-fracturing
Key personnel	Jong, Tony; Jenkins, Daymion
Research themes	Hydraulic fracturing, chemicals, hydraulic fracturing related impacts
Project information source	Survey

4.6.2 Canada

Table 4.122 Project 122: Chemical and isotopic characterization of shallow groundwater in the vicinity of coal bed methane operations in Alberta

Project characteristics	Details
Project title	Chemical and isotopic characterization of shallow groundwater in the vicinity of coal bed methane operations in Alberta
Project location	Canada
Principal investigator	Cheung, Katrina
Lead institution	University of Calgary
Project budget	\$200 000
Source of funding	Alberta Ingenuity Center for Water Research (and others)
Project duration	1 March 2014 – Unknown
Current status	Completed
Project summary	The production of coalbed methane (CBM) represents a vital new source of natural gas supply in Western Canada. There are, however, concerns over potential negative environmental impacts on shallow groundwater resources in the hypothetical case that leakage of fluids and gases from CBM operations occurs. This paper compares major ion and isotope geochemistry data for produced fluids or gases from two major coal deposits in Western Canada (Mannville Formation and the Horseshoe Canyon/Belly River Group) with similar data collected for shallow groundwater in south-central Alberta. The objective was to generate comprehensive baseline geochemical data to determine the key geochemical characteristics and differences of produced fluids and gases from two coal deposits and shallow groundwater in Alberta and to find parameters that are suitable for identifying potential leakage of fluids or gases into shallow groundwater.
Objectives	The objective of this study was to collect comprehensive baseline geochemical and isotopic data for produced fluids and gases from two coal deposits and shallow groundwater. The geochemistry of the produced fluids from CBM wells and shallow groundwater was assessed determining the concentrations of major ions, dissolved and free hydrocarbon gases, and by analyzing the isotopic composition of water, dissolved constituents and dissolved and free hydrocarbon gases. The ultimate goal of the study was to identify parameters that are suitable for identifying potential leakage of fluids or gases from CBM operations into shallow groundwater.
Achievements	It is concluded that d18O values of the fluids in concert with total dissolved solids, and the isotopic compositions of methane and ethane are sufficiently distinct in shallow groundwater and produced fluids from the Horseshoe Canyon and the Mannville Formations that they may serve as tracers for evaluating potential contamination of shallow groundwater with produced fluids or gases.
Outputs	Cheung K, Klassen P, Mayer B, Goodarzi F and Aravena R (2010) Major ion and isotope geochemistry of fluids and gases from coalbed methane and shallow groundwater wells in Alberta, Canada. <i>Applied Geochemistry</i> , 25(9): 1307–1329. IF 2.304 (5yr).

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Project characteristics	Details
Key personnel	Cheung, Katrina; Klassen, Patrick; Mayer, Bernhard; Goodarzi, Fari; Ramon, Aravena
Research themes	Hydraulic fracturing, water supplies
Project information source	Survey

4.6.3 China

Table 4.123 Project 123: The environmental impacts of coalbed methane industry on groundwater

Project characteristics	Details
Project title	The environmental impacts of coalbed methane industry on groundwater
Project location	China
Principal investigator	Not yet awarded
Lead institution	Project to be awarded in 2015
Project budget	TBA. Less than 100 million Yuan
Source of funding	Shanxi Basic Research Program - CBM Joint Research Fund" by the Science and Technology Department of Shanxi Province and Shanxi Jincheng Anthracite Mining Group Co. Ltd
Project duration	2015 – 2016
Current status	Planned
Project summary	Shanxi Basic Research Program – CBM Joint Research Fund has placed a call for funding applications on their website relevant to the programme title "The Environmental Impacts of Coalbed Methane industry on Groundwater".
Objectives	Project to be awarded in 2015
Achievements	Project to be awarded in 2015
Outputs	Project to be awarded in 2015
Key personnel	Project to be awarded in 2015
Research themes	Hydraulic fracturing, water supplies, co-produced/mine water
Project information source	Website

Table 4.124 Project 124: Regional environmental carrying capacity of coalbed methane hotspot and ecosystem restoration study

Project characteristics	Details
Project title	Regional environmental carrying capacity of coalbed methane hotspot and ecosystem restoration study
Project location	China
Principal investigator	Not yet awarded
Lead institution	Project to be awarded in 2015
Project budget	TBA. Less than 100 million Yuan
Source of funding	Shanxi Basic Research Program – CBM Joint Research Fund" by the Science and Technology Department of Shanxi Province and Shanxi Jincheng Anthracite Mining Group Co. Ltd
Project duration	2015 – 2016
Current status	Planned
Project summary	Shanxi Basic Research Program – CBM Joint Research Fund has placed a call for funding applications on their website relevant to the programme title "The Environmental Impacts of Coalbed Methane industry on Groundwater".
Objectives	Project to be awarded in 2015
Achievements	Project to be awarded in 2015
Outputs	Project to be awarded in 2015
Key personnel	Project to be awarded in 2015
Research themes	Water-dependent ecosystems, cumulative impact assessment
Project information source	Website

Table 4.125 Project 125: Research on treatment and resource recovery of produced water from coal methane production wells

Project characteristics	Details
Project title	Research on treatment and resource recovery of produced water from coal methane production wells
Project location	China
Principal investigator	Not yet awarded
Lead institution	Project to be awarded in 2015
Project budget	TBA. Less than 100 million Yuan
Source of funding	Shanxi Basic Research Program - CBM Joint Research Fund" by the Science and Technology Department of Shanxi Province and Shanxi Jincheng Anthracite Mining Group Co. Ltd
Project duration	2015 – 2016
Current status	Planned
Project summary	Shanxi Basic Research Program – CBM Joint Research Fund has placed a call for funding applications on their website relevant to the programme title "The Environmental Impacts of Coalbed Methane industry on Groundwater".
Objectives	Project to be awarded in 2015
Achievements	Project to be awarded in 2015
Outputs	Project to be awarded in 2015
Key personnel	Project to be awarded in 2015
Research themes	Co-produced/mine water
Project information source	Website

4.7 Quality and reliability of water supplies including environmental health

Coal seam gas and coal mining may impact the quality and reliability of water supplies both during operation and long after decommissioning. Research projects into this area include mine site and gas field remediation, the long-term impacts of mines and coal seam gas operations, contamination due to chemical use and salt and heavy metal management. There is significant overlap with research into R3 co-produced/mine water (Section 4.3).

Twelve projects were collated with the primary theme of R7 quality and reliability of water supplies, including environmental health, from Australia (4 projects), China (3 projects), Russia (1 project), the United Kingdom (2 projects) and the United States (2 projects).

4.7.1 Australia

Table 4.126 Project 126: Recharge estimation in the Surat Basin

Project characteristics	Details
Project title	Recharge estimation in the Surat Basin
Project location	Australia
Principal investigator	McIntyre, Neil
Lead institution	Centre for Water in the Minerals Industry (University of Queensland)
Project budget	\$313 928
Source of funding	Centre for Coal Seam Gas
Project duration	1 November 2013 – Unknown
Current status	In progress
Project summary	Due to the geological complexity of the Surat and Bowen Basins, recharge can occur via multiple pathways along the basin margins, principally within the 'intake beds', but other less direct pathways may also be important. The amount of recharge varies greatly across these different pathways due to physical and climatic factors. This research seeks to improve understanding of these pathways and the variation in recharge rates (in both space and time) within these basins. The current study incorporates desk-top review, workshops and modeling (Phase 1) to ensure current expertise and data is optimally used and included in recommendations for recharge estimation for the purpose of CSG groundwater impacts assessment. The need for a fieldwork phase will be assessed in the last quarter of 2014.
Objectives	To improve understanding of the spatial and temporal variation in recharge volumes along the multiple recharge pathways of the Surat Basin.
Achievements	A range of recharge estimation techniques have been evaluated and their application in different settings have been assessed.
Outputs	Reports and journal articles will be published at the completion of the project.
Key personnel	McIntyre, Neil; Reading, Lucy ; Larsen, Joshua
Research themes	Water supplies, cumulative impact assessments

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Project characteristics	Details
Project information source	Survey

Table 4.127 Project 127: Environmental stewardship: lessons for European unconventional gas from the United States and Australia

Project characteristics	Details
Project title	Environmental stewardship: lessons for European unconventional gas from the United States and Australia
Project location	Australia
Principal investigator	Wilkinson, Paul
Lead institution	CH2M Hill
Project budget	Unknown
Source of funding	Unknown
Project duration	Unknown—Literature output July 2014
Current status	Unknown—Literature output July 2014
Project summary	<p>Europe is on the cusp of an expansion in the development of unconventional gas resources, and many analysts are turning to the United States (US) and Australia to learn lessons from markets at different stages of the development curve. To date, most attention has been focussed on similarities and differences in geology, service industry, and gas price while consideration of environmental stewardship has been dominated by concerns over the potential environmental and health impacts of hydraulic fracturing. Broader issues of local water security, wastewater management, and landscape impact have, in contrast, received less attention.</p> <p>To address these issues, the authors take an alternative look at the European market by using experiences in the US and Australia to consider the risk-management practices, regulatory measures, and stakeholder-engagement techniques that have achieved greatest success in stimulating the industry while, at the same time, protecting environmental assets. Although the industries in the US and Australia exhibit notable differences to those that may develop in Europe, several overarching observations can be made. The importance of stakeholder collaboration, transparency, and carefully defined boundaries of jurisdiction are some of the key factors identified.</p>
Objectives	This paper aims to discuss how the environmental stewardship of any future European unconventional gas industry can be secured by analysing the economical, political, social and environmental contexts.
Achievements	<p>The authors conclude by identifying three initiatives essential to the emergence of a viable, publicly acceptable, and sustainable unconventional gas industry in Europe:</p> <ul style="list-style-type: none"> • collecting robust and reliable environmental baseline data • using and communicating sound science • implementing collaborative governance.
Outputs	https://www.onepetro.org/journal-paper/SPE-167714-PA
Key personnel	Wilkinson, Paul; von Lany, Peter; Lane, Alexander
Research themes	Water supplies

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Project information source	Literature

Table 4.128 Project 128: Unconventional gas: coal seam gas, shale gas, tight gas. An introduction and overview of issues relevant to the development of unconventional gas in Victoria

Project characteristics	Details
Project title	Unconventional gas: coal seam gas, shale gas, tight gas. An introduction and overview of issues relevant to the development of unconventional gas in Victoria
Project location	Australia
Principal investigator	Catriona, Ross
Lead institution	Department of Parliamentary Services, Victoria
Project budget	Unknown
Source of funding	Parliament of Victoria
Project duration	Unknown—Literature output 2013
Current status	Unknown—Literature output 2013
Project summary	This paper provides an overview of issues relevant to the development of unconventional gas – coal seam, shale and tight gas – in the Australian and specifically Victorian context.
Objectives	To provide an introduction and overview of issues relevant to the development of unconventional gas – coal seam, shale and tight gas – in the Australian and specifically Victorian context.
Achievements	<ul style="list-style-type: none"> • An introductory explanation of unconventional gas and the characteristics of coal seam, shale and tight gas. • An overview of some key reports on the coal seam gas industry in Australia and a summary of the issues identified in these reports regarding the potential environmental and social impacts of the industry. • A brief explanation of the current regulatory framework for unconventional gas in Victoria. • Information on developments in the regulation of unconventional gas in Victoria.
Outputs	http://www.parliament.vic.gov.au/publications/research-papers/8927-unconventional-gas-coal-seam-gas-shale-gas-and-tight-gas Catriona R (2013) " <i>Unconventional gas: coal seam gas, shale gas, tight gas. An introduction and overview of issues relevant to the development of unconventional gas in Victoria</i> ". Victoria, Australia: Research Service, Parliamentary Library, Department of Parliamentary Services.
Key personnel	Catriona, Ross
Research themes	Co-produced/mine water, water supplies
Project information source	Literature

Table 4.129 Project 129: Background paper on groundwater resources in relation to coal seam gas production

Project characteristics	Details
Project title	Background paper on groundwater resources in relation to coal seam gas production
Project location	Australia
Principal investigator	Anderson, Doug
Lead institution	University of New South Wales
Project budget	Approximately \$70 000
Source of funding	New South Wales Government
Project duration	May 2013 – November 2013
Current status	Completed
Project summary	The report provides the reader with a background of NSW groundwater and CSG resources and NSW water management practices, the science involved, a concise summary of consequences and risks, and methods for addressing these risks.
Objectives	To provide a background of NSW groundwater and CSG resources and NSW water management practices, the science involved, a concise summary of consequences and risks, and methods for addressing these risks.
Achievements	The final report contains 90 pages of text, tables and figures and approximately 390 references.
Outputs	http://www.chiefscientist.nsw.gov.au/coal-seam-gas-review/csg-background-papers Anderson D, Rahman P, Davey E, Miller B and Glamore W (2014) "Groundwater - technical background paper for NSW Chief Scientist and Engineer".
Key personnel	Anderson, Doug; Rahman, Priom; Davey, Erica; Miller, Brett; Glamore, Will
Research themes	Surface water, co-produced/mine water, hydraulic fracturing, water supplies, water-dependent ecosystems
Project information source	Survey

4.7.3 China

Table 4.130 Project 130: Characteristics of ion concentration in groundwater drainage from coalbed methane wells in Panzhuang of China

Project characteristics	Details
Project title	Characteristics of ion concentration in groundwater drainage from coalbed methane wells in Panzhuang of China
Project location	China
Principal investigator	Ge, Yan-Yan
Lead institution	China University of Mining and Technology
Project budget	Unknown
Source of funding	National Key Basic Research and Development Program (No. 2009CB219605), the Major National Special Science and Technology (No. 2011ZX05034-004), the Xinjiang Uygur Autonomous Region "Tianshan Scholars" Start Fund Projects (No. 11100213)
Project duration	Unknown—Literature output 2014
Current status	Unknown—Literature output 2014
Project summary	<p>Studies on hydro-geochemical system of coalbed methane (CBM) well indicated varied groundwater chemical changes among different gas wells at different time. Change rate (n) and change speed of ion concentration were introduced in the present study to reveal the differences in groundwater chemical characteristics and quantitatively analyze the production of CBM well in Panzhuang region of southern Qinshui Basin, Shanxi, China.</p> <p>Our results showed that there were open boundary and closed boundary two types of coal reservoir water system. The ion change rate in closed coal reservoir water system of CBM wells was higher than that in open coal reservoir water system, so were the change rate and change speed of ion concentration and total dissolved solids (TDS) in the drainage from CBM wells. The introduction of n and of ion concentration is of practical and directive significance to the partition of coal reservoir water system and analysis of groundwater dynamic change during CBM production.</p>
Objectives	To characterise the hydrogeochemistry of groundwater drainage from coalbed methane wells in Panzhuang, China.
Achievements	<p>The study has shown that the coal reservoir water systems can be divided into 2 modes, i.e. closed boundary coal reservoir water system (No. 1 CBM well) and open boundary coal reservoir water system (No. 2 CBM well).</p> <p>Results showed that the ion concentration change rates in No. 1 well were 100 to 1000 times higher than those in No. 2 well.</p>
Outputs	<p>http://www.ejge.com/2014/Ppr2014.364ma.pdf</p> <p>Ge Y-Y, Fu X-H, Sun W-Q and Li S (2014) "Characteristics of ion concentration in groundwater drainage from coalbed methane wells in Panzhuang of China". <i>Electronic Journal of Geotechnical Engineering</i>, 19 P. E-Journal of Geotechnical Engineering.</p>
Key personnel	Ge, Yan-Yan; Fu, Xue-Hai; Sun, Wen-Qing; Li, Sheng
Research themes	Water supplies

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Project characteristics	Details
Project information source	Literature

Table 4.131 Project 131: Evaluation of water environmental quality in Feng Zi Jian mining area based on analytic hierarchy process

Project characteristics	Details
Project title	Evaluation of water environmental quality in Feng Zi Jian mining area based on analytic hierarchy process
Project location	China
Principal investigator	Li, Yan
Lead institution	Department of Surveying and Mapping Science and Technology, College of Mining Engineering, Taiyuan University of Technology, Taiyuan, China
Project budget	Unknown
Source of funding	Unknown
Project duration	Unknown—Literature output 2014
Current status	Unknown—Literature output 2014
Project summary	Owing to a large number of coal mining in Feng Zi Jian mining Area in Da Tong, it leads to many water environmental quality problems. According to the principle of Haiti establishes hierarchical models, creates judgment matrix, counts its weight and maximum eigenvalue from the local to the whole, tests its consistent, analyzes the factors quantitatively which impact Feng Zi Jian mining Area water environmental quality, and makes status evaluation for the quality of water environment of the mine finally. The results show that, AHP is intuitive, effective and has an objective reality during the process of calculating the weights of each factor. It achieves the results of the evaluation with satisfactory.
Objectives	This project aims to make a status evaluation on the environmental problems of water caused by coal spontaneous combustion using an Analytic Hierachy Process (AHP).
Achievements	Application of AHP in the evaluation of the quality of water environment in the Feng Zi Jian mining area.
Outputs	http://dx.doi.org/10.4028/www.scientific.net/AMR.864-867.2350 Li Y, Jia XM and Xing PF (2014) "Evaluation of water environmental quality in Feng Zi Jian mining area based on analytic hierarchy process". 3 rd International Conference on Energy, Environment and Sustainable Development, EESD 2013, November 12, 2013 – November 13, 2013, 864-867. Shanghai, China: Trans Tech Publications Ltd.
Key personnel	Li, Yan; Jia, Xiu Ming; Xing, Peng Fei
Research themes	Co-produced/mine water, water-dependent ecosystems
Project information source	Literature

Table 4.132 Project 132: Coalbed methane produced water in China: status and environmental issues

Project characteristics	Details
Project title	Coalbed methane produced water in China: status and environmental issues
Project location	China
Principal investigator	Meng, YJ
Lead institution	School of Energy Resources, China University of Geoscience; National CBM Engineering Centre, Coal Reservoir Lab
Project budget	Unknown
Source of funding	This work was supported by the Major National Science and Technology Special Projects (Grant Nos. 2011ZX05062-01 and 2011ZX05034-001) and the National Natural Science Foundation Project (Grant No. 41272175).
Project duration	Unknown—Literature output June 2014
Current status	Unknown—Literature output June 2014
Project summary	<p>As one of the unconventional natural gas family members, coalbed methane (CBM) receives great attention throughout the world. The major associated problem of CBM production is the management of produced water. In the USA, Canada, and Australia, much research has been done on the effects and management of coalbed methane produced water (CMPW). However, in China, the environmental effects of CMPW were overlooked.</p> <p>The quantity and the quality of CMPW both vary enormously between coal basins or stratigraphic units in China. The unit produced water volume of CBM wells in China ranges from 10 to 271 280 L/well/day, and the concentration of total dissolved solids (TDS) ranges from 691 to 93 898 mg/L. Most pH values of CMPW are more than 7.0, showing the alkaline feature, and the Na-HCO₃ and Na-HCO₃-Cl are typical types of CMPW in China. Treatment and utilization of CMPW in China lag far behind the USA and Australia, and CMPW is mainly managed by surface impoundments and evaporation.</p> <p>Currently, the core environmental issues associated with CMPW in China are that the potential environmental problems of CMPW have not been given enough attention, and relevant regulations as well as environmental impact assessment (EIA) guidelines for CMPW are still lacking. Other potential issues in China includes:</p> <ul style="list-style-type: none"> • water quality monitoring issues for CMPW with special components in special areas • groundwater level decline issues associated with the de-watering process • potential environmental issues of groundwater pollution associated with hydraulic fracturing.
Objectives	To discuss the environmental issues associated with coalbed methane produced water in China.
Achievements	<p>Provided a literature review of studies investigating the environmental issues associated with coalbed methane produced water (CMPW).</p> <p>Discussed, within a Chinese context, the distribution and development status of CBM resources, quantity and quality of CMPW, the status of CMPW management and environmental challenges associated with CMPW</p>

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Project characteristics	Details
Outputs	http://link.springer.com/article/10.1007%2Fs11356-014-2675-4 Meng YJ, Tang DZ, Xu H, Li Y and Gao LJ (2014). "Coalbed methane produced water in China: status and environmental issues". <i>Environmental Science and Pollution Research</i> , 21 (11).
Key personnel	Meng, YJ; Tang, DZ; Xu, H; Li, Y; Gao, LJ
Research themes	Co-produced/mine water, water supplies, water-dependent ecosystems
Project information source	Literature

4.7.5 Russia

Table 4.133 Project 133: Diagnostics of soils in the areas of abandoned coal mines of Primorskiy Krai

Project characteristics	Details
Project title	Diagnostics of soils in the areas of abandoned coal mines of Primorskiy Krai
Project location	Russia
Principal investigator	Nazarkina, Alina
Lead institution	Far Eastern Federal University
Project budget	\$60 000
Source of funding	The Ministry of Education and Science of Russian Federation
Project duration	4 October 2012 – 30 November 2013
Current status	Completed
Project summary	The main sources of pollution in the area studied are spoil heaps (mine waste), filtering underspoil waters and mine waters discharged on the surface after termination of controlled hydraulic funnel. The study of technogenic landscape of the abandoned mines industrial area showed that its morphologic view is dominated by waste heaps.
Objectives	When mines are abandoned, contaminated mine waters are discharged on the surface. The impact of mine waters on the soil has not been studied recently. The objective of this paper is to study the composition of mine waters from abandoned mines and their impact on soil solutions.
Achievements	The research conducted has shown that by chemical composition the mine waters of abandoned coal mines are a source of environmental contamination. The statistical analysis of the research results showed that mine waters are transforming the chemical composition of soil-water extracts. As our research showed, the chemical composition transformation of soil-water extracts occurs under the impact of waste coal technogenic deposits: pH is varying; sulfides and silicon compounds appear in humus horizon; iron, chrome, copper compounds are accumulated in mineral horizons. Close correlation between the chemical composition of mine waters and the composition of soil solution by some parameters was found.
Outputs	<p>Derbentseva A, Krupskaya L, Arefieva O, Nazarkina A, Orlov A, Morin V and Volobueve N (2013) Analysis and assessment of the environment in the area of abandoned coal mines in Primorsky Region. <i>Applied Mechanics and Materials</i>. Vols. 260–261. pp. 872–875.</p> <p>Arefieva OD, Perfilev AV, Nazarkina AV, Ksenik TV, Yudakov AA and Kondratyeva AA (2013) Using modified perlites to treat mine water of abandoned coal mines in Partizansk city, Primorskiy Krai. <i>Advanced Materials Research</i>. Vols. 726–731. pp. 4041–4044.</p> <p>Nazarkina AV, Arefieva OD, Kadyrova TM, Buyanova LG and Savenkova EM (2013) Impact of mine waters of abandoned coal mine "Avangard" on the environment. <i>Advanced Materials Research</i>. Vol. 807–809. pp. 158–161.</p> <p>Arefieva OD, Nazarkina AV, Gruschakova NV and Sidorova DV (2014) Impact of waste coal on chemical composition of soil solutions in industrial areas of</p>

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Project characteristics	Details
	abandoned coal mines (evidence from Avangard mine, south of the Russian Far East). <i>Applied Mechanics and Materials</i> . Vols. 448–453. pp. 402–405.
Key personnel	Nazarkina, Alina; Arefieva, Olga; Tregubova, Valentina; Perfilev, Alexander; Gruschakova, Natalya; Kondratieva, Anastasia
Research themes	Co-produced/ mine water, water supplies, cumulative impact assessments
Project information source	Survey

4.7.6 United Kingdom

Table 4.134 Project 134: Detection of mixing dynamics during pumping of a flooded coal mine

Project characteristics	Details
Project title	Detection of mixing dynamics during pumping of a flooded coal mine
Project location	United Kingdom
Principal investigator	Elliot, T
Lead institution	Queen's University Belfast
Project budget	Unknown
Source of funding	This work was funded by an Urgency Grant (GR3/13205) from the UK Natural Environment Research Council (NERC).
Project duration	Unknown—Literature output 2014
Current status	Unknown—Literature output 2014
Project summary	<p>In complex hydrogeological environments the effective management of groundwater quality problems by pump-and-treat operations can be most confidently achieved if the mixing dynamics induced within the aquifer by pumping are well understood. The utility of isotopic environmental tracers (C-, H-, O-, S-stable isotopic analyses and age indicators(¹⁴C, H-3) for this purpose is illustrated by the analysis of a pumping test in an abstraction borehole drilled into flooded, abandoned coal mine workings at Deerplay (Lancashire, UK).</p> <p>Interpretation of the isotope data was undertaken conjunctively with that of major ion hydrochemistry, and interpreted in the context of the particular hydraulic setting of flooded mine workings to identify the sources and mixing of water qualities in the groundwater system. Initial pumping showed breakdown of initial water quality stratification in the borehole, and gave evidence for distinctive isotopic signatures (S-34(SO₄) -1.6 parts per thousand, O-18(SO₄) +15 parts per thousand) associated with primary oxidation of pyrite in the zone of water table fluctuation the first time this phenomenon has been successfully characterised by these isotopes in a flooded mine system.</p> <p>The overall aim of the test pumping to replace an uncontrolled outflow from a mine entrance in an inconvenient location with a pumped discharge on a site where treatment could be provided was swiftly achieved. Environmental tracing data illustrated the benefits of pumping as little as possible to attain this aim, as higher rates of pumping induced in-mixing of poorer quality waters from more distant old workings, and/or renewed pyrite oxidation in the shallow subsurface.</p>
Objectives	To provide a rare worked example of the application of environmental tracers to detect groundwater sources and mixing dynamics in a system of large inter-connected underground voids, which could be regarded as a pseudo-karstic system, comprising the abandoned, flooded underground workings of a coal mine.
Achievements	<ul style="list-style-type: none"> Used environmental tracers, integrated with dissolved hydrochemistries, and placed within its hydraulic setting, to follow the dynamics and mixing of water qualities into the Abs Borehole. Established that Sample E reflects a (deeper) water signature unaffected by evaporation but mixed with a water quality (SO₄ 2-) impacted by shallower system waters.

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Project characteristics	Details
Outputs	http://www.ncbi.nlm.nih.gov/pubmed/23557132 Elliot T and Younger PL (2014) "Detection of mixing dynamics during pumping of a flooded coal mine". <i>Ground Water</i> , 52 (2).
Key personnel	Elliot, T; Younger, PL
Research themes	Co-produced/mine water, water supplies, water-dependent ecosystems
Project information source	Literature

Table 4.135 Project 135: Scottish Government: Expert Scientific Panel on Unconventional Oil and Gas

Project characteristics	Details
Project title	Scottish Government: Expert Scientific Panel on Unconventional Oil and Gas
Project location	United Kingdom
Principal investigator	Younger, Paul
Lead institution	Scottish Government
Project budget	\$25 000
Source of funding	Scottish Government – though please note the above is an estimate as all the university staff invited to work on this did so on a pro bono basis. The above is an estimate of Secretariat costs.
Project duration	1 September 2013 – 30 June 2014
Current status	Completed
Project summary	An evaluation was made of the international state-of-the art in the development and use of unconventional gas (shale and CBM) and its social, economic and environmental impacts, related to Scottish conditions.
Objectives	See above
Achievements	Report successfully completed
Outputs	http://www.scotland.gov.uk/Publications/2014/07/1758
Key personnel	Younger, Paul; Stuart, Fin; Waldron, Susan
Research themes	Aquifer interconnectivity, surface water, co-produced/mine water, seismicity, well integrity, hydraulic fracturing, water supplies, water-dependent ecosystems, cumulative impact assessments
Project information source	Survey

4.7.7 United States

Table 4.136 Project 136: Acute toxicity of sodium bicarbonate, a major component of coal bed natural gas produced waters, to 13 aquatic species as defined in the laboratory

Project characteristics	Details
Project title	Acute toxicity of sodium bicarbonate, a major component of coal bed natural gas produced waters, to 13 aquatic species as defined in the laboratory
Project location	USA
Principal investigator	Harper, David D
Lead institution	U.S. Geological Survey
Project budget	Unknown
Source of funding	US Bureau of Land Management and the US Environmental Protection Agency
Project duration	Unknown—Literature output 2014
Current status	Unknown—Literature output 2014
Project summary	<p>Water produced during coal bed natural gas (CBNG) extraction in the Powder River Structural Basin of Wyoming and Montana (USA) may contain concentrations of sodium bicarbonate (NaHCO_3) of more than 3000 mg/L. The authors evaluated the acute toxicity of NaHCO_3, also expressed as bicarbonate (HCO_3^-), to 13 aquatic organisms. Of the 13 species tested, 7 had a median lethal concentration (LC50) less than 2000 mg/L NaHCO_3, or 1300 mg/L HCO_3^-. The most sensitive species were <i>Ceriodaphnia dubia</i>, freshwater mussels (<i>Lampsilis siliquoidea</i>), pallid sturgeon (<i>Scaphirhynchus albus</i>), and shovelnose sturgeon (<i>Scaphirhynchus platyrhynchus</i>). The respective LC50s were 989 mg/L, 1120 mg/L, 1249 mg/L, and 1430 mg/L NaHCO_3, or 699 mg/L, 844 mg/L, 831 mg/L, and 1038 mg/L HCO_3^-.</p> <p>Age affected the sensitivity of fathead minnows, even within life stage. Two days posthatch, fathead minnows were more sensitive to NaHCO_3 and HCO_3^- compared with 4-d-old fish, even though fish up to 14-d-old are commonly used for toxicity evaluations. The authors recommend that ion toxicity exposures be conducted with organisms less than 24h posthatch to ensure that experiments document the most sensitive stage of development. The results of the present study, along with historical and current research regarding the toxicity of bicarbonate, may be useful to establish regulatory standards for HCO_3^-.</p>
Objectives	The purpose of this study is to expand the state of scientific knowledge about the acute sensitivity of multiple aquatic species to NaHCO_3 under controlled, laboratory conditions.
Achievements	The conclusion that acute toxicity exposures to salts should be conducted with the youngest possible organisms to ensure that experiments document the most sensitive stage of development.
Outputs	<p>http://onlinelibrary.wiley.com/doi/10.1002/etc.2452/abstract</p> <p>Harper DD, Farag AM and Skaar D (2014) "Acute toxicity of sodium bicarbonate, a major component of coal bed natural gas produced waters, to 13 aquatic species as defined in the laboratory". <i>Environmental Toxicology and Chemistry</i>, 33 (3). 1010 North 12th Avenue, Pensacola, FL 32501-3367, United States: SETAC Press.</p>

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Key personnel	Harper, David D; Farag, Aida M; Skaar, Don
Research themes	Co-produced/mine water, water supplies, water-dependent ecosystems
Project information source	Literature

Table 4.137 Project 137: Geochemical processes controlling trace elemental mobility in coalbed natural gas (CBNG) disposal ponds in the Powder River Basin, WY

Project characteristics	Details
Project title	Geochemical processes controlling trace elemental mobility in coalbed natural gas (CBNG) disposal ponds in the Powder River Basin, WY
Project location	USA
Principal investigator	Reddy, KJ
Lead institution	University of Wyoming
Project budget	Unknown
Source of funding	We acknowledge some of the funds received for this research from the US Department of Energy National Energy Technology Laboratory under Award Number "DE-FC26-06NT15568" and School of Energy Resources, University of Wyoming, Laramie, WY USA.
Project duration	Unknown—Literature output 2014
Current status	Unknown—Literature output 2014
Project summary	A concern with CBNG produced water disposal ponds is the potential migration of trace elements into the underlying shallow aquifers.
Objectives	The specific objectives of this research were to: <ul style="list-style-type: none"> determine chemistry of CBNG produced water in outfalls and corresponding disposal ponds determine possible leaching of trace elements from the disposal pond sediments into shallow aquifers.
Achievements	<ul style="list-style-type: none"> Geochemistry of CBNG produced water in outfalls and in disposal ponds was examined. Geochemical processes of trace elements in CBNG disposal ponds were discussed. Trace element leaching potential from the sediments of CBNG ponds was discussed.
Outputs	http://www.sciencedirect.com/science/article/pii/S0166516214000032 Reddy KJ, Helmericks C, Whitman A and Legg D (2014) "Geochemical processes controlling trace elemental mobility in coalbed natural gas (CBNG) disposal ponds in the Powder River Basin, WY". In: Wyoming, U. O. (ed.) <i>International Journal of Coal Geology</i> , 126 (0).
Key personnel	Reddy, KJ; Helmericks, C; Whitman, A; Legg, D
Research themes	Co-produced/mine water, water supplies
Project information source	Literature

4.8 Water-dependent ecosystems

This section outlines projects researching the impact of coal seam gas and coal mining on water-dependent ecosystems, such as streams, rivers, floodplains, wetlands, GDEs and peat swamps. This may include response and tolerances of water-dependent ecosystems to changes in water regimes (quantity, seasonal patterns, variability, interactions) and water quality; measures for mitigating impacts and monitoring techniques.

Thirty-nine projects were identified with the primary theme of water-dependent ecosystems, with representation from Australia (28 projects), China (3 projects), India (1 project), the United Kingdom (2 projects) and the United States (5 projects).

4.8.1 Australia

Table 4.138 Project 138: Bioregional Assessment Programme

Project characteristics	Details
Project title	Bioregional Assessment Programme
Project location	Australia
Principal investigator	Australian Government – Department of the Environment (Office of Water Science), Bureau of Meteorology, CSIRO and Geoscience Australia
Lead institution	The bioregional assessments are being delivered through a collaboration between the Department of the Environment, the Bureau of Meteorology, CSIRO and Geoscience Australia
Project budget	Approximately \$85 million
Source of funding	Australian Government – Department of the Environment
Project duration	1 July 2013 – 30 June 2016
Current status	In progress
Project summary	<p>The Bioregional Assessment Programme is one of a number of actions being undertaken by the Australian Government to strengthen the science underpinning decision making on coal seam gas and large coal mining developments.</p> <p>The science-based studies follow a methodology to develop multi-layered records of the natural environment in specific bioregions. The studies are analysing the ecology, hydrology, geology and hydrogeology of bioregions, with explicit assessment of potential direct, indirect and cumulative impacts on water resources both above and below ground. In general, the findings are at a community level, rather than on a property basis.</p> <p>Products from the bioregional assessments include compilations of relevant data, descriptions of coal resources, lists of water-dependent assets, conceptual models, diagrams of water balances, outputs of numerical and analytical models, lists of possible risks and their likelihoods, and descriptions of the possible impacts of coal seam gas and coal mining developments on water resources.</p>
Objectives	The objective of the Bioregional Assessment Programme is to strengthen the understanding of the potential impacts of coal seam gas and large coal mining developments on water-dependent assets. The Programme is making analysis, data and methodologies publicly available, so that all interested parties are able to access the results of the assessments.

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
	Over the period to June 2016, assessments will be undertaken in 13 subregions with six bioregions with significant coal deposits across Central and Eastern Australia.
Achievements	See http://www.bioregionalassessments.gov.au
Outputs	For a list of outputs go to: http://www.bioregionalassessments.gov.au/products.shtml
Key personnel	Listed in each product published
Research themes	Aquifer interconnectivity, surface water, co-produced/mine water, water-dependent ecosystems, cumulative impact assessments
Project information source	Survey

Table 4.139 Project 139: Hydrogeological characterisation of Temperate Highland Peat Swamps on Sandstone on the Newnes Plateau

Project characteristics	Details
Project title	Hydrogeological characterisation of Temperate Highland Peat Swamps on Sandstone on the Newnes Plateau
Project location	Australia
Principal investigator	Corbett, Peter
Lead institution	Centennial Coal
Project budget	\$200 000
Source of funding	Centennial Coal
Project duration	1 March 2014 – 5 May 2014
Current status	Completed
Project summary	Investigations were conducted to describe the hydrogeological characteristics of THPSSs located on the Newnes Plateau.
Objectives	The purpose of these investigations was to ascertain the coincident characteristics that lead to THPSS formation and then understand the sensitivity of those characteristics to mine subsidence behaviour. This paper discusses the investigative process and its findings.
Achievements	A robust model has been prepared for several THPSS on the Newnes Plateau, based on a synthesis of topographic, geological, hydrological and ecosystem data
Outputs	Corbett P, White E and Kirsch B (2014) Hydrogeological characterisation of Temperate Highland Peat Swamps on Sandstone on the Newnes Plateau. Proceedings of the 9 th Triennial Conference on Mine Subsidence, 2014.
Key personnel	Corbett, Peter; White, Edwina; Kirsch, Bernard
Research themes	Water-dependent ecosystems
Project information source	Survey

Table 4.140 Project 140: The geology of the shrub swamps within Angus Place, Springvale and the Springvale Mine Extension project areas

Project characteristics	Details
Project title	The geology of the shrub swamps within Angus Place, Springvale and the Springvale Mine Extension project areas
Project location	Australia
Principal investigator	McHugh, Elizabeth
Lead institution	Centennial Coal
Project budget	\$50 000
Source of funding	Centennial Coal
Project duration	1 July 2014 – Unknown
Current status	In progress
Project summary	Synthesis of topographic, geological, hydrological and ecosystem data to characterise the hydrogeology of individual THPSS on the Newnes Plateau.
Objectives	Characterisation of the hydrogeology of individual THPSS on the Newnes Plateau. This will also enable understanding of key aquifer systems which supply groundwater to THPSS on the Newnes Plateau.
Achievements	A robust hydrogeological model has been prepared for several THPSS on the Newnes Plateau, which assists in understanding of formation of THPSS and associated hydrological processes.
Outputs	Interim Report "Geology of the shrub swamps within Angus Place, Springvale & Springvale Extension Areas" available on www.planning.nsw.gov.au under Springvale Mine Extension Project as Appendix to Response to Submissions
Key personnel	McHugh, Elizabeth
Research themes	Water-dependent ecosystems
Project information source	Survey

Table 4.141 Project 141: Tool to assess mining impacts on river condition C21031

Project characteristics	Details
Project title	Tool to assess mining impacts on river condition C21031
Project location	Australia
Principal investigator	Sellens, Claire
Lead institution	Central Queensland University
Project budget	\$325 945
Source of funding	Australian Coal Association Research Program (ACARP)
Project duration	2013 – November 2014
Current status	In progress
Project summary	The management of mining impacts on rivers and other aquatic ecosystems at a local and regional level is a key priority for the coal industry. The industry needs to be able to accurately monitor and assess its onsite and downstream impacts on water quality. Existing guidelines and predictive models for river health are not suitable for assessing mine site impacts because they are typically determined from steady state conditions. This project is developing a region specific tool for assessing the condition of temporary streams on Central Queensland mines. Changes to the macroinvertebrate communities during the wet and dry cycles are being examined to determine the effect of change on aquatic health assessments, a predictive modelling tool for assessing river health is being developed, and the feasibility of alternative approaches to assessing the health of streams is being explored.
Objectives	This purpose of this project is to develop an AUSRIVAS style predictive model for the Bowen Basin. This project is developing a region specific tool for assessing the condition of temporary streams on Central Queensland mines.
Achievements	All field work is now complete and all macroinvertebrate samples have been analysed and checked. Field and climate data has been collected but still need to be checked for accuracy. Final models are being prepared.
Outputs	Report expected at the end of 2014. http://www.acarp.com.au/Media/ACARPCurrentProjectsReport.pdf Sellens C (2013) "Tool to assess mining impacts on river condition". (C21031).
Key personnel	Sellens, Claire
Research themes	Water-dependent ecosystems
Project information source	ACARP website

Table 4.142 Project 142: Temperate Highland Peat Swamps on Sandstone: ecological characteristics, sensitivities to change, and monitoring and reporting techniques

Project characteristics	Details
Project title	Temperate Highland Peat Swamps on Sandstone: ecological characteristics, sensitivities to change, and monitoring and reporting techniques
Project location	Australia
Principal investigator	Jacobs/Sinclair Knight Merz Pty Ltd
Lead institution	Jacobs/Sinclair Knight Merz Pty Ltd; Australian Government – Department of the Environment (Office of Water Science)
Project budget	\$436 595 (GST inclusive)
Source of funding	Australian Government – Department of the Environment
Project duration	2012 – 2014
Current status	Completed
Project summary	<p>The 'Temperate Highland Peat Swamps on Sandstone' ecological community consists of both temporary and permanent swamps developed in peat overlying Triassic Sandstone formations at high elevations, generally between 600 to 1200 m above sea level. This ecological community is largely located in the Sydney geological basin in NSW. The Temperate Highland Peat Swamps on Sandstone are listed as a Threatened Ecological Community under the <i>Environment Protection and Biodiversity Conservation Act 1999</i> (EPBC Act), and are also listed as endangered under the <i>NSW Threatened Species Conservation Act 1995</i> (TSC Act).</p> <p>This report is the first report in a series of three focussed on peat swamps and longwall coal mining, commissioned by the Office of Water Science, on the advice of the Interim Independent Expert Scientific Committee on Coal Seam Gas and Coal Mining.</p> <p>The project reviewed and synthesised existing knowledge of peat swamps, used expert opinion to model potential impacts from longwall mining, and proposed a monitoring and reporting framework.</p> <p>This report provides recommendations for ecological monitoring of impacts to the swamps. The intended audience for the report includes aquatic ecosystem researchers, government agencies involved with regulation of coal mining, and mining companies whose operations may impact on peat swamps.</p> <p>Project tasks included:</p> <ul style="list-style-type: none"> • a literature review of information on the ecology, geology, hydrogeology and hydrology of the peat swamp community. This review established three conceptual models that broadly characterise the peat swamps: headwater swamps, valley infill swamps, and hanging swamps • modelling the sensitivity of the swamps to impacts from longwall mining, using a Bayesian Belief Network (BBN). BBNs were developed for each conceptual model, and for the community as a whole as well as a selection of species of flora and fauna found within the swamps. The models indicated which effect from longwall mining was likely to have the greatest impact on the peat swamps • evaluating monitoring techniques that can be used to identify impacts to the swamps, and recommending (and scoping) monitoring and reporting

Project characteristics	Details
	<p>approaches to be adopted by mining proponents. The techniques primarily focus on monitoring of ecological impacts to the peat swamps.</p> <p>This report provides an overview and conceptualisation of upland peat swamps, and analyses the sensitivity of upland peat swamp communities and species to changes in environmental processes as a result of longwall coal mining impacts. It evaluates monitoring techniques, provides recommendations on monitoring programs and methods, and identifies knowledge gaps.</p>
Objectives	<p>The objectives of this project were to:</p> <ul style="list-style-type: none"> • provide a hydrological and geological characterisation of the peat swamp communities • model the sensitivity of the swamps to changes in the surface and groundwater flows, and changes in water quality, caused by longwall mining • advise on the development of a monitoring and reporting approach for detecting the potential impacts of longwall mining on the swamps.
Achievements	<p>Key findings are listed below.</p> <ul style="list-style-type: none"> • The THPSS ecological community can be categorised and described using three conceptual types: headwater swamps, valley infill swamps and hanging swamps. • Bayesian belief network (BBN) modelling was used to model the sensitivity of these swamp types to environmental change. The BBN modelling showed that ecological sensitivity was most strongly influenced by an altered inundation regime. • A monitoring programme that aims to identify impacts early so that management can be adapted must focus on the subsidence or hydrological impacts since these precede any ecological response. • Information linking subsidence effects to ecological impacts is limited, with little information that specifically describes how swamp ecology responds to changes in the surrounding environment. • In light of this, a multiple before–after control–impact (M-BACI) approach to monitoring swamp ecology is proposed as an appropriate basis for designing an ecological monitoring programme. • A monitoring programme that is capable of detecting impacts to the swamps and attributing the impacts to a specific cause (e.g. longwall coal mining) must incorporate three phases of monitoring, with associated reporting: <ul style="list-style-type: none"> – Phase 1—baseline characterisation – Phase 2—assessment of risks – Phase 3—ongoing impact monitoring.
Outputs	<p>Published on the Australian Government – Department of the Environment website and the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) website.</p> <ul style="list-style-type: none"> • Commonwealth of Australia (2014) <i>Temperate Highland Peat Swamps on Sandstone: ecological characteristics, sensitivities to change, and monitoring and reporting techniques, Knowledge report</i>, prepared by Jacobs SKM for the Department of the Environment, Commonwealth of Australia, Canberra. http://www.environment.gov.au/water/publications/temperate-highland-peat-swamps-sandstone-ecological-characteristics
Key personnel	Jacobs/Sinclair Knight Merz Pty Ltd

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Research themes	Water-dependent ecosystems
Project information source	Survey

Table 4.143 Project 143: Temperate Highland Peat Swamps on Sandstone: longwall mining engineering design – subsidence prediction, buffer distances and mine design options

Project characteristics	Details
Project title	Temperate Highland Peat Swamps on Sandstone: longwall mining engineering design – subsidence prediction, buffer distances and mine design options
Project location	Australia
Principal investigator	Coffey Geotechnics
Lead institution	Coffey Geotechnics; Australian Government – Department of the Environment (Office of Water Science)
Project budget	Approx. \$274 725 (GST inclusive)
Source of funding	Australian Government – Department of the Environment
Project duration	2012 – 2014
Current status	Completed
Project summary	<p>This report is the second report in a series of three focussed on peat swamps and longwall coal mining, commissioned by the Office of Water Science, on the advice of the Interim Independent Expert Scientific Committee on Coal Seam Gas and Coal Mining.</p> <p>The report provides scientific advice to the Department of the Environment about subsidence from longwall mining that may impact temperate peat swamps in the Southern and Western Coalfields of NSW, based on a review of national and international knowledge relevant to peat swamps. It addresses the following priority research areas identified by the Interim Committee:</p> <ul style="list-style-type: none"> • predicting subsidence-related impacts on peat swamps from longwall mining • engineering and mine design, particularly in terms of longwall orientation and dimensions, and the relationships between mine design and potential subsidence risks • defining appropriate buffer distances and standoff distance between longwall panels and high conservation value aquatic ecosystems. <p>This report is focused on peat swamps, the physical impacts of longwall mining on the rock strata that underlies these swamps, the potential for impacts on groundwater systems, and the opportunities for management of the impacts through prediction, engineering intervention (including mine design and provision for suitable buffers), mitigation and remediation. Recommendations for further work are also presented. It reviews published national and international experience and includes a review of the mechanics of the subsidence processes involved.</p> <p>The first part of the report characterises the three types of peat swamps that are regarded as being representative of the broad spectrum of peat swamps that exist in areas where there is, has been, or is planned to be longwall mining activity. These are:</p> <ul style="list-style-type: none"> • headwater swamps • valley infill swamps • hanging swamps. <p>The report then presents an overview of the geology of the Southern and Western Coalfields, and peat swamp locations, and describes longwall mining</p>

Project characteristics	Details
	<p>techniques and subsidence behaviour as measured around longwall panels. Both vertical subsidence and horizontal movements are discussed, as well as the caving processes that cause disturbance to the overburden strata. A conceptual model of ground behaviour is described, based on a review of the subsidence and subsurface data presented, and the experience of subsidence-related impacts on peat swamps and river channels is discussed in association with the understanding of pre-mining groundwater conditions within and beneath peat swamps.</p> <p>Finally, techniques to predict vertical subsidence are discussed, along with monitoring techniques to help assess subsidence and its impact on peat swamps, and techniques to manage the impacts of longwall mining on peat swamps. Preliminary guidelines to assess potential subsidence impacts to peat swamps are provided. The report concludes with recommendations for further work.</p>
Objectives	<p>The purpose of this project is to provide scientific advice to the Department of the Environment about subsidence from longwall mining that may impact temperate peat swamps in the Southern and Western coalfields of NSW, based on a review of national and international knowledge relevant to peat swamps.</p>
Achievements	<p>Key findings within the report are listed below.</p> <ul style="list-style-type: none"> • The subsidence-related ground movements most likely to impact peat swamps are associated with fracturing of the rock strata that lie directly beneath swamps and drawdown of near-surface groundwater levels. • Where peat swamps occur in areas of topographic relief, subsidence movements associated with conventional or systematic subsidence behaviour tend to be overshadowed by the effects of horizontal subsidence movements that are collectively called 'valley closure effects'. • This report proposes using thresholds of tensile and compressive horizontal strain as the basis for buffer or stand-off distances between longwall mining and peat swamps. • Trigger action response plans (TARPs) are widely used in the underground coalmining industry; however, the difficulty of quickly finding suitable parameters to indicate impacts on peat swamps makes TARPs ineffective for managing the impacts of longwall mining on peat swamps. • Provided adequate planning occurs based on knowledge of peat swamps to be protected, mine layouts can be modified by adjusting the length and, in some circumstances, the width of individual longwall panels to change the magnitude and nature of surface movements, and therefore mitigate impacts on peat swamps.
Outputs	<p>Published on the Australian Government – Department of the Environment website and the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) website.</p> <ul style="list-style-type: none"> • Commonwealth of Australia (2014) <i>Temperate Highland Peat Swamps on Sandstone: longwall mining engineering design—subsidence prediction, buffer distances and mine design options, Knowledge report</i>, prepared by Coffey Geotechnics for the Department of the Environment, Commonwealth of Australia, Canberra. <p>http://www.environment.gov.au/water/publications/temperate-highland-peat-swamps-sandstone-longwall-mining-engineering</p>
Key personnel	Coffey Geotechnics
Research	Water-dependent ecosystems, mitigation measures

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
themes	
Project information source	Survey

Table 4.144 Project 144: Temperate Highland Peat Swamps on Sandstone: mitigation and remediation techniques

Project characteristics	Details
Project title	Temperate Highland Peat Swamps on Sandstone: mitigation and remediation techniques
Project location	Australia
Principal investigator	Glamore, William
Lead institution	Water Research Laboratory, University of New South Wales; Australian Government – Department of the Environment (Office of Water Science)
Project budget	\$176 000 (GST inclusive)
Source of funding	Australian Government – Department of the Environment
Project duration	2012 – 2014
Current status	Completed
Project summary	<p>This report is the final in a series of three reports focussed on peat swamps and longwall coal mining, commissioned by the Office of Water Science, on the advice of the Interim Independent Expert Scientific Committee on Coal Seam Gas and Coal Mining.</p> <p>The report provides background information on upland peat swamps and longwall mining, as well as details of recorded attempts at remediation. Where possible, the original references have been provided to avoid duplication of citations or excessive cross-citations.</p>
Objectives	To provide background information on upland peat swamps and longwall mining, as well as details of recorded attempts at remediation.
Achievements	<p>Key points identified within the report include:</p> <ul style="list-style-type: none"> • longwall mining beneath upland peat swamps may fracture the sandstone substrate and alter the swamp's water balance. To date, no strategies—other than changes in mine plan layout—have been proven to effectively mitigate longwall mining impacts • remediation strategies in regions affected by longwall mining are primarily designed to restore the hydrological regime. To date, on-ground remediation strategies have focussed on sealing fracture networks on cracked stream beds and have not addressed fractures occurring beneath peat sediments. No examples were found of upland peat swamps impacted by longwall mining that have been remediated • direct remediation to combat vertical seepage beneath upland peat swamps has not been attempted. Existing remediation techniques are unproven and appear insufficient without the destruction of the surface environment.
Outputs	<p>Published on the Australian Government – Department of the Environment website and the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) website.</p> <ul style="list-style-type: none"> • Commonwealth of Australia (2014) <i>Temperate Highland Peat Swamps on Sandstone: evaluation of mitigation and remediation techniques, Knowledge report</i>, prepared by the Water Research Laboratory, University of New South Wales, for the Department of the Environment, Commonwealth of Australia. http://www.environment.gov.au/water/publications/temperate-highland-peat-

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
	swamps-mitigation
Key personnel	Glamore, William; Davey, Erica; Smith, Grantley
Research themes	Groundwater-dependent ecosystems
Project information source	Survey

Table 4.145 Project 145: The spatial distribution, geomorphic evolution and genetic biodiversity of upland swamps in Eastern Australia: Implications for protecting these endangered ecosystems

Project characteristics	Details
Project title	The spatial distribution, geomorphic evolution and genetic biodiversity of upland swamps in Eastern Australia: Implications for protecting these endangered ecosystems
Project location	Australia
Principal investigator	Fryirs, Kirsty; Hose, Grant
Lead institution	Macquarie University
Project budget	\$40 000
Source of funding	Macquarie University Research and Development Grant
Project duration	1 July 2010 – 30 June 2014
Current status	Completed
Project summary	Upland swamps provide key services of regulating water quality and quantity in catchments. We have identified critical knowledge gaps of swamp evolution and biodiversity that are limiting swamp management and research progress. It is the aim of this project to provide basic knowledge on the spatial distribution, evolutionary formation and genetic biodiversity in these endangered ecosystems. Addressing these questions will provide foundational data for improved management and rehabilitation of upland swamps.
Objectives	<p>Aim 1: What types of upland swamps are prevalent in Eastern Australia and what are the threshold conditions under which they are formed?</p> <p>Aim 2: What is the geomorphic evolution of these upland swamp and how long have they been functioning as landscape sponges and filters?</p> <p>Aim 3: What is the genetic biodiversity of macroinvertebrate communities in these groundwater systems and can this be related to the geomorphic evolution of these systems?</p>
Achievements	Publications
Outputs	<p>Fryirs K, Freidman B, Williams R and Jacobsen G (2014) Peatlands in Eastern Australia? Sedimentology and age structure of Temperate Highland Peat Swamps on Sandstone (THPSS) in the Southern Highlands and Blue Mountains of NSW, Australia. <i>The Holocene</i>. 24(11), 1527–1538.</p> <p>Fryirs K, Gough J and Hose G (2014) The geomorphic character and hydrological function of an upland swamp, Budderoo Plateau, Southern Highlands, NSW, Australia. <i>Physical Geography</i>. 35:4, 313–334.</p> <p>Hose GC, Bailey J, Stumpp C and Fryirs K (in press) Groundwater depth and topography correlate with vegetation structure of an upland peat swamp, Budderoo Plateau, NSW, Australia. <i>Ecohydrology</i>.</p> <p>Freidman BL and Fryirs KA (in press) Rehabilitating upland swamps using environmental histories: a case study of the Blue Mountains Peat Swamps, Eastern Australia. <i>Geographiska Annaler: Series A, Physical Geography</i>.</p> <p>Ashby N, Fryirs K and Howitt R (in press) Prospects for, and challenges of, research design and training in cross-disciplinary environmental management research. <i>Geographical Research</i>.</p> <p>Kohlhagen T, Fryirs K and Semple AL (2013) Highlighting the need and potential</p>

Project characteristics	Details
	<p>for use of interdisciplinary science in adaptive environmental management: the case of endangered upland swamps in the Blue Mountains, NSW, Australia. <i>Geographical Research</i>. 51(4), 439–453.</p> <p>Ashby N, Fryirs K and Howitt R (2014) Adaptive management of Temperate Highland Peat Swamps on Sandstone in the Blue Mountains: Is it occurring? In Vietz G, Rutherford ID and Hughes R (editors) Proceedings of the 7th Australian Stream Management Conference. Townsville, Queensland, pp. 378–384.</p> <p>Fryirs K, Freidman B, Williams R, Jacobsen G and Hose G (2014) Developing a model of upland swamp structure, function and evolution for biodiversity conservation and rehabilitation: the case of threatened Temperate Highland Peat Swamps on Sandstone (THPSS), In Vietz G, Rutherford ID and Hughes R (editors) Proceedings of the 7th Australian Stream Management Conference. Townsville, Queensland, pp. 262–267.</p> <p>Fryirs K, Freidman B and Kohlhagen T (2012) The formation and geomorphic condition of upland swamps in the Blue Mountains: Implications for the rehabilitation of these endangered ecosystems, In Grove JR and Rutherford ID (editors) Proceedings of the 6th Australian Stream Management Conference. Managing for Extremes. 6–8 February 2012, Canberra, Australia. Published by the River Basin Management Society, Melbourne. pp. 574–580.</p>
Key personnel	Fryirs, Kirsty; Hose, Grant; Freidman, Benjamin; Kohlhagen, Trent
Research themes	Groundwater-dependent ecosystems
Project information source	Survey

Table 4.146 Project 146: A multi-criteria evaluation of water management for sustainable development in mining

Project characteristics	Details
Project title	A multi-criteria evaluation of water management for sustainable development in mining
Project location	Australia
Principal investigator	Zhang, Xiangfeng
Lead institution	CSIRO
Project budget	Unknown
Source of funding	Australian Coal Association Research Program (ACARP), CSIRO, Shanghai Municipal Science and Technology Commission (No.11DZ1200207), Innovation Program of Shanghai Municipal Education Commission (NO.13YZ139, 12YZ186).
Project duration	Unknown—Literature output 2013
Current status	Unknown—Literature output 2013
Project summary	Mining is a water intensive activity. Mining companies are expected to bear responsibility for their impacts on water resources. Mine water management is a significant issue for sustainable development to maximise shareholder's value, secure production, and minimise environmental impacts. The identification of sustainable mining water management practices is technically challenging because of the lack of scientific tools available to evaluate optimal decisions. The paper proposes a multi-criteria evaluation method that aims at selecting reasonable water management practices for sustainable development in mining. The method is based on the analytic hierarchy process (AHP) together with a technique for order preference by similarity to ideal solution (TOPSIS). Water must be managed at all stages of the life cycle of mining operations. However, the focus in this paper is the evaluation of mine water management practices at the mine operating stage. A decision hierarchy and a criterion set for assessing sustainability of mine water management were proposed, and used to evaluate management practices in a number of coal mines in the Bowen Basin. The AHP method was used to determine the weights of evaluative criteria. The ranking of the mine water management practices was calculated with the fuzzy TOPSIS method. The evaluation results illustrate the usefulness of the proposed method in identifying leading mine water management practices. Finally, some management implications were derived from the work to improve water management towards a more sustainable mining industry.
Objectives	This paper presents a case study of the evaluation of sustainable water management practices in six mines located in the Bowen Basin.
Achievements	The application of a multi-criteria evaluation method that aims at selecting reasonable water management practices for sustainable development in mining.
Outputs	http://www.mssanz.org.au/modsim2013/A11/zhang.pdf Zhang X, Gao L, Barrett D and Chen Y (2013) "A multi-criteria evaluation of water management for sustainable development in mining". MODSIM2013, 20 th International Congress on Modelling and Simulation. Adelaide: Modelling and Simulation Society of Australia and New Zealand
Key personnel	Zhang, Xiangfeng; Gao, Lei; Barrett, Damian; Chen, Yun

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Research themes	Water-dependent ecosystems
Project information source	Literature

Table 4.147 Project 147: Secure mine water use with compliant discharge

Project characteristics	Details
Project title	Secure mine water use with compliant discharge
Project location	Australia
Principal investigator	Gao, Lei
Lead institution	CSIRO
Project budget	Unknown
Source of funding	Australian Coal Association Research Program project 51088 and CSIRO Water for a Healthy Country Flagship
Project duration	Unknown—Literature output December 2013
Current status	Unknown—Literature output December 2013
Project summary	<p>Rapidly increasing production, intensifying competition with other water users, and significant climate variability have been leading the mining industry to face challenges in securing water use. Mine water systems must be managed to achieve dual competing goals:</p> <ul style="list-style-type: none"> • water security at a quality that is ‘fit-for-purpose’ during water limited periods • ensuring compliant discharge from mine sites when water is in excess (a “dual goal problem”). <p>These goals are mutually exclusive and, under current mine water management strategies, may lead to significant external environmental impacts expressed through unregulated discharge of worked water during excess supply periods. The paper aims to address the external environmental impacts caused by mine water discharge through improved water management and securing water use. We embed a simulator of mine water use within a multi-objective optimisation scheme in order to solve this “dual goal problem”. The simulator is built based on the advances in the Australian Water Accounting Framework, accounting for generating state variables, or objective indicators, for a multi-objective optimiser to evaluate candidate solutions. The trade-offs are presented between two conflicting objectives – securing water for mine production and minimising unregulated discharge during this period.</p> <p>The results show that the proposed approach offers a tool capable of developing objectives and providing scientific basis to advise industry and government on policy development associated with water management and discharge regulations.</p>
Objectives	The study aims to examine the feasibility of a solution suggesting that actively regulated discharge can be used to reduce the risk of occurrence of unregulated discharge.
Achievements	Evaluation of the effect of actively regulated discharge on diminishing unregulated discharges caused by overflows from the worked water store.
Outputs	<p>http://www.mssanz.org.au/modsim2013/A11/gao2.pdf</p> <p>Gao L, Barrett D, Chen Y, Zhang X, Cuddy S, Zhou M, Paydar Z and Renzullo L (2013) "Secure mine water use with compliant discharge". MODSIM2013, 20th International Congress on Modelling and Simulation. Adelaide, South Australia: Modelling and Simulation Society of Australia and New Zealand.</p>
Key personnel	Gao, Lei; Barrett, Damian; Chen, Yun; Zhang, Xiangfeng; Cuddy, Susan; Zhou, Mingwei; Paydar, Zahra; Renzullo, Luigi

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Research themes	Water-dependent ecosystems
Project information source	Literature

Table 4.148 Project 148: Enhanced groundwater modelling – Coal seam gas and large coal mines

Project characteristics	Details
Project title	Enhanced groundwater modelling – Coal seam gas and large coal mines
Project location	Australia
Principal investigator	Unknown
Lead institution	Department of Primary Industries (NSW Government); NSW Office for Water (NSW Government); NICTA
Project budget	Unknown
Source of funding	Unknown
Project duration	Unknown – end 2014
Current status	In progress
Project summary	<p>This project will combine groundwater data from a range of sources using new methods to develop more sophisticated groundwater models in terms of predictions including the potential risks associated with assessing and monitoring coal seam gas (CSG) exploration and large coal mining (LCM) developments. The overall aim of this project is to bring all useful groundwater data together into a single integrated model to enable ‘best science-based’ groundwater decision making. While the project will include and process existing information about NSW groundwater systems and activities, the results of the modelling will also help identify areas where more work can be done including the type, extent and location where more useful or additional data is required.</p> <p>This project is currently in the research phase, it is hoped that it will eventually provide an accurate risk-based assessment of current and future groundwater activities in NSW. The approach used in this project differs from other modelling techniques because it uses “machine learning” and “data fusion”.</p>
Objectives	<p>The primary aim of this project is to improve existing groundwater modelling and prediction capabilities undertaken by the Office of Water to ensure that decisions in relation to the assessment, approval and monitoring of CSG and LCM proposals and developments are based on accurate information. By combining groundwater information from a wide range of sources, such as the comprehensive Namoi Water Study, with the data already collected through the Office of Water’s regional groundwater monitoring network, the project will be able to provide better information of potential groundwater impacts. The project will also help identify where there is a lack of information in the existing regional groundwater monitoring network.</p>
Achievements	For a list of achievements refer to: http://www.water.nsw.gov.au/Water-Management/Modelling/default.aspx
Outputs	http://www.water.nsw.gov.au/Water-Management/Modelling/default.aspx
Key personnel	Unknown
Research themes	Co-produced water, water impacts
Project information source	Website

Table 4.149 Project 149: Ecological and hydrological survey of the Great Artesian Basin springs - Springsure, Eulo, Bourke and Bogan River supergroups – Volume 1 History, ecology and hydrogeology, and Volume 2 Hydrogeological profiles

Project characteristics	Details
Project title	Ecological and hydrological survey of the Great Artesian Basin springs - Springsure, Eulo, Bourke and Bogan River supergroups Volume 1 History, ecology and hydrogeology Volume 2 Hydrogeological profiles
Project location	Australia
Principal investigator	UniQuest
Lead institution	UniQuest; Australian Government – Department of the Environment (Office of Water Science)
Project budget	Approx. \$500 000 (GST inclusive)
Source of funding	Australian Government – Department of the Environment
Project duration	2012 – 2014
Current status	Completed
Project summary	<p>These reports deal with the surveys of 848 springs; 252 in the Great Artesian Basin (GAB) Springsure supergroup, 436 in the Eulo, 145 in the Bourke, and seven in the Bogan River supergroup. Included are all the likely <i>Environment Protection and Biodiversity Conservation Act 1999</i> (EPBC Act) listed springs. A further eight spring locations in the Eulo, Bourke and Bogan River supergroups, and 105 in the Springsure supergroup have not yet been surveyed but are considered unlikely to be EPBC Act related.</p> <p>The project team surveyed 503 springs in 94 spring-complexes that had not previously been surveyed, and extended the current knowledge base of other previously surveyed springs.</p> <p>Volume 1 of this report is divided into two main sections:</p> <ul style="list-style-type: none"> • Part 1 - Cultural history and ecological values of GAB springs in the Springsure, Eulo, Bourke and Bogan River supergroups, which provides information on the history and ecology of the spring supergroups. • Part 2 - Hydrogeological survey of the GAB Springs in the Springsure, Eulo, Bourke and Bogan River supergroups. This part provides information on the hydrogeology of the spring supergroups, including identification of source aquifers and an analysis of the potential impacts of coal seam gas development on the springs. <p>Volume 2 of this project report includes a database of GAB springs and hydrogeological profiles for springs with both a high conservation ranking and EPBC Act listing in the targeted supergroups.</p>
Objectives	<p>For each spring supergroup, Volume 1 of this report aimed to:</p> <ul style="list-style-type: none"> • assess the location and status of all springs mentioned in historical sources • record the history and cultural values of springs • assess their contemporary biological values, and • determine any signs of recovery with bore capping and potential for habitat restoration. <p>Volume 2 of this report aimed to identify and tabulate the geology, regional</p>

Project characteristics	Details
	stratigraphy and underlying aquifers, water chemistry and artesian status of potential source aquifers with reference to figures and other data, for each spring.
Achievements	The project team surveyed 503 springs in 94 spring complexes that had not previously been surveyed, and extended the current knowledge base of other previously surveyed springs. All 92 EPBC Act-listed discharge springs in the Springsure supergroup were surveyed.
Outputs	<p>Published on the Australian Government – Department of the Environment website and the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) website.</p> <ul style="list-style-type: none"> Report Volume 1 http://www.environment.gov.au/water/publications/great-artesian-basin-springs-survey-vol-1 Commonwealth of Australia (2014) <i>Ecological and hydrogeological survey of the Great Artesian Basin springs - Springsure, Eulo, Bourke and Bogan River supergroups. Volume 1: history, ecology and hydrogeology, Knowledge report</i>, prepared by UniQuest for the Department of the Environment, Commonwealth of Australia, Canberra. Report Volume 2 http://www.environment.gov.au/water/publications/great-artesian-basin-springs-survey-vol-2 Commonwealth of Australia (2014) <i>Ecological and hydrogeological survey of the Great Artesian Basin springs - Springsure, Eulo, Bourke and Bogan River Supergroups. Volume 2: hydrogeological profiles, Knowledge report</i>, prepared by UniQuest for the Department of the Environment, Commonwealth of Australia, Canberra.
Key personnel	Australian Government – Department of the Environment; University of Queensland (UniQuest) – Fensham, Rod; Esterle, Joan; Vink, Sue; Wolhuter, Alexandra; Silcock, Jennifer; Hines, Kimberley; Drimer, Jeremy
Research themes	Water-dependent ecosystems
Project information source	Survey

Table 4.150 Project 150: Modelling water-related ecological responses to coal seam gas extraction and coal mining

Project characteristics	Details
Project title	Modelling water-related ecological responses to coal seam gas extraction and coal mining
Project location	Australia
Principal investigator	Auricht Projects
Lead institution	Auricht Projects; Australian Government – Department of the Environment (Office of Water Science)
Project budget	\$200 000
Source of funding	Australian Government – Department of the Environment
Project duration	1 March 2014 – January 2015
Current status	In progress
Project summary	<p>Ecological conceptual models are rarely used in Environmental Impact Statements (EISs) for coal seam gas extraction and coal mining proposals in Australia. In contrast, hydrological and hydrogeological conceptual models are well-established tools for identifying and assessing potential impacts of development projects. There is a need to integrate current hydrological and hydrogeological conceptual models with ecological ones to provide a complete picture of the likely water-related ecological impacts of coal seam gas extraction and coal mining. These combined models should then be used in EISs to support statements of likely ecological responses to coal seam gas extraction and coal mining, and to illustrate mechanisms by which proposed mitigation strategies would operate to reduce potential impacts.</p> <p>This report presents the findings of a project exploring an approach to ecological conceptual modelling aimed at improving the assessment of water-related ecological impacts of coal seam gas extraction and coal mining. The approach, presented as a series of consecutive steps and illustrated with worked examples, could assist those preparing and reviewing EISs to construct ecological conceptual models and associated narrative tables that specify hypothesised responses, and document supporting evidence. By using this approach, assumptions about ecological impacts in assessment of development proposals are made explicit, response pathways are identified and illustrate interactive and cumulative effects, and there is a transparent and consistent framework for design of monitoring programmes to test the implicit hypotheses.</p>
Objectives	The purpose of this project was to examine how ecological conceptual models could be used to improve current methods of assessment of the water-related ecological impacts of coal seam gas extraction and coal mining. Specifically, the project aimed to find the most feasible approach for developing ecological conceptual models to support this assessment process, trial the approach as a 'proof-of-concept' using a case study in the Clarence Moreton Basin, and discuss the models and results with scientific experts at a facilitated workshop that included a field visit to the case study area.
Achievements	A key conclusion of the report is that the approaches to modelling and conceptualisation of hydrology and hydrogeology currently used in EISs should be extended to incorporate ecological components to produce ecohydrological models capable of illustrating likely water-related ecological responses to coal seam gas extraction and coal mining. Given that nearly all stressors interact,

Project characteristics	Details
	<p>they should not be treated independently when assessing likely responses. Despite the challenges, the approach outlined in this report seeks to provide proponents of development proposals with the tools to better portray and understand the hydrology-ecology relationships in areas of planned coal seam gas extraction and coal mining, and to clearly articulate hypothesised stressor and response pathways, supported by reference to scientific and other credible literature. However, it is important to note that compiling conceptual models and the supporting narrative tables is not the final step. The purpose is to provide a transparent rationale, referenced to the scientific literature, for the ecological responses and proposed mitigation actions and monitoring strategies identified in an EIS.</p> <p>Application of the proposed approach is expected to:</p> <ul style="list-style-type: none"> • enhance capability in the resources industries to identify and predict the water-related impacts of coal seam gas extraction and coal mining, through uptake of the approach to ecological conceptual modelling and integration of the ecological modelling approach with hydrological and hydrogeological modelling and conceptualisation • improve identification and understanding of the potential water-related ecological responses to coal seam gas extraction and coal mining in Australia, achieved through assisting the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) in its evaluation of EIS documentation for coal seam gas and coal mining proposals and provision of advice to regulators • provide a framework for ecological conceptual modelling that could be drawn upon in the bioregional assessments.
Outputs	<p>To be published on the Australian Government – Department of the Environment website and the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) website.</p> <ul style="list-style-type: none"> • Commonwealth of Australia (in production) <i>Modelling water-related ecological responses to coal seam gas extraction and coal mining</i>, prepared by Auricht Projects and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) for the Department of the Environment, Commonwealth of Australia, Canberra. <p>http://www.environment.gov.au/water/publications#iesc</p>
Key personnel	<p>Auricht Projects (Christopher Auricht, Sarah Imgraben); Adjunct Professor Andrew Boulton (University of New England); Dr Justine Murray (CSIRO); Dr Carmel Pollino (CSIRO); Dr Moya Tomlinson (Office of Water Science, Department of the Environment)</p>
Research themes	<p>Water-dependent ecosystems</p>
Project information source	<p>Survey</p>

Table 4.151 Project 151: Impact of mine subsidence on threatened ecological communities C22019

Project characteristics	Details
Project title	Impact of mine subsidence on threatened ecological communities C22019
Project location	Australia
Principal investigator	Frazier, Paul
Lead institution	Eco Logical Australia
Project budget	\$93 680
Source of funding	Australian Coal Association Research Program (ACARP)
Project duration	Unknown – October 2014
Current status	In progress
Project summary	Longwall mine subsidence is recognised by state and federal governments as a process that threatens to impact surface environments. Current approval requirements for impact monitoring vary from site to site. A standard monitoring methodology may assist industry to meet approval requirements and streamline the monitoring process.
Objectives	This project will use quantitative means to assess the impact of longwall mine subsidence on bluegrass and Brigalow communities across several longwall mining areas. In addition, an integrated monitoring method that combines targeted field survey with remote sensing analysis will be developed and tested over several mine areas to lead industry best practice.
Achievements	Unknown
Outputs	http://www.acarp.com.au/Media/ACARPCurrentProjectsReport.pdf Frazier P (2014) "Impact of mine subsidence on threatened ecological communities". (C22019).
Key personnel	Frazier, Paul
Research themes	Water-dependent ecosystems
Project information source	ACARP website

Table 4.152 Project 152: Monitoring of geochemical and isotopic characteristics of CSG formation waters, adjacent aquifers and springs

Project characteristics	Details
Project title	Monitoring of geochemical and isotopic characteristics of CSG formation waters, adjacent aquifers and springs
Project location	Australia
Principal investigator	Leaney, Fred
Lead institution	GISERA (CSIRO)
Project budget	\$667 053
Source of funding	APLNG, CSIRO
Project duration	2011 – 2014
Current status	In progress
Project summary	<p>Characterise the baseline geochemistry of groundwater and formation water prior to and during initial stages of development to understand groundwater age and origin.</p> <p>Outcomes: baseline measures of groundwater quality and protocols for monitoring changes in groundwater quality, during and after development.</p>
Objectives	<p>Year 1: A set of sampling protocols for baseline monitoring of geochemical and isotopic parameters in groundwater and surface water systems. Qualitative conceptual model of groundwater flow systems inferred from geochemistry and hydraulics.</p> <p>Year 2: Initial maps and depth distribution of geochemical and isotopic characteristics. Report on interpretation of geochemical and isotopic data in the hydrogeological framework.</p> <p>Year 3: Final report including: assessment of changes in geochemistry of key aquifer systems, criteria for assessment of changes to groundwater flow dynamics and assessment of changes to discharge to surface water systems.</p>
Achievements	<p>Sampling protocols and conceptual model completed.</p> <p>Report on isotopic and geochemical distributions including maps and depth profile (including transect sampling).</p>
Outputs	<p>http://www.gisera.org.au/research/waterprojects/water-project-4-baseline-monitoring.pdf</p> <p>Suckow A (2014) "Environmental tracer measurements along north–south transects in the Hutton Sandstone", Geological Society of Australia, 2014 Australian Earth Sciences Convention (AESC), Sustainable Australia. Abstract No 110 of the 22nd Australian Geological Convention, Newcastle City Hall and Civic Theatre, Newcastle, New South Wales. July 7–10.</p> <p>Leaney F, Wolf L, Suckow A and Davies P (2014) "<i>Monitoring of geochemical and isotopic characteristics of CSG formation waters, adjacent aquifers and springs (Geochemical baseline monitoring)</i>".</p>
Key personnel	Leaney, Fred; Wolf, Leif; Suckow, Axel; Davies, Phil
Research themes	Water-dependent ecosystems

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Project information source	GISERA website

Table 4.153 Project 153: Towards an integrated study of the Gladstone Marine System

Project characteristics	Details
Project title	Towards an integrated study of the Gladstone Marine System
Project location	Australia
Principal investigator	Babcock, Russ
Lead institution	GISERA (CSIRO)
Project budget	\$1 693 199
Source of funding	APLNG, CSIRO
Project duration	May 2012 – Dec 2014
Current status	In progress
Project summary	<p>Port Curtis lies within the Great Barrier Reef Marine Park World Heritage Area and the region supports considerable areas of mangroves, seagrasses and saltmarsh. These vegetated habitats contribute to the high productivity of the area, in particular supporting commercially and recreationally important fisheries for crabs, prawns and finfish. The seagrasses also provide critical foraging grounds for turtles and dugongs. The residents of the region also use the waters in the Port Curtis area for recreational purposes, including fishing, sailing and access to the nearby southern reaches of the Great Barrier Reef.</p> <p>Australia Pacific LNG's project proposes to develop more than 35 000 km² of coal seam gas (CSG) acreage in southeast Queensland. The whole CSG industry will be considerably larger.</p> <p>The projects consist of three main elements:</p> <ul style="list-style-type: none"> • the gas fields themselves • a high pressure gas pipeline from the gas fields to Gladstone • LNG processing and ship-loading facilities on Curtis Island in Gladstone harbour. <p>While the major impacts of the project will be on the terrestrial environment, impacts on the inter- and sub-tidal environments of Gladstone harbour will also be significant.</p> <p>The goal of the marine research program is to understand the vulnerable components of the marine ecosystem surrounding Gladstone with a view to minimising these impacts or identifying appropriate offsets. This project will provide initial data on the distribution and abundance of seagrasses, movement patterns of turtles and dugongs and a coastal hydrodynamic/biogeochemical model for Port Curtis. This will make possible more accurate prediction and understanding of impacts and trends in water quality as well as ecological responses in primary producers (seagrass) and grazers. It will also provide information that may lead to the reduction of impacts on these key ecological assets in the future, well beyond the current phase of development.</p>
Objectives	<p>The goal of the marine research program is to understand the vulnerable components of the marine ecosystem surrounding Gladstone with a view to minimising these impacts. It is proposed that the program be conducted in 2 phases. Phase 1 (years 1 & 2, May 2012 to June 2014) will provide initial data on the distribution and abundance of seagrasses, movement patterns of turtles and dugong, and a coastal model for Port Curtis. Phase 2 will rely on future funding and it is proposed that this will comprise further development and</p>

Project characteristics	Details
	integration of the models.
Achievements	Task 1.1 Report on project establishment and set up of reference panel Task 1.2 Deploy acoustic receiver array Task 1.3 Complete initial seagrass field surveys Task 1.4 Assemble underpinning data sets for Port Curtis model parameterisation Task 2.1 Range testing of receivers at locations throughout the array in order to ensure array effectiveness. Task 2.2 Dual GPS and acoustic tagging of turtles Task 2.3 Complete analysis of seagrass surveys Task 2.4 Revise existing Port Curtis model grid and implement optics and biogeochemical component Task 3.1 Complete turtle tagging, download acoustic receivers Task 3.2 Complete assessment of dugong tagging feasibility Task 3.3 Complete yr. 2 seagrass field surveys
Outputs	For more information see: http://www.gisera.org.au/research/marineprojects/marine-projects.pdf Babcock R, Pillans R, Fry G, Haywood M, Dunbabin M, Patterson T, Wilcox C, Forcey K, Morello B, Oubelkheir K, Gillibrand P, Wild-Allen K, Margvelashvili N, Andrewartha J and Rizwi F (2014) "Towards an integrated study of the Gladstone Marine System".
Key personnel	Babcock, Russ; Pillans, Richard; Fry, Gary; Haywood, Mick; Dunbabin, Matthew; Patterson, Toby; Wilcox, Chris; Forcey, Karl; Morello, Bee; Oubelkheir, Khadija; Gillibrand, Philip; Wild-Allen, Karen; Margvelashvili, Nugzar; Andrewartha, John; Rizwi, Farahan
Research themes	Water-dependent ecosystems
Project information source	GISERA website

Table 4.154 Project 154: Priority threat identification, management and appraisal

Project characteristics	Details
Project title	Priority threat identification, management and appraisal
Project location	Australia
Principal investigator	Martin, Tara
Lead institution	GISERA (CSIRO)
Project budget	\$945 400
Source of funding	APLNG, CSIRO
Project duration	October 2012 – September 2015
Current status	Unknown—Literature output 2014
Project summary	<p>Outputs include:</p> <ul style="list-style-type: none"> information on how much protection is needed for various threatened ecosystems across the CSG development region prioritised set of management actions to abate threats in southern Queensland foundational threat management planning tools in place.
Objectives	<p>The objectives of the study are to:</p> <ul style="list-style-type: none"> determine how much of each vegetation type needs to be protected in the region to ensure long term biodiversity persistence identify and assess the cost-effectiveness of threat management actions for improving the persistence of wildlife and vegetation communities in the study region over 50 years estimate the likely outcomes for wildlife and vegetation communities of a 'no management' scenario and the minimum level of funding required to support management actions to avoid likely wildlife and vegetation community losses and secure species over 50 years, assuming thresholds of <50% persistence probability indicates a species is likely to be lost and ≥90% indicates a species is likely to be secure estimate the maximum number of wildlife species that can be improved to above each of these thresholds if only part of the budget required to avoid wildlife losses were available.
Achievements	Literature review completed
Outputs	<p>Outputs include:</p> <ul style="list-style-type: none"> information on how much protection is needed for various threatened ecosystems across the CSG development region prioritised set of management actions to abate threats in southern Queensland foundational threat management planning tools in place. <p>http://www.gisera.org.au/research/biodiversityprojects/biodiversity-proj-1-threat-ident.pdf</p> <p>Martin T, Fuller R and Maron M (2014) "Priority threat identification, management and appraisal".</p>
Key personnel	Martin, Tara; Fuller, Richard; Maron, Martine

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Research themes	Water-dependent ecosystems
Project information source	GISERA website

Table 4.155 Project 155: Assessing the cumulative risks of mining and extractive industries to the Namoi Catchment's Natural Resource Assets

Project characteristics	Details
Project title	Assessing the cumulative risks of mining and extractive industries to the Namoi Catchment's Natural Resource Assets
Project location	Australia
Principal investigator	Hutchinson-Smith, James
Lead institution	North West Local Land Services
Project budget	Unknown
Source of funding	Unknown
Project duration	Unknown --end 2014
Current status	In progress
Project summary	The expansion of extractive industries has been identified as a key driver of change for the Namoi Catchment. This was highlighted through the development of the new Namoi Catchment Action Plan (2010–2020). This supported previous findings that emerged through Scenario Planning and other initiatives undertaken previously by Namoi CMA in collaboration with the Catchment community, natural resource management stakeholders and experts. In light of this, and based on the critical thresholds identified for natural resource assets in the Namoi Catchment Action Plan (2010–2020), Namoi CMA initiated a project to investigate developing a framework to assess the cumulative risk of multiple mines to natural resource assets in the Namoi Catchment. Namoi CMA wanted to see if it was possible to develop an interactive GIS tool based on best available science and mapping that would allow the testing of different scenarios to produce cumulative risk statements and associated maps.
Objectives	It is hoped this approach can be a useful tool in informing landuse decisions and balancing the interests of a range of industry and community interests across the catchment.
Achievements	Framework developed (2011). Assessment tool constructed (2012).
Outputs	http://www.namoi.cma.nsw.gov.au/41885.html http://specialplaces.namoi.xceed.com.au/pub/41885.html
Key personnel	Hutchinson-Smith, James
Research themes	Water supplies, water-dependent ecosystems
Project information source	Website

Table 4.156 Project 156: On the establishment of acceptability criteria for subsidence impacts on the natural environment

Project characteristics	Details
Project title	On the establishment of acceptability criteria for subsidence impacts on the natural environment
Project location	Australia
Principal investigator	Pells, P
Lead institution	Pells Consulting
Project budget	Unknown
Source of funding	Unknown
Project duration	Unknown—Literature output 2014
Current status	Unknown—Literature output 2014
Project summary	<p>Every new underground coal mine in NSW, or extension to a mine, has to have some form of environmental assessment study. Such studies must determine the likely impacts on the natural and built environments. Criteria for the built environment, such as houses, roads, rail, communications and power lines, have been established over the years, or are established for specific projects by relevant authorities. These matters are not without dispute, particularly in respect to private homes, but are not the subject of this paper.</p> <p>The issue dealt with herein is that criteria for protection of the natural environment do not exist, probably because they are strongly subjective. The extremes of subjective views range from those for whom any creek, swamp, tree or frog has intrinsic value so great that no disturbance is acceptable, to those for whom the economic and postulated societal benefits from mining far outweigh other considerations. Our society must find a reasonable path between these extremes.</p> <p>To date many consider that we have not done a good job, from both the technical and political viewpoints. This paper gives consideration to the impacts of mining on the natural environment under the following categories:</p> <ul style="list-style-type: none"> • groundwater systems • swamps • water quality in streams • cliffs. <p>The paper suggests criteria to be applied, or issues to be addressed, in finding the greatest common benefit when assessing mining proposals, and reviewing the progress of mines operating in sensitive environments. While the viewpoints expressed in this paper are substantially influenced by experiences in the Southern and Western Coalfields, it is suggested that the concepts have wider applicability.</p>
Objectives	<p>To consider the impacts of mining on the natural environment under the following categories:</p> <ul style="list-style-type: none"> • groundwater systems • swamps • water quality in streams • cliffs.

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Achievements	The development of suggested criteria to be applied, or issues to be addressed, in finding the greatest common benefit when assessing mining proposals, and reviewing the progress of mines operating in sensitive environments.
Outputs	Pells P, Young A and Turner P (2014) "On the establishment of acceptability criteria for subsidence impacts on the natural environment". 9 th Triennial Conference on Mine Subsidence, 11–13 May 2014, Hunter Valley, NSW. http://www.mstsociety.org/
Key personnel	Pells, P; Young, A; Turner, P
Research themes	Surface water flow, water-dependent ecosystems
Project information source	Literature

Table 4.157 Project 157: Preferential flow paths in a complex coal seam system

Project characteristics	Details
Project title	Preferential flow paths in a complex coal seam system
Project location	Australia
Principal investigator	Ma, Ye
Lead institution	School of Civil Engineering, University of Queensland
Project budget	Unknown
Source of funding	Unknown
Project duration	December 2010 – Unknown
Current status	In progress
Project summary	Coal seam gas operation is raising a national debate over the potential of interfering with water sources and increasing greenhouse gas emission. Fluid flow in the coal seams and overlying sedimentary strata is predominately controlled by preferential flow paths provided by faults and fractures. A non-invasive surface geochemical exploration was performed to detect soil gas concentration and gamma ray anomalies, which indicate the location of permeable geological structures/faults. In order to better understand gas seepage/migration mechanism in the subsurface, microbubble transport is studied.
Objectives	To investigate preferential flow paths in a complex coal seam system.
Achievements	A non-invasive surface geochemical exploration was performed to detect soil gas concentration and gamma ray anomalies, which indicate the location of permeable geological structures/faults.
Outputs	PhD thesis http://research.ccsq.uq.edu.au/projects/preferential-flow-paths-complex-coal-seam-system Ma Y and Li L (2014) "Preferential flow paths in a complex coal seam system". School of Civil Engineering (University of Queensland)
Key personnel	Ma, Ye; Li, Ling
Research themes	Water-dependent ecosystems
Project information source	UQ website

Table 4.158 Project 158: Remote sensing of peatland swamps

Project characteristics	Details
Project title	Remote sensing of peatland swamps
Project location	Australia
Principal investigator	Raval, S
Lead institution	School of Mining Engineering, University of New South Wales
Project budget	\$24 960
Source of funding	UNSW School of Mining Engineering research grant
Project duration	January 2014 – December 2014
Current status	In progress
Project summary	This study is aimed to investigate a novel framework for monitoring the condition of upland peat swamps that store water and which can be affected by the underground mining activities. It will examine the feasibility of using the combination of three different remotely sensed data i.e. lidar, radar and optical data to assist with estimates of swamp condition and peat water content. The study will utilise data from optical (WorldView-2), and radar (ALOS/PALSAR) satellites. Success of this study will result in a cost effective, accurate and reliable monitoring tool to assist with swamp water balance monitoring. Application of this study is universal and the results could be directly applied to the swamps with similar vegetation cover in the vicinity of underground mines.
Objectives	Evaluate the feasibility of using the combination of three different remotely sensed data i.e. lidar, radar and optical data to assist with estimates of swamp condition and peat water content.
Achievements	In development, site selection
Outputs	Petravic J and Raval S (2013) "Understanding the impacts of coal mining on groundwater and surrounding vegetation in the Hunter Valley Region", BE Honours Thesis, UNSW Australia School of Mining.
Key personnel	Raval, S
Research themes	Water-dependent ecosystems
Project information source	Survey

Table 4.159 Project 159: Background review: Co-produced water – risks to aquatic ecosystems

Project characteristics	Details
Project title	Background review: Co-produced water – risks to aquatic ecosystems
Project location	Australia
Principal investigator	Sinclair Knight Merz Pty Ltd
Lead institution	Sinclair Knight Merz Pty Ltd; Australian Government – Department of the Environment
Project budget	\$110 000 (GST inclusive)
Source of funding	Australian Government – Department of the Environment
Project duration	2012 – 2014
Current status	Completed
Project summary	<p>The subject of this report is co-produced water, including issues associated with quantity, quality, timing and potential risks to aquatic ecosystems and their environmental values. The report focusses primarily on co-produced water in Australia, but also includes some international context.</p> <p>The report contains a discussion of co-produced water from both coal seam gas extraction and coal mining and provides background to aquatic ecosystems and co-produced water management options. It also describes issues associated with the quality and quantity of co-produced water, including primary toxicants, water treatment options, importance of natural flow regimes and ecological risks associated with changing the natural regimes. The report also includes discussions of recent risk management frameworks and the current situation regarding publicly available impact assessments and water management options being proposed for future co-produced water management.</p>
Objectives	<p>The review was commissioned to provide a critique of:</p> <ul style="list-style-type: none"> • impacts of changed surface water flow regimes and quality due to discharge of treated co-produced water • existing knowledge, including documentation on environmental impact assessments • examples of releasing co-produced water into natural flow regimes with a high seasonal variability • risk management frameworks and their applicability to coal seam gas and coal mining activities • industry practice in managing co-produced water.
Achievements	<p>Key findings from the review include:</p> <ul style="list-style-type: none"> • volumes of co-produced water vary significantly between coal seam gas sites in Australia (190 megalitres (ML) per petajoule of gas in the Surat Basin compared with 1.2 ML per petajoule of gas in the Sydney Basin) • in 2010, the co-produced water volume across Australia was estimated to be 33 gegalitres (GL) per year, of which 40% was from coal seam gas extraction. Over the next 25 to 35 years, co-produced water volumes are estimated to be larger, driven by projected development of coal seam gas sources in Queensland and New South Wales • the quality of water also varies but typically contains elevated levels of salts. Other variables that may require management attention include: temperature,

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
	<p>pH, sodium, chloride, fluoride, boron, some heavy metals, ammonia, and phosphorus</p> <ul style="list-style-type: none"> management options include: re-using the water for agriculture or other industries; injection; and discharge to surface water systems the impacts of these options in the environment must be assessed on a case-by-case basis – a risk-based, quantitative approach that takes into account cumulative impacts is advocated key risks to be considered when discharging co-produced water to surface water systems include salinity, toxicity and changes in flow regime, especially for streams that are weakly perennial or ephemeral.
Outputs	<p>Published on the Australian Government – Department of the Environment website and the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) website.</p> <ul style="list-style-type: none"> Commonwealth of Australia (2014) <i>Co-produced water - risks to aquatic ecosystems, Background review</i>. Department of the Environment, Canberra. http://www.environment.gov.au/water/publications#iesc
Key personnel	Sinclair Knight Merz Pty Ltd; Hart, Barry; Chapman, Heather; Cartwright, Ian
Research themes	Co-produced water – contaminant management, effects on land and water resources, effects on water-dependent ecosystems, mitigation and management options to protect water-dependent ecosystems from co-produced water impacts
Project information source	Survey

Table 4.160 Project 160: Peer review of exploration impact on groundwater in the AGL Hunter Gas Exploration Project

Project characteristics	Details
Project title	Peer review of exploration impact on groundwater in the AGL Hunter Gas Exploration Project
Project location	Australia
Principal investigator	Willgoose, Garry
Lead institution	University of Newcastle, Australia
Project budget	Cost plus budgeting
Source of funding	Department of Industry and Investment (NSW)
Project duration	2008 – ongoing
Current status	In progress
Project summary	<p>This project is to peer review water-related work done by AGL and its consultants at the Broke/Bulga/Hunter exploration sites for CSG. This has included:</p> <ul style="list-style-type: none"> • design monitoring, and review of analysis for pump testing at a number of fracked wells near Broke • design and oversight of a monitoring program for all of these Hunter sites • assistance to the community consultative committee for the project in understanding and prioritising water issues related to the project.
Objectives	Reassure the local community that AGL's activities are proceeding without impact on the ground and surface water environments
Achievements	<ul style="list-style-type: none"> • Reassurance to the community. • Development of a defensible monitoring methodology to CSG exploration. • Pump testing of a fracked gas pilot well.
Outputs	<p>Willgoose GR (2010) Peer review of the HB02 pump test (October 2009) and the PB Report "Broke groundwater investigation and monitoring report - AGL Hunter Gas Project". Broke-Bulga Community Consultative Committee and NSW Department of Primary Industry.</p> <p>Willgoose GR (2011) Coal seam gas, water and fraccing, Air Water Coal Health Gloucester, Clean Air Society of Australia and New Zealand, Gloucester, 13 May 2011.</p> <p>Willgoose GR (2011) Lessons learned about groundwater monitoring from the Broke exploration project, Coal Seam Gas Water Management 2011, Brisbane, 29–30 March 2011.</p> <p>Various short reports reviewing the progress of the monitoring program.</p> <p>Numerous community and professional group presentations.</p>
Key personnel	Willgoose, Garry
Research themes	Aquifer interconnectivity, surface water disruption, well integrity, cumulative impact assessments, co-produced/mine water, salt management
Project information source	Survey

Table 4.161 Project 161: Flora monitoring methods for Newnes Plateau Shrub Swamps and Hanging Swamps

Project characteristics	Details
Project title	Flora monitoring methods for Newnes Plateau Shrub Swamps and Hanging Swamps
Project location	Australia
Principal investigator	Brownstein, Gretchen
Lead institution	University of Queensland
Project budget	\$1 000 000
Source of funding	Centennial Coal
Project duration	5 March 2012 – 17 April 2015
Current status	Completed
Project summary	To develop a statistically rigorous and ecologically meaningful method for flora monitoring of Newnes Plateau Shrub and Hanging Swamps.
Objectives	The Newnes Plateau Flora monitoring program aims to detect negative impacts on the vegetation structure and condition of Temperate Highland Peat Swamps on Sandstone (TPHSS) as a result of subsidence and/or changes to ground and surface water associated with mining activity by Centennial Coal.
Achievements	A statistically rigorous and ecologically meaningful method for flora monitoring of Newnes Plateau Shrub and Hanging Swamps has been developed, which is suitable for use across Centennial Coal's Angus Place, Springvale and Clarence collieries.
Outputs	Brownstein G, Johns C, Blick R, Fletcher A and Erskine P (2014) Flora monitoring methods for Newnes Plateau Shrub Swamps and Hanging Swamps. Centre for Mined Land Rehabilitation, Sustainable Minerals Institute, The University of Queensland.
Key personnel	Brownstein, Gretchen; Johns, Caitlin; Blick, Ray; Fletcher, Andrew; Erskine, Peter
Research themes	Water-dependent ecosystems
Project information source	Survey

Table 4.162 Project 162: THPSS identification and classification in the Blue Mountains and Lithgow region of NSW

Project characteristics	Details
Project title	Temperate Highland Peat Swamps on Sandstone (THPSS) identification and classification in the Blue Mountains and Lithgow region of NSW
Project location	Australia
Principal investigator	Tierney, David
Lead institution	University of Queensland
Project budget	\$250 000
Source of funding	Centennial Coal
Project duration	7 January 2013 – Unknown
Current status	In progress
Project summary	Research on communities identified as temperate treeless palustrine swamps in a 268 square kilometre area which includes the Newnes Plateau. Based on publicly available combined mapping from the temperate zone of New South Wales and manual interpretation of the numerous vegetation classifications used, a region containing more than 1000 shrub swamp communities per degree of latitude/longitude was identified which contained the communities mapped as Newnes Plateau shrub swamps.
Objectives	THPSS classification, class numbers, descriptions and justification in the Blue Mountains/Lithgow area.
Achievements	Based on publicly available combined mapping from the temperate zone of New South Wales and manual interpretation of the numerous vegetation classifications used, a region containing more than 1000 shrub swamp communities per degree of latitude/longitude was identified which contained the communities mapped as Newnes Plateau shrub swamps.
Outputs	Report due end 2014
Key personnel	Tierney, David; Fletcher, Andrew; Erskine, Peter
Research themes	Water-dependent ecosystems
Project information source	Survey

Table 4.163 Project 163: Monitoring surface condition of upland swamps subject to mining subsidence with very high-resolution imagery C20046

Project characteristics	Details
Project title	Monitoring surface condition of upland swamps subject to mining subsidence with very high-resolution imagery C20046
Project location	Australia
Principal investigator	Fletcher, Andrew
Lead institution	University of Queensland
Project budget	\$300 000
Source of funding	Australian Coal Association Research Program (ACARP)
Project duration	1 March 2011 – 10 July 2014
Current status	Completed
Project summary	<p>Project C20046 investigated the potential of small unmanned aerial vehicle (UAV) platforms to capture imagery of the shrub swamp communities to develop monitoring tools for detecting change in condition and composition that may be correlated to the impacts of longwall underground mining. The project demonstrated the ability to track individual shrubs and tussock grasses over a 15 month period and developed methodology to automatically generate multi-spectral orthophoto mosaics at sub-decimetre resolutions. The photogrammetric method employed in this project is suited to difficult target geometries and is recommended for future monitoring programs where photogrammetric products are required routinely. Photographic coverage of a single shrub swamp community was achieved with low energy fixed wing UAVs in approximately 30 min with set up and recovery requiring approximately equal time (total time 1hr).</p> <p>Patchy cloud cover causes significant variability in illumination of the target during a 30 min capture window and creates artefacts in the orthophoto mosaic. Variability in illumination also requires that sensors for all spectral bands required are carried and triggered simultaneously to allow interpretation of spectral indices. Current positional and attitudinal accuracies combined with the difficult photogrammetric targets presented by shrub swamps limits orthophoto geometric accuracies to 15–40 cm errors. Small UAV platforms provide a niche product that provides hyper-temporal and hyper-spatial imagery at community scale. Ground based measures to support image interpretation should be a combination of marked features of concern and cross community transects. Both should be marked to be inherently visible in the imagery collected.</p>
Objectives	<ul style="list-style-type: none"> • Generate orthophoto mosaics covering a number of shrub swamp communities on a seasonal basis. • Converge on-ground and remotely sensed imagery to generate confidence and coverage while minimising impacts of monitoring. • Develop methodology to generate multi-spectral imagery. • Achieve an on-ground spatial resolution of less than 2 cm. • Develop automated image processing to assess change in community condition between seasons and as a result of subsidence. • Detect changes in vegetation condition and composition at a species level.
Achievements	UAV imagery currently sits between field photo monitoring and traditional remote

Project characteristics	Details
	<p>sensing. During this project we have been able to develop and demonstrate multispectral imagery of complex vegetation communities. To be an effective monitoring tool UAV imagery needs be able to detect change in a timely manner. There are a number of inherent compromises that must be made in collection of remotely sensed imagery by small UAVs including sensor quality, platform size, platform stability, endurance and coverage. Where manual interpretation is possible and field resources are synchronised with image capture it is possible at sub decimetre resolutions to identify bare ground and shrub death at community scale with high confidence. Many of the current monitoring methods assess a range of characteristics that are conceptually meaningless to understanding and detecting change in swamp health or condition. For example, changes in seasonal species abundance and cover in Newnes Plateau swamps is primarily correlated with search effort, observer bias and prior knowledge (Blick et al. in review) and as a result is unable to reliably detect massive changes including fire in vegetation composition with any degree of statistical confidence (Brownstein et al. in review). This is due to observational errors and the spatially heterogeneous and biodiverse nature of the target swamps. At other sites extremely precise assessment of sub-canopy species rooted within 0.25 m² contiguous quadrats fails to capture major structural components of the community while assessing a miniscule proportion of the target community.</p>
Outputs	<p>http://www.acarp.com.au/abstracts.aspx?repld=C20046</p> <p>Peer reviewed publications:</p> <p>RAJ Blick, A Fletcher and P Erskine (in review) Assessing vegetation impacts and informing restoration: a role for unmanned aerial systems. Submitted to Biodiversity and Conservation.</p> <p>Andrew T Fletcher, Peter D Erskine (2012) Mapping of a rare plant species (<i>Boronia deanei</i>) using hyper-resolution remote sensing and concurrent ground observation. <i>Ecological Management and Restoration</i> 13(2) 195–198.</p> <p>Christoph Strecha, Andrew Fletcher, Alex Lechner, Peter Erskine and Pascal Fua (2012) Developing species specific vegetation maps using multi-spectral hyperspatial imagery from unmanned aerial vehicles. <i>ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences</i>, Volume I-3, XXII ISPRS Congress, 25 August – 01 September 2012, Melbourne, Australia.</p> <p>AM Lechner, A Fletcher, K Johansen, P Erskine (2012) Characterising upland swamps using object-based classification methods and hyper-spatial resolution imagery derived from an Unmanned Aerial Vehicle. <i>ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences</i>, Volume I-4, XXII ISPRS Congress, 25 August – 01 September 2012, Melbourne, Australia.</p> <p>Conference papers:</p> <p>Fletcher A, Lechner A and Erskine P (2011) <i>Boronia deanei</i>: using hyper-resolution imagery for effective conservation. <i>Spatial Ecology and Conservation</i>, Birmingham, United Kingdom.</p> <p>Shortis M (2012) Multi-lens, multi-camera calibration of Sony Alpha NEX5 digital cameras. In <i>GSR 2</i>, pp. 1–11, RMIT University.</p>
Key personnel	Fletcher, Andrew; Erskine, Peter
Research themes	Water-dependent ecosystems, surface water
Project information	ACARP website and survey

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Project characteristics	Details
source	

Table 4.164 Project 164: Guidelines for establishing ecologically sustainable discharge criteria in seasonally flowing streams C19024

Project characteristics	Details
Project title	Guidelines for establishing ecologically sustainable discharge criteria in seasonally flowing streams C19024
Project location	Australia
Principal investigator	Vink, Sue
Lead institution	University of Queensland
Project budget	\$238 000
Source of funding	Australian Coal Association Research Program (ACARP)
Project duration	Unknown – June 2014
Current status	In progress
Project summary	This project will develop guidelines for establishing ecologically sustainable discharge criteria in seasonally flowing streams.
Objectives	<p>The project has the following specific objectives:</p> <ul style="list-style-type: none"> • develop new knowledge for determining the sustainable salt load for the river system • quantify the impact of saline discharge on aquatic ecosystem processes by examining changes in hyporheic (below surface of river bed) microbial community structure and function and the dynamics of system flushing under highly-variable seasonal river-flow conditions • develop guidelines for flow and water quality conditions that will minimise environmental impacts of mine site discharge.
Achievements	Genomic data has been re-analysed and the final report is undergoing revision and editing.
Outputs	<p>PhD thesis</p> <p>http://www.acarp.com.au/Media/ACARPCurrentProjectsReport.pdf</p> <p>http://research.ccsq.uq.edu.au/projects/understanding-origin-recharge-and-flow-regimes-coal-seam-waters-better-constrain-aquifer</p> <p>Vink S (2014) "Guidelines for establishing ecologically sustainable discharge criteria in seasonally flowing streams". (C19024).</p>
Key personnel	Vink, Sue
Research themes	Co-produced/mine water, water-dependent ecosystems
Project information source	ACARP website

Table 4.165 Project 165: A field study of irrigated soil properties comparing land conditioning of applied coal seam gas (CSG) water, application of chemically amended CSG water and good quality groundwater

Project characteristics	Details
Project title	A field study of irrigated soil properties comparing land conditioning of applied coal seam gas (CSG) water, application of chemically amended CSG water and good quality groundwater
Project location	Australia
Principal investigator	Unknown
Lead institution	University of Southern Queensland
Project budget	Unknown
Source of funding	Unknown
Project duration	2014
Current status	In progress
Project summary	This project is just commencing with the experimental design having been initiated in the field. This project is currently commercial in confidence.
Objectives	Unknown
Achievements	Unknown
Outputs	http://research.ccsq.uq.edu.au/projects/field-study-irrigated-soil-properties-comparing-land-conditioning-applied-coal-seam-gas-csg
Key personnel	Unknown
Research themes	Water-dependent ecosystems
Project information source	UQ CCSG Online Portal

4.8.2 China

Table 4.166 Project 166: Ground control and water resources protection

Project characteristics	Details
Project title	Ground control and water resources protection
Project location	China
Principal investigator	Liqiang, Ma
Lead institution	China University of Mining and Technology
Project budget	\$100 000
Source of funding	Ministry of Education of the People's Republic of China
Project duration	1 March 2014 – 31 December 2015
Current status	In progress
Project summary	<p>Maximizing protection of water resources while mining of coal resources in large scale is an urgent problem to be solved at ecological fragile mining area in the northwest of China. The existing research results for water-preserved mining are mainly applied for single coal seam, however, this research project is aimed at:</p> <ul style="list-style-type: none"> • study of spatial-temporal evolution laws and phase transition criticality for overlying strata repeated mining at disturbed area regarding the characteristics of northwest mines with shallow burial depth of coal seam, close distance and thin bedrock, and proposes a method to determine water resource loss zone in close distance coal seams • study of cumulative damage mechanism of overlying strata and their closing features, and reveal the change law of Lithologic Association of overlying strata to provide a criterion for aquifuge, and then determine the judgment index of water resource loss quantitative early-warning • analysis of control effects of critical layer on fractures in overlying strata to reveal the water-preserved mining mechanism for mining induced overlying strata • study of the whole process of mechanism of action and control of mining parameters on fractures in overlying strata at repeated mining disturbed area regarding initiation, extension and closure (resurrection, secondary development and recovery), and propose a water resource protective mining method for repeated mining at disturbed area in shallow buried and close distance coal seams.
Objectives	Through this research project, theoretical guidance and technical support have been provided to achieve the ecological environment protection and sustainable development, based on the establishment of spatial-temporal evolution laws for fractures in mining induced overlying strata, on the premise of the control of structural stability of overlying strata, and mining parameters as a means to intervene in water-preserved mining mechanism and technology system for water-preserved mining at mining induced overlying strata in shallow buried and close distance coal seams and provide theoretical guidance and technical support for the realization of the protection and sustainable development of ecological environment in northwest of China.
Achievements	Unknown
Outputs	Liqiang Ma, Xun Du, Fei Wang, Jimeng Liang (2013) "Water-preserved mining

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
	<p>technology for shallow buried coal seam in ecologically-vulnerable coal field: A case study in the Shendong Coal field of China" [J]. <i>Disaster Advances</i>, 6(S5): 268–278.</p> <p>Ma L-q, Zhang D-s, Li X, Fan G-w and Zhao Y-f (2009) "Technology of groundwater reservoir construction in goafs of shallow coalfields". <i>Mining Science and Technology (China)</i>, 19 (6), pp.730–735.</p> <p>Ma L-q, Zhang D-s, Jing S-g, Zhang W and Fan G-w (2008) "Numerical simulation analysis by solid-liquid coupling with 3DEC of dynamic water crannies in overlying strata". <i>Journal of China University of Mining and Technology</i>, 18 (3), pp.347–352.</p>
Key personnel	Liqiang, Ma; Dongsheng, Zhang; Gangwei, Fan; Xufeng, Wang; Wei, Zhang
Research themes	Aquifer interconnectivity, surface water, co-produced/mine water, hydraulic fracturing, water supplies, water-dependent ecosystems, cumulative impact assessments
Project information source	Survey

Table 4.167 Project 167: The application of chemical tracer experiments on exploring the mine water filling conditions

Project characteristics	Details
Project title	The application of chemical tracer experiments on exploring the mine water filling conditions
Project location	China
Principal investigator	Yin, Shang-Xian
Lead institution	Hebei State Key Laboratory of Mine Disaster Prevention, North China Institute of Science and Technology, Beijing, China
Project budget	Unknown
Source of funding	Unknown
Project duration	Unknown—Literature output 2014
Current status	Unknown—Literature output 2014
Project summary	In order to obtain hydrogeological parameters, such as, groundwater flow velocity and permeability coefficient, identify the aquifer hydraulic connection and verify mine hydrogeological conditions, a chemical tracer experiment was designed in a coal mine in Inner Mongolia. Based on the analysis of chemical tracer experiment data collected, the empirical formulas of the tracer dosage were summed up, taking account of the influence of the delivery distance and aquifer properties, and tracer dosage in this time were evaluated. At the same time, the phenomenon that the concentration of Cl ⁻ were not increased in the monitored water were explained with scientific theories, and the theories were put forward that those chemical agents which are similar to chlorine ion tracers, easy to obtain, cheap and able to achieve test results with one ion can be selected as a tracer, even some ions may be absorbed by rock layers.
Objectives	To obtain hydrogeological parameters, such as, groundwater flow velocity and permeability coefficient, identify the aquifer hydraulic connection and verify mine hydrogeological conditions.
Achievements	Unknown
Outputs	http://www.mtxb.com.cn/EN/abstract/abstract11569.shtml# Yin, S.-X., Xu, B., Xu, H. and Xia, X.-X. (2014). "The application of chemical tracer experiments on exploring the mine water filling conditions". <i>Meitan Xuebao/Journal of the China Coal Society</i> , 39 (1). Hepingli, Beijing, 100013, China: China Coal Society.
Key personnel	Yin, Shang-Xian; Xu, Bin; Xu, Hui; Xia, Xiang-Xue
Research themes	Co-produced/mine water, water supplies, water-dependent ecosystems
Project information source	Literature

Table 4.168 Project 168: Impacts of coal mining on groundwater environment in northwestern coal mine area

Project characteristics	Details
Project title	Impacts of coal mining on groundwater environment in northwestern coal mine area
Project location	China
Principal investigator	Wang, Hao
Lead institution	Xi'an Research Institute of China Coal Technology and Engineering Group Corp, Xi'an, China
Project budget	Unknown
Source of funding	Unknown
Project duration	Unknown—Literature output 2014
Current status	Unknown—Literature output 2014
Project summary	By conducting field investigation and tests, such as groundwater pumping test and rock mechanics test, and building numerical models to simulate damage of coal mining to aquifers, it was proved that coal mining in some coal mine area caused impacts to groundwater environment, including impact on water cycle, the structure of aquifers, and groundwater flow field, as a result of which some water supply sources in coal mine area become unavailable. In addition, a couple of solutions are presented to mitigate the impacts.
Objectives	To examine the effects of coal mining on groundwater resource in the coal mine areas of northwestern China.
Achievements	Field investigations, including landform investigation, surface water investigation, and groundwater level observation were conducted.
Outputs	http://dx.doi.org/10.4028/www.scientific.net/AMM.448-453.823 Wang H (2014) "Impacts of coal mining on groundwater environment in northwestern coal mine area". <i>2013 International Conference on Renewable Energy and Environmental Technology, REET 2013, September 21, 2013 – September 22, 2013</i> , pp. 448–453. Jilin, China: Trans Tech Publications Ltd.
Key personnel	Wang, Hao
Research themes	Surface water, co-produced/mine water, water-dependent ecosystems
Project information source	Literature

4.8.3 India

Table 4.169 Project 169: Pilot project on remediation of AMD in catchment of Kopili River at the upstream of Kopili Hydro Electric Plant, Umrongso, Assam, India

Project characteristics	Details
Project title	Pilot project on remediation of AMD in catchment of Kopili River at the upstream of Kopili Hydro Electric Plant, Umrongso, Assam, India
Project location	India
Principal investigator	Singh, OM
Lead institution	Department of Environmental Studies, North-Eastern Hill University, Shillong-793022, India
Project budget	\$150 000
Source of funding	Funding sought from Kopili Hydro Electric Plant, NEEPCOUmrongso, Assam, India
Project duration	1 October 2014 – 30 September 2016
Current status	On hold
Project summary	The Kopili Hydro-Electric Project (KHEP) of North Eastern Electric Power Corporation Limited (NEEPCO) is one of the pioneering Hydro-Electric Projects in the North Eastern Region (NER) of India. The Kopili Hydro Electric Plant is a 275 MW storage type hydro electric plant consisting of two dams which have created two reservoirs namely Kopili and Umrong on Kopili River and Umrong stream, respectively. The Kopili River and its tributaries feed water to the reservoirs of the project. The Kharkor is a major tributary of river Kopili and drains a vast area of Jaintia Hills Districts of Meghalaya. The Jaintia Hills being well known for coal mining areas is contributing acidic water in the form of Acid Mine Drainage (AMD) to the river Kharkor through its different tributaries such as Um Pai, Myntriang, Um Ropang, Sarbang, Mostem etc. as these streams drain through the active and inactive coal mining areas of Jaintia Hills. The acidic water finally reaches to Khandong and Umrong reservoirs of KHEP. As a result, the water of the reservoirs has become highly acidic. The pH of the water has been reported in the range 4 to 5 after year 2006. In recent years, it has been found that acidity of reservoir water is a major threat to equipment and machinery due to corrosion/metal decay and erosion. Components such as Cooling water header pipe, Bends, Throttling valves, Pressure equalizer pipe of turbine etc. made up of different metals and alloys are getting severely affected and incurring high maintenance cost. In view of the grave situation mentioned above, the NEEPCO has proposed to undertake a pilot project for remediation of AMD in the catchment area of river Kopili.
Objectives	Remediation of AMD in Catchment of Kopili River at upstream of Kopili HEP.
Achievements	Project is under consideration by the funding Agency.
Outputs	Nil
Key personnel	Singh, OM
Research themes	Water supplies, water-dependent ecosystems
Project information	Survey

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Project characteristics	Details
source	

4.8.5 United Kingdom

Table 4.170 Project 170: Applying natural tracer technologies in the environmental monitoring of unconventional gas extraction

Project characteristics	Details
Project title	Applying natural tracer technologies in the environmental monitoring of unconventional gas extraction
Project location	United Kingdom
Principal investigator	Gilfillan, Stuart
Lead institution	University of Edinburgh
Project budget	\$313 000
Source of funding	NERC, Scottish Government, University of Edinburgh
Project duration	1 March 2014 – unknown
Current status	In progress
Project summary	<p>This consortium project aims to use natural chemical components in groundwater and gases, to provide legally-defensible evidence in case of future allegations of methane contamination of groundwaters. This will be by obtaining chemical analyses of produced CBM and Shale Gas methane, shallow methane sources, and uncontaminated groundwater. Existing chemical analyses of baseline groundwater samples provide information on methane concentrations and the source of the water that the methane is contained in. However, they do not provide the unique fingerprint required to unequivocally determine the origin of methane.</p> <p>We will collect samples of shale gas, CBM and produced waters and undertake measurements of the C and H stable isotopes, radiocarbon (^{14}C) and noble gases (He Ne Ar Kr Xe) in the produced gases. These will allow the CBM and Shale Gas to be distinguished from other gas sources and provide a clear fingerprint for assessing groundwater contamination. We will also collect samples of baseline groundwaters and measure methane concentrations, C stable isotopes in the Dissolved Inorganic Carbon (DIC), H and O stable isotopes to provide a simple low-cost screening. Should the methane gas content of these groundwaters be found to be above 2 milligrams per litre we will separate the methane gas and measure the H and C stable isotope signature. This will allow us to determine the separate origins of both the groundwater and of the methane (which may be shallow bacterial or deep thermal source).</p> <p>If sampling and analysis of groundwater during or after CBM or Shale Gas production shows that methane concentrations have increased, then analysis of the H, C, radiocarbon and noble gas components should be made on the groundwaters. This will allow the source of methane to be categorically resolved - is that methane of shallow bacterial origin, or from deep thermal sources which have previously been trapped at shallow depth, or is the increased methane an unambiguous addition of deep thermogenic methane from CBM or Shale Gas exploitation?</p>
Objectives	<p>We will target regions where CBM and Shale Gas exploration or production is occurring through collaboration with three of the key industry players; Cuadrilla Resources, Dart Energy and Reach Coal Seam Gas. Gas and water samples will be collected to:</p> <ul style="list-style-type: none"> determine the natural tracer fingerprint contained in produced shale and

Project characteristics	Details
	<p>CBM gases and waters</p> <ul style="list-style-type: none"> • establish the groundwater natural tracer "baseline" prior to CBM or Shale Gas production • utilise the analytical information gained to develop a robust and unequivocal test for contamination.
Achievements	Sample collection and analysis is currently ongoing
Outputs	Unknown
Key personnel	Gilfillan, Stuart; Haszeldine, Stuart; Stuart, Fin; Waldron, Susan; McKavney, Rory
Research themes	Surface water, hydraulic fracturing, water supplies
Project information source	Survey

Table 4.171 Project 171: Fugitive emissions associated with existing coal mining

Project characteristics	Details
Project title	Fugitive emissions associated with existing coal mining
Project location	United Kingdom
Principal investigator	Waldron, Susan
Lead institution	University of Glasgow
Project budget	Not yet applicable as in pilot status
Source of funding	Internal University Funds
Project duration	2014
Current status	In progress
Project summary	To assess the background of existing fugitive methane emissions in surface waters prior to likely unconventional hydrocarbon extraction and identify the source of this methane.
Objectives	To assess the background of existing fugitive methane emissions in surface waters prior to likely unconventional hydrocarbon extraction. To use isotopic measurements to identify the source of methane detected. To use upscaling techniques to quantify an efflux.
Achievements	Detected methane in micromole quantities in surface waters.
Outputs	Unknown
Key personnel	Waldron, Susan
Research themes	Co-produced/mine water, water-dependent ecosystems, mitigation, monitoring
Project information source	Survey

4.8.6 United States

Table 4.172 Project 172: Organic substances in produced and formation water from unconventional natural gas extraction in coal and shale

Project characteristics	Details
Project title	Organic substances in produced and formation water from unconventional natural gas extraction in coal and shale
Project location	USA
Principal investigator	Orem, William
Lead institution	U.S. Geological Survey
Project budget	Unknown
Source of funding	USGS Energy Resources Program (B. Pierce, Program Coordinator), U.S. Department of Energy, National Energy Technology Laboratory, under contract DE-FE0000888.
Project duration	Unknown—Literature output 2014
Current status	Unknown—Literature output 2014
Project summary	<p>Organic substances in produced and formation water from coalbed methane (CBM) and gas shale plays from across the USA were examined in this study. Disposal of produced waters from gas extraction in coal and shale is an important environmental issue because of the large volumes of water involved and the variable quality of this water. Organic substances in produced water may be environmentally relevant as pollutants, but have been little studied.</p> <p>Results from five CBM plays and two gas shale plays (including the Marcellus Shale) show a myriad of organic chemicals present in the produced and formation water. Organic compound classes present in produced and formation water in CBM plays include: polycyclic aromatic hydrocarbons (PAHs), heterocyclic compounds, alkyl phenols, aromatic amines, alkyl aromatics (alkyl benzenes, alkyl biphenyls), long-chain fatty acids, and aliphatic hydrocarbons. Concentrations of individual compounds range from b1 to 100 µg/L, but total PAHs (the dominant compound class foremost CBM samples) range from 50 to 100 µg/L. Total dissolved organic carbon (TOC) in CBM produced water is generally in the 1–4 mg/L range. Excursions from this general pattern in produced waters from individual wells arise from contaminants introduced by production activities (oils, grease, adhesives, etc.). Organic substances in produced and formation water from gas shale unimpacted by production chemicals have a similar range of compound classes as CBM produced water, and TOC levels of about 8 mg/L. However, produced water from the Marcellus Shale using hydraulic fracturing has TOC levels as high as 5500 mg/L and a range of added organic chemicals including, solvents, biocides, scale inhibitors, and other organic chemicals at levels of 1000s of µg/L for individual compounds. Levels of these hydraulic fracturing chemicals and TOC decrease rapidly over the first 20 days of water recovery and some level of residual organic contaminants remain up to 250 days after hydraulic fracturing. Although the environmental impacts of the organics in produced water are not well defined, results suggest that care should be exercised in the disposal and release of produced waters containing these organic substances into the environment because of the potential toxicity of many of these substances.</p>
Objectives	To examine organic substances in produced and formation water from coalbed methane (CBM) and gas shale plays from across the USA.

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Achievements	<ul style="list-style-type: none"> • Organics characterized in waters from coalbed methane and shale gas wells. • Results from five CBM and two gas shale plays show a myriad of organic chemicals. • Water from gas shales unimpacted by production chemicals similar compounds as CBM. • High TOC in gas shale waters up to 5500 mg/L, mostly hydraulic fracturing additives.
Outputs	http://www.sciencedirect.com/science/article/pii/S0166516214000056 Orem W, Tatu C, Varonka M, Lerch H, Bates A, Engle M, Crosby L and McIntosh J (2014) "Organic substances in produced and formation water from unconventional natural gas extraction in coal and shale". <i>International Journal of Coal Geology</i> , 126 (0).
Key personnel	Orem, William; Tatu, Calin; Varonka, Matthew; Lerch, Harry; Bates, Anne; Engle, Mark; Crosby, Lynn; McIntosh, Jennifer
Research themes	Co-produced/mine water, hydraulic fracturing, water supplies, water-dependent ecosystems
Project information source	Literature

Table 4.173 Project 173: A review of environmental impacts of salts from produced waters on aquatic resources

Project characteristics	Details
Project title	A review of environmental impacts of salts from produced waters on aquatic resources
Project location	USA
Principal investigator	Farag, Aida M
Lead institution	U.S. Geological Survey
Project budget	Unknown
Source of funding	U.S. Geological Survey
Project duration	Unknown—Literature output June 2014
Current status	Unknown—Literature output June 2014
Project summary	Salts are frequently a major constituent of waste waters produced during oil and gas production. These produced waters or brines must be treated and/or disposed and provide a daily challenge for operators and resource managers. Some elements of salts are regulated with water quality criteria established for the protection of aquatic wildlife, e.g. chloride (Cl ⁻), which has an acute standard of 860 mg/L and a chronic standard of 230 mg/L. However, data for establishing such standards has only recently been studied for other components of produced water, such as bicarbonate (HCO ₃ ⁻), which has acute median lethal concentrations (LC50s) ranging from 699 to 8000 mg/L and effects on chronic toxicity from 430 to 657 mg/L. While Cl ⁻ is an ion of considerable importance in multiple geographical regions, knowledge about the effects of hardness (calcium and magnesium) on its toxicity and about mechanisms of toxicity is not well understood. A multiple-approach design that combines studies of both individuals and populations, conducted both in the laboratory and the field, was used to study toxic effects of bicarbonate (as NaHCO ₃). This approach allowed interpretations about mechanisms related to growth effects at the individual level that could affect populations in the wild. However, additional mechanistic data for HCO ₃ ⁻ , related to the interactions of calcium (Ca ²⁺) precipitation at the microenvironment of the gill would dramatically increase the scientific knowledge base about how NaHCO ₃ might affect aquatic life. Studies of the effects of mixtures of multiple salts present in produced waters and more chronic effect studies would give a better picture of the overall potential toxicity of these ions. Organic constituents in hydraulic fracturing fluids, flowback waters, etc. are a concern because of their carcinogenic properties and this paper is not meant to minimize the importance of maintaining vigilance with respect to potential organic contamination.
Objectives	To review environmental impacts of salts from produced waters on aquatic resources.
Achievements	A multiple-approach design that combines studies of both individuals and populations, conducted both in the laboratory and the field, was used to study toxic effects of bicarbonate.
Outputs	http://www.sciencedirect.com/science/article/pii/S0166516213002735 Farag AM and Harper DD (2014) "A review of environmental impacts of salts from produced waters on aquatic resources". <i>International Journal of Coal Geology</i> , 126. Elsevier

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Key personnel	Farag, Aida M; Harper, David D
Research themes	Co-produced/mine water, water supplies
Project information source	Literature

Table 4.174 Project 174: Stream methane monitoring for evaluating impacts of coal seam and shale gas development on water resources

Project characteristics	Details
Project title	Stream methane monitoring for evaluating impacts of coal seam and shale gas development on water resources
Project location	USA
Principal investigator	Heilweil, Victor
Lead institution	U.S. Geological Survey
Project budget	\$170 000
Source of funding	USGS Utah Water Science Center USGS Pennsylvania Water Science Center USGS Office of Groundwater USGS Southwest Region
Project duration	1 March 2012 – unknown
Current status	In progress
Project summary	<p>Natural-gas production has increased rapidly because of technological advances that have allowed extraction from unconventional resources. Horizontal drilling and hydraulic fracturing (the process by which specific formations adjacent to a well are fractured to increase permeability) have made existing natural gas reservoirs more productive and have allowed the development of new coal-seam and shale gas plays.</p> <p>The rapid development and widespread application of hydraulic fracturing have resulted in significant public concern about the environmental effects on watersheds, ecosystems, and surface and groundwater resources. Groundwater contamination from hydraulic fracturing is possible if fluids and (or) gases migrate along faults, fractures, or wells. Recent studies have established a possible link between increased methane concentrations in overlying aquifers with horizontal drilling, hydraulic fracturing, and improperly completed boreholes. The development of stream-based methane assessment methods for evaluating groundwater impacts from natural gas development will have a wide range of applications for both:</p> <ul style="list-style-type: none"> • the initial regional reconnaissance stage for determining areas of impact, and • detailed studies evaluating point-source fluxes of groundwater methane entering gaining streams. <p>The approach utilizes baseflow conditions of a gaining stream as an integrated average of watershed-scale groundwater quality. These methods are cost-effective and relatively easy to implement, in comparison to the installation and sampling of monitoring-well networks. The biggest benefit in implementing this monitoring protocol will be in areas not yet disturbed by natural gas development efforts. Baseline stream water quality can be determined prior to development and followed up by repeat base-flow sampling to determine trends in methane (and other potential contaminant) concentrations.</p>
Objectives	<p>The objective of this study is to develop simple yet robust methods for using dissolved methane measurements in streams to assess impacts of natural gas development. Such methods have the distinct advantage of using stream-integrated chemical signatures to indirectly monitor groundwater processes and potential contamination at the watershed scale. The ultimate goal is to implement an integrated methane monitoring approach for a diverse range of streams.</p>

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Achievements	Completion of stream methane injections at Nine-Mile Creek, Utah, and West Bear Creek, North Carolina, for development of the stream methane measurement. Application of the method in the Marcellus Shale-Gas play of northeastern Pennsylvania
Outputs	<p>Heilweil VM, Stolp BJ, Kimball BA, Susong DD, Marston TM and Gardner PM (2013) A stream-based methane monitoring approach for evaluating groundwater impacts associated with unconventional gas development. <i>Groundwater</i>, 51: 511–524. doi: 10.1111/gwat.12079.</p> <p>Heilweil VM, Risser DW, Conger RW, Grieve PL and Hynek SA (2014) Estimation of methane concentrations and loads in groundwater discharge to Sugar Run, Lycoming County, Pennsylvania", US Geological Survey Open-File Report 2014-1126.</p> <p>"Stream measurements reveal thermogenic methane migration from a shale-gas formation", in review (Environmental Science and Technology).</p> <p>Other product information is given at: http://ut.water.usgs.gov/projects/methanestream/</p>
Key personnel	Heilweil, Victor; Solomon, D Kip ; Risser, Dennis; Brantly, Susan; Stolp, Bert; Hyneck, Scott
Research themes	Aquifer interconnectivity, co-produced/mine water, hydraulic fracturing, water supplies, water-dependent ecosystems
Project information source	Survey

Table 4.175 Project 175: Use of reconstituted waters to evaluate effects of elevated major ions associated with mountaintop coal mining on freshwater invertebrates

Project characteristics	Details
Project title	Use of reconstituted waters to evaluate effects of elevated major ions associated with mountaintop coal mining on freshwater invertebrates
Project location	USA
Principal investigator	Kunz, James L
Lead institution	U.S. Geological Survey, Columbia Environmental Research Center, Columbia
Project budget	Unknown
Source of funding	USEPA STAR Fellowship (GAD FP917322)
Project duration	Unknown—Literature output October 2013
Current status	Unknown—Literature output October 2013
Project summary	<p>In previous laboratory chronic 7-d toxicity tests conducted with the cladoceran <i>Ceriodaphnia dubia</i>, surface waters collected from Appalachian sites impacted by coal mining have shown toxic effects associated with elevated total dissolved solids (TDS). The objective of the present study was to evaluate the effects of elevated major ions in chronic laboratory tests with <i>C. dubia</i> (7-d exposure), a unionid mussel (<i>Lampsilis siliquoidea</i>; 28-d exposure), an amphipod (<i>Hyalella azteca</i>; 28-d exposure), and a mayfly (<i>Centroptilum triangulifer</i>; 35-d exposure) in three reconstituted waters designed to be representative of three Appalachian sites impacted by coal mining. Two of the reconstituted waters had ionic compositions representative of alkaline mine drainage associated with mountaintop removal and valley fill-impacted streams (Winding Shoals and Boardtree, with elevated Mg, Ca, K, SO₄, HCO₃), and a third reconstituted water had an ionic composition representative of neutralized mine drainage (Upper Dempsey, with elevated Na, K, SO₄, and HCO₃). The waters with similar conductivities but with different ionic compositions had different effects on the test organisms. The Winding Shoals and Boardtree reconstituted waters were consistently toxic to the mussel, the amphipod, and the mayfly. In contrast, the Upper Dempsey reconstituted water was toxic to the mussel, the amphipod, and the cladoceran but was not toxic to the mayfly. These results indicate that, although elevated TDS can be correlated with toxicity, the specific major ion composition of the water is important. Moreover, the choice of test organism is critical, particularly if a test species is to be used as a surrogate for a range of faunal groups.</p>
Objectives	<p>The objective of the present study was to evaluate the effects of elevated major ions in chronic laboratory tests with four aquatic invertebrates exposed to dilutions of three reconstituted waters designed to be representative of three Appalachian sites impacted by coal mining in southwestern West Virginia with high TDS downstream of valley fill: Winding Shoals Branch, Boardtree Branch, and Upper Dempsey Branch.</p>
Achievements	<p>In the present study, two central ideas in the assessment of toxicity associated with major ions were reinforced:</p> <ul style="list-style-type: none"> • specific ionic composition of the water is critical, and • selection of laboratory test species is also critical for relating major ion toxicity to field data.

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Outputs	http://dx.doi.org/10.1002/etc.2391 Kunz JL, Conley JM, Buchwalter DB, Norberg-King TJ, Kemble NE, Wang N and Ingersoll CG (2013) "Use of reconstituted waters to evaluate effects of elevated major ions associated with mountaintop coal mining on freshwater invertebrates". <i>Environmental Toxicology and Chemistry</i> , 32 (12). 1010 North 12 th Avenue, Pensacola, FL 32501-3367, United States: SETAC Press
Key personnel	Kunz, James L; Conley, Justin M; Buchwalter, David B; Norberg-King, Teresa J; Kemble, Nile E; Wang, Ning; Ingersoll, Christopher G
Research themes	Water-dependent ecosystems
Project information source	Literature

Table 4.176 Project 176: Application of a Bayesian model to infer the contribution of coalbed natural gas produced water to the Powder River, Wyoming and Montana

Project characteristics	Details
Project title	Application of a Bayesian model to infer the contribution of coalbed natural gas produced water to the Powder River, Wyoming and Montana
Project location	USA
Principal investigator	Mailloux, Jason M
Lead institution	University of Wyoming
Project budget	Unknown
Source of funding	Department of Energy. Grant Number: DE-FC26-06NT155568
Project duration	Unknown—Literature output 2014
Current status	Unknown—Literature output 2014
Project summary	<p>The Powder River Basin (PRB) of Wyoming and Montana contains significant coal and coal bed natural gas (CBNG) resources. CBNG extraction requires the production of large volumes of water, much of which is discharged into existing drainages. Compared to surface waters, the CBNG produced water is high in sodium relative to calcium and magnesium, elevating the sodium adsorption ratio (SAR). To mitigate the possible impact this produced water may have on the quality of surface water used for irrigation, the State of Montana passed water anti-degradation legislation, which could affect CBNG production in Wyoming. In this study, we sought to determine the proportion of CBNG produced water discharged to tributaries that reaches the Powder River by implementing a four end-member mixing model within a Bayesian statistical framework. The model accounts for the $^{87}\text{Sr}/^{86}\text{Sr}$, $^{13}\text{CDIC}$, $[\text{Sr}]$ and $[\text{DIC}]$ of CBNG produced water and surface water interacting with the three primary lithologies exposed in the PRB. The model estimates the relative contribution of the end members to the river water, while incorporating uncertainty associated with measurement and process error. Model results confirm that both of the tributaries associated with high CBNG activity are mostly composed of CBNG produced water (70–100%). The model indicates that up to 50% of the Powder River is composed of CBNG produced water downstream from the CBNG tributaries, decreasing with distance by dilution from non-CBNG impacted tributaries from the point sources to ~10–20% at the Montana border. This amount of CBNG produced water does not significantly affect the SAR or electrical conductivity of the Powder River in Montana. 2013 John Wiley Sons, Ltd.</p>
Objectives	This study aims to determine the proportion of CBNG produced water discharged to tributaries that reaches the Powder River by implementing a four end-member mixing model within a Bayesian statistical framework.
Achievements	The model indicates that up to 50% of the Powder River is composed of CBNG produced water downstream from the CBNG tributaries, decreasing with distance by dilution from non-CBNG impacted tributaries from the point sources to ~10–20% at the Montana border. This amount of CBNG produced water does not significantly affect the SAR or electrical conductivity of the Powder River in Montana.

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Outputs	http://onlinelibrary.wiley.com/doi/10.1002/hyp.9784/abstract Mailloux JM, Ogle K and Frost CD (2014). "Application of a Bayesian model to infer the contribution of coalbed natural gas produced water to the Powder River, Wyoming and Montana". <i>Hydrological Processes</i> , 28 (4). Southern Gate, Chichester, West Sussex, PO19 8SQ, United Kingdom: John Wiley and Sons Ltd
Key personnel	Mailloux, Jason M; Ogle, Kiona; Frost, Carol D
Research themes	Co-produced/mine water, water supplies, water-dependent ecosystems
Project information source	Literature

4.9 Cumulative impact assessments

Cumulative impact assessments recognise that the cumulative impact of multiple industries may be far greater than that of either the individual impacts or even the sum of the individual industries.

Eleven projects were collated in total with the primary theme of cumulative impact assessments from Australia (9 projects), China (1 project) and the United Kingdom (1 project).

4.9.1 Australia

Table 4.177 Project 177: The potential impacts of coal seam gas on biodiversity in Australia: Identification of knowledge gaps and research priorities

Project characteristics	Details
Project title	The potential impacts of coal seam gas on biodiversity in Australia: Identification of knowledge gaps and research priorities
Project location	Australia
Principal investigator	Williams, Elizabeth
Lead institution	Centre for Coal Seam Gas, The University of Queensland
Project budget	\$50 000
Source of funding	Centre for Coal Seam Gas
Project duration	1 March 2014 – unknown
Current status	In progress
Project summary	<p>Terrestrial biodiversity in eastern Australia has been extensively affected by agricultural development and the expansion of coal seam gas (CSG) developments will potentially have additional impacts. Currently, there is little scientific research on the current or potential impacts of CSG activities and infrastructure on biodiversity in Australia. Internationally, the limited research (mainly in the USA), has found that CSG-related activities are having a range of measurable ecological impacts on the wildlife and habitats studied. It has also been found that these impacts are multi-scale (local and regional) and potentially cumulative (different projects in a region having compounded effects).</p> <p>We identified four key research gaps:</p> <ul style="list-style-type: none"> • mandated studies address threatened species, not biodiversity/ecosystems • no knowledge about effects of mitigation measures • insufficient information on effective rehabilitation practices specific to the CSG industry • no research agenda on biodiversity enhancement as a positive legacy.
Objectives	<p>This scoping study aimed to investigate the potential impacts of CSG infrastructure and operations on terrestrial biodiversity through:</p> <ul style="list-style-type: none"> • a review of scientific and industry literature • eliciting expert opinion, and • by analysis of remote sensing data through a case study.
Achievements	The study identifies a number of common areas where scientific research can

Project characteristics	Details
	address the major knowledge gaps identified from reviews of scientific literature, environmental assessments and expert opinion. Although it is recognised by the scientific and CSG industry communities that CSG activities will potentially impact terrestrial biodiversity, no independent research has been completed to date in Australia to address these knowledge gaps. Failure to understand the effect on Australian species may mean that current CSG industry management plans will not effectively address impacts of operations on threatened species, and additional remedial actions or regulation may be required that will increase the cost of compliance.
Outputs	Terrestrial biodiversity and unconventional gas extraction: potential cumulative impacts and implications (report in prep).
Key personnel	Williams, Elizabeth; Adams-Hosking, Christine; McAlpine, Clive; Leonie, Seabrook; Erskine, Peter; Schoettker, Birte
Research themes	Cumulative impact assessments
Project information source	Survey

Table 4.178 Project 178: Cumulative socioeconomic impacts: Phase 1

Project characteristics	Details
Project title	Cumulative socioeconomic impacts: Phase 1
Project location	Australia
Principal investigator	Rifkin, Will
Lead institution	Centre for Social Responsibility in Mining, University of Queensland
Project budget	Unknown
Source of funding	University of Queensland, Santos, QGC, Arrow Energy
Project duration	August 2012 – July 2015
Current status	In progress
Project summary	<p>Large-scale development of CSG resources presents communities in the Western Downs of Queensland with what are known as 'cumulative impacts' -- social, economic, and environmental. These cumulative impacts present significant challenges to regulators, who have historically focussed on project-by-project approval. The four CSG companies in the Western Downs can have their impacts and reputations entangled with those of a range of other players as well as confounded by factors such as drought and variations in the price of agricultural commodities. Residents and businesses can face impacts that are unexpected and seemingly disproportionate to the resource development that they are experiencing.</p> <p>Assessment and response to cumulative impacts benefit from connecting perception with evidence, which can be done through collective agreement on a set of salient and credible indicators of impact at the regional scale. These indicators need to draw on reliable data and suggest implications for industry, government, community residents, and others that assist with decision making about the future. This project is engaging these stakeholders to track cumulative social and economic (but not environmental) impacts by developing socioeconomic indicators so as to foster more effective regional development.</p>
Objectives	<p>The project has two key aims:</p> <ul style="list-style-type: none"> • avoid information overload and limit the negative impact of 'consultation fatigue' in impacted communities • develop mechanisms for bridging a gap between the measurement and forecasting of impacts and ongoing governance processes.
Achievements	<p>Key research outcomes – in terms of conceptual and theoretical development, analytical frameworks and tools and methods – will have more general application. In addition, insights gained from this research project will be used to:</p> <ul style="list-style-type: none"> • inform a broader policy dialogue about improving processes of regulation, governance, compliance and co-existence relating to cumulative impacts • enhance the capabilities of – and relationships among – key actors in industry, government and the community in relation to forecasting and responding to cumulative socioeconomic impacts in a systematic and efficient way.
Outputs	http://www.ccsq.uq.edu.au/Research/cumulativesocioeconomicimpacts.aspx
Key personnel	Rifkin, Will; Uhlmann, Vikki; Everingham, Jo-Anne; May, Kylie

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
Research themes	Cumulative impact assessment
Project information source	UQ CCSG Online Portal

Table 4.179 Project 179: Impacts of CSG production on regional groundwater systems

Project characteristics	Details
Project title	Impacts of CSG production on regional groundwater systems
Project location	Australia
Principal investigator	Reid, Lynn B
Lead institution	COM Smith, Perth, WA, Australia
Project budget	Unknown
Source of funding	Unknown
Project duration	Unknown—Literature output 2013
Current status	Unknown—Literature output 2013
Project summary	<p>The emergence of a coal seam gas (CSG) industry in Australia has been accompanied by concern about potential impacts on regional aquifers, including the Great Artesian Basin. The volumes of water withdrawn during production of CSG need to be understood in the context of water use from all sources, including both surface water and groundwater. Nevertheless, prediction of the potential impacts of CSG production has been difficult, for a number of reasons, including the limitations of readily available groundwater modelling software and a lack of understanding of the differences between approaches taken by reservoir engineers and hydrogeologists.</p> <p>The purpose of this paper is to explain:</p> <ul style="list-style-type: none"> • the differences between methods used by reservoir engineers and hydrogeologists • why traditional groundwater modelling, without modification, is not capable of predicting the quantity and quality of groundwater produced during gas production • how impacts on the surrounding environment can be predicted with a greater level of confidence once modifications to traditional groundwater modelling methods are made. <p>Multiphase reservoir models (e.g. based on ECLIPSE) predict desorption of gas, migration of gas towards production wells and co-production of water, but are not designed to predict regional impacts at the water table or where coal seams sub-crop alluvial aquifers. Regional scale groundwater flow models (e.g. based on MODFLOW and FEFLOW) represent changes in storage of water in a fundamentally different way, and cannot predict rates of production of water or de-pressurisation to match the predictions of reservoir models.</p> <p>A number of CSG projects have been approved in Australia in recent years. This paper will compare and contrast the approaches taken to predict potential impacts on regional aquifers, as described in publicly available Environmental Impact Statements. The Australian experience will be compared with what has been learned in the Powder River Basin in the USA, including the differences between predictions and observations, before and after the start of gas production. Modifications to traditional groundwater modelling software will be described, based on the use of TOUGH-j2 to predict multiphase behaviour and on internal modifications to MODFLOW.</p>
Objectives	<p>The purpose of this paper is to explain:</p> <ul style="list-style-type: none"> • the differences between methods used by reservoir engineers and

Project characteristics	Details
	<p>hydrogeologists</p> <ul style="list-style-type: none"> • why traditional groundwater modelling, without modification, is not capable of predicting the quantity and quality of groundwater produced during gas production • how impacts on the surrounding environment can be predicted with a greater level of confidence once modifications to traditional groundwater modelling methods are made.
Achievements	<p>This paper compares and contrasts the approaches taken to predict potential impacts on regional aquifers, as described in publicly available Environmental Impact Statements. The Australian experience is also compared with what has been learned in the Powder River Basin in the USA, including the differences between predictions and observations, before and after the start of gas production.</p>
Outputs	<p>Reid LB, Townley LR and Smith AJ (2013) "Impacts of CSG production on regional groundwater systems". 40th IAH Congress on Solving the Groundwater Challenges of the 21st Century. Perth, Australia.</p>
Key personnel	<p>Reid, Lynn B; Townley, Lloyd R; Smith, Anthony J</p>
Research themes	<p>Aquifer interconnectivity, water-dependent resources</p>
Project information source	<p>40th IAH Congress</p>

Table 4.180 Project 180: A collaborative approach to address the cumulative impacts of mine-water discharge: Negotiating a cross-sectoral waterway partnership in the Bowen Basin, Australia

Project characteristics	Details
Project title	A collaborative approach to address the cumulative impacts of mine-water discharge: Negotiating a cross-sectoral waterway partnership in the Bowen Basin, Australia
Project location	Australia
Principal investigator	Eberhard, Rachel
Lead institution	Eberhard Consulting
Project budget	Unknown
Source of funding	Unknown
Project duration	Unknown—Literature output 2013
Current status	Unknown—Literature output 2013
Project summary	<p>The social and environmental impacts of rapidly expanding coal and gas industries have generated high levels of public concern and there is increasing evidence of cumulative impacts. In the Bowen Basin of Queensland (Australia) water quality issues have triggered a collaborative response to coordinate monitoring efforts, integrate data and information and undertake regional analysis to inform landscape-scale management. Collaborative governance is promoted as a response to complex environmental problems, such as cumulative impacts. However, application of this approach to the resources and energy sectors remains a significant research gap.</p> <p>This paper reports the results of action research in the 2 years taken to negotiate the establishment of collaborative governance arrangements to address mine-water discharge impacts in the Bowen Basin. The long establishment phase has been required to refine objectives, build trust, develop governance mechanisms and secure resourcing commitments. The partnership established involves more than 20 organisations including regulators, resources and energy companies, agricultural industries and research organisations. The breadth of participating sectors is a significant innovation, but also represents a major challenge in establishing this model of regional environmental governance. Promising strategies adopted to manage these tensions have included neutral brokerage, facilitative leadership, establishing legitimacy of the collaboration and credibility of its reports. The case study provides a cautionary tale of the pursuit of the promise of 'everyone working together' to address cumulative impacts. Policy implications include the need for extended commitment and integration of collaborative and other responses.</p>
Objectives	This research aims to explore the application of regional collaborative governance models to manage the cumulative impacts of resource industries.
Achievements	This paper reports on the outcomes of a 2-year action research process that followed the progressive negotiation of partnership objectives, membership, funding arrangements and governance structures. In the following section we review literature on cumulative impacts and collaborative governance. "Research questions" details the research questions that guided our enquiry and "Methods" outlines the methodology and data collection methods. In "Background to the Fitzroy partnership for river health", we provide background on the establishment of the partnership and in "Results", detail the results. The paper concludes with

Project characteristics	Details
	implications for policy and practice.
Outputs	http://dx.doi.org/10.1016/j.resourpol.2013.02.002 Eberhard R, Johnston N and Everingham, J-A (2013) "A collaborative approach to address the cumulative impacts of mine-water discharge: Negotiating a cross-sectoral waterway partnership in the Bowen Basin, Australia". <i>Resources Policy</i> , 38 (4). Langford Lane, Kidlington, Oxford, OX5 1GB, United Kingdom: Elsevier Ltd.
Key personnel	Eberhard, Rachel; Johnston, Nathan; Everingham, Jo-Anne
Research themes	Water-dependent ecosystems, cumulative impact assessment
Project information source	Literature

Table 4.181 Project 181: Water sharing and coal mining in the Gunnedah Basin – an overallocated catchment

Project characteristics	Details
Project title	Water sharing and coal mining in the Gunnedah Basin – an overallocated catchment
Project location	Australia
Principal investigator	Timms, W
Lead institution	School of Mining Engineering, University of New South Wales
Project budget	Unfunded
Source of funding	Unfunded
Project duration	2014 – 2015
Current status	In planning
Project summary	This project will be an undergraduate 4 th year honours project focussing on water sharing and coal mining in the Gunnedah Basin.
Objectives	Unknown
Achievements	Unknown
Outputs	Unknown
Key personnel	Timms, W
Research themes	Water supplies, mine water discharge, salt management
Project information source	Survey

Table 4.182 Project 182: Towards best practice in sustainability reporting on water for the mining industry in Australia

Project characteristics	Details
Project title	Towards best practice in sustainability reporting on water for the mining industry in Australia
Project location	Australia
Principal investigator	Taplin, R
Lead institution	School of Mining Engineering, University of New South Wales
Project budget	\$4900
Source of funding	UNSW School of Mining Engineering research grant
Project duration	2012 – end of 2013
Current status	Completed
Project summary	<p>This pilot research investigated sustainability reporting on water by the mining industry in Australia. Research aims were to:</p> <ul style="list-style-type: none"> • review current sustainability reporting practices • sustainability indicators used for reporting • current best practice internationally. <p>Research impact will be in comparison of sustainability reporting processes in Australia and internationally for the mining industry. Outcomes include: preliminary conclusions about effective approaches to sustainability reporting for mining companies that allow for corporate inter-comparisons and benchmarking; and recommendations for further research required to develop best practice guidelines for industry in Australia.</p>
Objectives	To evaluate water sustainability reporting by the mining industry in the Central West of NSW as a pilot project.
Achievements	Pilot study complete.
Outputs	<p>Timms W, Leong S, Taplin R, Hazelton J and Laurence D (2013) Mine site water information disclosures in the context of watersheds and reporting frameworks, Eastern Australia. In: Brown A, Figueroa L, Wolkersdorfer C (Eds.) <i>Reliable mine water technology</i>, Proceedings of the International Mine Water Association Annual Conference, 5–9 August 2013, Golden, Colorado. Abstract. ISBN 978-0-615-79385-6.</p> <p>Leong S, J Hazleton, R Taplin, Timms W, D Laurence (2013) Mining company information provision for the needs of the local community: water usage disclosures for the Macquarie And Lachlan Catchments, Australia. <i>Journal of Cleaner Production</i>. In press.</p> <p>Leong S, J Hazleton, R Taplin, Timms W, D Laurence (2013) Mining company information provision for the needs of the local community: water usage disclosures for the Macquarie And Lachlan Catchments, Australia. <i>Journal of Cleaner Production</i>. Accepted with revision.</p>
Key personnel	Taplin, R
Research themes	Water supplies, groundwater-dependent ecosystems, mine water discharge, salt management
Project	Survey

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
information source	

Table 4.183 Project 183: Leading practice framework for coal seam gas development in Australia

Project characteristics	Details
Project title	Leading practice framework for coal seam gas development in Australia
Project location	Australia
Principal investigator	Lennon, Louise
Lead institution	Sinclair Knight Merz
Project budget	Unknown
Source of funding	Unknown
Project duration	Unknown—Literature output 2013
Current status	Unknown—Literature output 2013
Project summary	<p>Leading practice is defined as an activity that is currently in use in a jurisdiction, nationally or internationally that constitutes the forefront approach to that activity. It should not be confused with best practice, as best practice may not be achievable, practical or economic. To identify leading practice for coal seam gas (CSG) development in Australia, the various threats and/or hazards as a result of CSG activity were determined. The key identified threats were large scale de-pressurisation of aquifers which has the potential to cause impacts to the groundwater resource and environment more generally through reduced groundwater levels; altered flow regimes; changes to water quality and supply volumes and the potential release of gas into existing bores. In addition, poor well integrity has the potential to impact regional groundwater resources, existing and future users and the environment via the uncontrolled release of fluids, solids and gases into both the surface and sub-surface environment.</p> <p>Strategies and specific actions that could be undertaken to mitigate these threats were assessed and it is the combination of these mitigation strategies that is termed leading practice. The CSG industry in Australia appears to be operating under leading practice in many areas. By far the majority of strategies identified internationally as 'leading' are already being practiced in NSW or Queensland (or both). Consequently, leading practice in Australia can be specified from the existing regulations without significant change from current practice in Australia.</p> <p>The development of leading practice in CSG operations raised several issues however, that will require further consideration. For example, there are a number of cross-compliance issues that need to be resolved that extend beyond the CSG industry. Two specific examples include:</p> <ul style="list-style-type: none"> • the manner in which CSG impacts on water resources are dealt with within current water resource planning regimes • the role of the closely-related regulations concerning exploration in the coal industry may have in mitigating impacts of CSG development. <p>Notably, water resource planning is recognised as a major issue in relation to the management of the impacts of CSG development in Australia and is currently managed differently in different States.</p>
Objectives	To identify leading practice for coal seam gas (CSG) development in Australia, the various threats and/or hazards as a result of CSG activity.
Achievements	Unknown
Outputs	Lennon L, Evans R and Richardson S (2013) "Leading practice framework for coal seam gas development in Australia". 40 th IAH Congress on Solving the

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project characteristics	Details
	Groundwater Challenges of the 21 st Century. Perth, Australia.
Key personnel	Lennon, Louise; Evans, Ray; Richardson, Stuart
Research themes	Cumulative impact assessment
Project information source	40 th IAH Congress

Table 4.184 Project 184: Quantifying the uncertainty associated with predicting CSG production impacts

Project characteristics	Details
Project title	Quantifying the uncertainty associated with predicting CSG production impacts
Project location	Australia
Principal investigator	Kelly, Bryce
Lead institution	University of New South Wales
Project budget	\$375 000* (*figure sourced from Connected Waters Institute 2013 Annual Review)
Source of funding	Cotton Research and Development Corporation (Primary Funding)
Project duration	1 July 2013 – 30 June 2015
Current status	In progress
Project summary	This project will examine the impact of the expansion of coal seam gas (CSG) production in the Surat Basin on groundwater levels in the upper Condamine alluvium and the eastern portion of the Great Artesian Basin. The research will highlight any potential concerns that would impinge upon the future availability of groundwater to the irrigation sector. This project will also benchmark in priority areas in the Condamine Alluvium groundwater quality, major ion chemistry, and groundwater and air methane concentrations.
Objectives	<ul style="list-style-type: none"> • Baseline groundwater quality in the Condamine Catchment. • Major ion chemistry and hydrochemical facies analysis. • Dating the age of the groundwater. • Background methane levels in the groundwater and air. • 3D geological modelling. • Assessing the cumulative impacts using flow modelling.
Achievements	Groundwater sampling and mobile gas surveys completed.
Outputs	http://www.connectedwaters.unsw.edu.au/news/2014/01/study-assess-water-connectivity-condamine
Key personnel	Kelly, Bryce
Research themes	Aquifer interconnectivity, surface water, water supplies, water-dependent ecosystems, cumulative impact assessment
Project information source	Survey

Table 4.185 Project 185: Characterisation of current groundwater uses in the Surat and Bowen Basins

Project characteristics	Details
Project title	Characterisation of current groundwater uses in the Surat and Bowen Basins
Project location	Australia
Principal investigator	McIntyre, Neil
Lead institution	University of Queensland, Centre for Water in the Minerals Industry
Project budget	Unknown
Source of funding	Centre for Water in the Minerals Industry, University of Queensland
Project duration	21 August 2013 – Unknown
Current status	On hold
Project summary	This project will explore the use of geostatistical methods to combine the limited data about metered groundwater use with other available data that relates to groundwater use, such as land use type, stock type, dwelling density and vegetation cover. If enough data is available, the project will develop and trial new techniques for estimating current groundwater use and evaluate the potential to improve groundwater modelling outcomes.
Objectives	Develop improved techniques for estimating groundwater use by non-CSG activities and improve groundwater modelling outcomes.
Achievements	Suitable spatial and temporal datasets have been identified and suitable geostatistical methods have been identified. Project on hold pending consideration of extent of available data and potential impact of improved methodologies.
Outputs	Project reports and journal articles will be released.
Key personnel	McIntyre, Neil; Keir, Greg
Research themes	Water-dependent ecosystems, cumulative impact assessments
Project information source	Survey

4.9.3 China

Table 4.186 Project 186: The coal and water consumption forecast analysis of China's coal chemical industry

Project characteristics	Details
Project title	The coal and water consumption forecast analysis of China's coal chemical industry
Project location	China
Principal investigator	Hong, Liu
Lead institution	Energy System Analysis Center, Energy Research Institute, National Development and Reform Commission
Project budget	50 000 RMB Yuan
Source of funding	Energy Research Institute, NDRC, China
Project duration	2014
Current status	In progress
Project summary	Based on collected the information of China's current capacities of coal and water resources in different areas, the study would analysis the coal and water recourses demand/constraints for China's possible technical pathways of coal chemical production, including coal seam gas, etc.
Objectives	To identify the constraints of coal and water resources for China's Coal chemical industry development.
Achievements	This study results will hopefully submitted to government for the policy drafting of national coal chemical industry planning.
Outputs	Unknown
Key personnel	Hong, Liu
Research themes	Cumulative impact assessments
Project information source	Survey

4.9.5 United Kingdom

Table 4.187 Project 187: An Environmental Risk Assessment for coal bed methane, coal mine methane and abandoned mine methane operations in England

Project characteristics	Details
Project title	An Environmental Risk Assessment for coal bed methane, coal mine methane and abandoned mine methane operations in England
Project location	United Kingdom
Principal investigator	Parsons Brinckerhoff
Lead institution	Environment Agency
Project budget	\$10 000
Source of funding	Environment Agency
Project duration	20 November 2013 – 30 June 2014
Current status	Completed
Project summary	The ERA will provide a firm and comprehensive view of the environmental risks from coal bed methane operations to inform both regulatory and operational decision-making and the advice we provide to Planning Authorities. It will enable us to communicate our understanding to technical and non-technical audiences in a clear and consistent manner. It will provide the basis for guidance to Area permitting staff. It will give confidence to local communities and NGOs that we are capable of regulating this high-profile industry in an appropriate and evidence-based way.
Objectives	To develop a methodology for, and a high-level assessment of, the environmental risks from coal bed methane (CBM) and coal mine methane (CMM) exploration and production including any closure and decommissioning. This should include operations at, or around, conventional coal mines where gas extraction is an additional activity rather than the main purpose of the site.
Achievements	See summary. Aim to assist with decision making/planning once report is ready to be circulated.
Outputs	A report to be published externally on www.gov.uk in due course.
Key personnel	Parsons Brinckerhoff
Research themes	Cumulative impact assessment
Project information source	Survey

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Appendix A – Project survey

Literature and Science Review of Coal Seam Gas and Coal Mining Recently Commissioned Research 2000-

The Office of Water Science at the Department of the Environment, Australia (<http://www.environment.gov.au>) is seeking to identify recently commissioned or completed projects researching the potential impacts of coal seam gas (coal bed methane) and coal mining on water resources and water-dependent ecosystems in China, India, the United Kingdom, Russia, North America and Australia since 2000.

To be included in this important international review, please complete the following form for **each** of your projects researching the potential impacts of coal seam gas (coal bed methane) and coal mining on water resources and water-dependent ecosystems. Thank you for your participation.

Return completed forms to Alexandra Badenhop

Email: a.badenhop@wrl.unsw.edu.au

Fax: +612 9949 4188

If you have any questions, please call +612 8071 9867.

Project title	Click here to enter text.	
Project location	Click here to enter text.	
Principal researcher	Click here to enter text.	
Lead institution	Click here to enter text.	
Project budget/cost	Click here to enter text.	
Source of funding	Click here to enter text.	
Project duration	Start: Click here to enter a date.	Finish: Click here to enter a date.
Current status	Choose an item.	
Project summary		
Click here to enter text.		
Objectives		
Click here to enter text.		
Achievements		
Click here to enter text.		
Outputs (<i>Please enter references or links to available reports/journal articles/conference paper etc</i>)		

Reference list for water-related coal seam gas and coal mining research (Report 4)

Click here to enter text.	
Key personnel 1	
Name:	Click here to enter text.
Phone:	Click here to enter text.
Email:	Click here to enter text.
Key personnel 2	
Name:	Click here to enter text.
Phone:	Click here to enter text.
Email:	Click here to enter text.
Which of these research areas best describe your work <i>(Please check as many as are relevant)</i>	
<div style="margin-bottom: 10px;"> <input type="checkbox"/> Aquifer interconnectivity <div style="margin-left: 20px;"> <input type="checkbox"/> Baseline information (water quality and quantity) <input type="checkbox"/> Field based and modelling approaches for assessing connectivity <input type="checkbox"/> Groundwater flow and solute transport dynamics </div> </div> <div style="margin-bottom: 10px;"> <input type="checkbox"/> Disruption of surface water flow pathways <div style="margin-left: 20px;"> <input type="checkbox"/> Subsidence <input type="checkbox"/> Mine cone of depression <input type="checkbox"/> Stream diversions <input type="checkbox"/> Infrastructure </div> </div> <div style="margin-bottom: 10px;"> <input type="checkbox"/> Co-produced water and salt management (CSG) and mine water & salt management (coal mines) <div style="margin-left: 20px;"> <input type="checkbox"/> Aquifer injection and/or water treatment (technologies, relative cost benefit) <input type="checkbox"/> Effect on land and water resources (including. Irrigation) <input type="checkbox"/> Effect on Water-dependent ecosystems (streams, rivers, floodplains, wetlands, GDEs, peat swamps) </div> </div> <div style="margin-bottom: 10px;"> <input type="checkbox"/> Seismicity </div> <div style="margin-bottom: 10px;"> <input type="checkbox"/> Integrity of wells - installation, operation, decommissioning </div> <div style="margin-bottom: 10px;"> <input type="checkbox"/> Hydraulic fracturing <div style="margin-left: 20px;"> <input type="checkbox"/> Chemical - Surface and groundwater quality <input type="checkbox"/> Physical - Aquitard disruption, borehole collapse </div> </div> <div style="margin-bottom: 10px;"> <input type="checkbox"/> Quality and reliability of water supplies including environmental health <div style="margin-left: 20px;"> <input type="checkbox"/> Mine site and gas field remediation, including well decommissioning and post mining voids <input type="checkbox"/> Long term impacts, including, timescales for water levels to return to pre-development levels (quality/quantity) <input type="checkbox"/> Chemical migration and toxicity <input type="checkbox"/> Managing salt and heavy metals </div> </div> <div style="margin-bottom: 10px;"> <input type="checkbox"/> Water-dependent ecosystems <div style="margin-left: 20px;"> <input type="checkbox"/> Prediction of potential impacts to water-dependent ecosystems(streams, rivers, floodplains, wetlands, GDEs, peat swamps) <input type="checkbox"/> Response and tolerances of water-dependent ecosystems to changes in water regime (surface and groundwater quantity, seasonal patterns, variability, interactions) and water quality </div> </div>	

Reference list for water-related coal seam gas and coal mining research (Report 4)

- ☐ Mitigation measures
- ☐ Monitoring techniques
- ☐ Cumulative impact assessments
- ☐ Other: Please list all

Do you know of other colleagues or counterparts involved with relevant research?

☐ Yes

☐ No

Name:	Click here to enter text.
Research Institution:	Click here to enter text.
Email:	Click here to enter text.
Phone:	Click here to enter text.

Name:	Click here to enter text.
Research Institution:	Click here to enter text.
Email:	Click here to enter text.
Phone:	Click here to enter text.

Appendix B – Project survey recipients

A listing of the personnel contacted (as of 10 October 2014) for information regarding relevant research is summarised in Table B1.

Table B1 Contacted personnel

Country	Research institution	Contact name	Online survey completed	Active researcher	Information source
Australia	ACARP	Roger Wischusen	x	Yes	ACARP
Australia	AGL Energy	Scott Thomas	x	Yes	US EPA CMOP
Australia	Alluvium Consulting	Rohan Lucas	x	Yes	Literature
Australia	Arrow Energy	Xuyan Wang	x	x	Literature
Australia	Australian National University	Simon McClusky	x	Yes	Literature
Australia	Australian National University	Dr. Kuntala Lahiri-Dutt	x	Yes	US EPA CMOP
Australia	Central Queensland University	Claire Sellens	x	Yes	Literature
Australia	CH2M Hill	Paul Wilkinson	x	Yes	Literature
Australia	Coffey Geotechnics	Ben Rotter	x	Yes	Literature
Australia	COM Smith	Lynn B Reid	x	Yes	Literature
Australia	Cooperative Research Centre for Spatial Information	Philip Tickle	x	Yes	Literature
Australia	CSIRO	Michael Karsten	x	Yes	Literature
Australia	CSIRO	Graeme Batley	x	Yes	Literature
Australia	CSIRO	Greg Rowan	x	x	US EPA CMOP
Australia	CSIRO	Xiangfeng Zhang	x	Yes	Literature
Australia	CSIRO	Rob Jeffrey	x	Yes	Literature
Australia	CSIRO	Sunil Varma	x	Yes	Literature
Australia	CSIRO	Damian Barrett	x	Yes	Literature
Australia	CSIRO	Ramesh Thiruvengkatachari	x	Yes	Literature
Australia	CSIRO	Reem Freij-Ayoub	x	x	Literature
Australia	CSIRO	Peter Dillon	x	x	Literature
Australia	CSIRO	Catherine Moore	x	x	Literature

Reference list for water-related coal seam gas and coal mining research (Report 4)

Country	Research institution	Contact name	Online survey completed	Active researcher	Information source
Australia	CSIRO	Deepak Adhikary	x	Yes	Literature
Australia	CSIRO	David Post	Yes	Yes	Literature
Australia	CSIRO	Tara Martin	x	Yes	Literature
Australia	CSIRO	Rai Kookana	x	Yes	Literature
Australia	CSIRO	Neil Huth	x	Yes	Literature
Australia	CSIRO	Leif Wolf	x	x	Literature
Australia	CSIRO	Konrad Miotlinski	x	x	Literature
Australia	CSIRO	Sebastien Lamontagne	x	Yes	Literature
Australia	CSIRO	Lei Gao	x	Yes	Literature
Australia	CSIRO	Russ Babcock	x	Yes	Literature
Australia	CSIRO	Julian Strand	x	Yes	Literature
Australia	CSM Energy Limited	Duncan van der Merwe	x	x	US EPA CMOP
Australia	Curtin University	Brian Evans	x	Yes	Literature
Australia	Curtin University	Kelly Pilgrim-Byrne	x	Yes	Literature
Australia	Curtin University	Roberto Aguilera	x	Yes	Literature
Australia	Curtin University	Jeff Charrois	x	x	Literature
Australia	Department of Natural Resources and Mines	Andrew Biggs	x	Yes	Literature
Australia	Department of Parliamentary Services, Victoria	Ross Catriona	x	Yes	Literature
Australia	DNRM	Joan Meecham	x	x	Literature
Australia	DNRM	Evan Marshall	x	Yes	Literature
Australia	Eastern Star Gas Limited	Ashley Edgar	x	x	US EPA CMOP
Australia	Eberhard Consulting	Rachel Eberhard	x	Yes	Literature
Australia	Eco Logical Australia	Emma Garraway	x	Yes	Literature
Australia	Flinders University	Craig Simmons	x	Yes	Literature
Australia	Flinders University	Peter J. Cook	x	Yes	Literature
Australia	Flinders University	Ilka Wallis	x	Yes	Literature
Australia	Geoscience Australia	Luke. Wallace	x	Yes	Literature
Australia	Geoscience Australia	Barry Drummond	x	x	Literature
Australia	Geoscience Australia	Kriton Glenn	x	Yes	Literature

Reference list for water-related coal seam gas and coal mining research (Report 4)

Country	Research institution	Contact name	Online survey completed	Active researcher	Information source
Australia	Geoscience Australia	Gabrielle Yates	x	Yes	Literature
Australia	GISERA	Henning Prommer	x	x	Literature
Australia	Golder Associates	Ray Hatley	x	x	Literature
Australia	Golder Associates Pty Ltd	Lange Jorstad	x	x	Literature
Australia	Healthy Headwaters CSG Water Feasibility Study	Angus Veitch	x	x	Literature
Australia	High Commission of India in Australia	The High Commission of India in Australia	x	Yes	Literature
Australia	Hyder Consulting	Andrew Jones	x	Yes	US EPA CMOP
Australia	Hyder Consulting	Hari Pokharel	x	Yes	Literature
Australia	Klohn Crippen Berger	Matthew Landers	x	Yes	Literature
Australia	Lunagas Pty Limited	Les Lunarzewski	x	Yes	US EPA CMOP
Australia	Macquarie University	Peter Davies	Yes	Yes	Literature
Australia	Macquarie University	Damian Gore	x	Yes	Literature
Australia	Mine Subsidence Engineering Consultants	Arthur Waddington	x	Yes	Literature
Australia	Mine Subsidence Engineering Consultants	Daryl Kay	x	Yes	Literature
Australia	Mine Subsidence Engineering Consultants	Paul Austin	Yes	Yes	Literature
Australia	Mine Subsidence Engineering Consultants	Don Kay	Yes	Yes	Literature
Australia	Mine Subsidence Engineering Consultants	James Barbato	Yes	Yes	Literature
Australia	Monash University	I Cartwright	x	Yes	Literature
Australia	Monitor Optics Systems	Giorgio Nosenzo	x	Yes	Literature
Australia	MWH Australia	Johann Poinapen	x	Yes	Literature
Australia	MWH Global	Ryan Jakubowski	x	Yes	Literature

Reference list for water-related coal seam gas and coal mining research (Report 4)

Country	Research institution	Contact name	Online survey completed	Active researcher	Information source
Australia	Namoi Catchment Management Authority	Francesca Andreoni	x	x	Literature
Australia	North West Local Land Services	James Hutchinson-Smith	x	x	Literature
Australia	NSW Department of Trade and Investment, Regional Infrastructure and Services	Steve Cozens	x	x	Literature
Australia	NSW Government	Mary O'Kane	x	Yes	Literature
Australia	NSW Office for Water (NSW Government)	NSW Department of Primary Industries	x	Yes	Literature
Australia	Origin Energy	Ryan Morris	x	Yes	Literature
Australia	Origin Energy	Marcus Horgan	x	Yes	Literature
Australia	Origin Energy	Ned Hamer	x	Yes	Literature
Australia	Origin Energy Queensland	Gerard Mckay	x	x	US EPA CMOP
Australia	Pells Consulting	Phillip Pells	Yes	Yes	Literature
Australia	QGC - A BG Group Business	Stuart Young	x	x	Literature
Australia	Queensland Department of Natural Resources and Mines	Sanjeev Pandey	x	Yes	Literature
Australia	Queensland University of Technology	Matthias Raiber	x	Yes	Literature
Australia	Queensland University of Technology	Maree Corkeron	x	Yes	Literature
Australia	Queensland University of Technology	Nicola Swayne	x	Yes	Literature
Australia	Queensland University of Technology	O. Gaede	x	Yes	Literature
Australia	Queensland University of Technology	Malcolm E Cox	x	Yes	Literature
Australia	Queensland University of Technology	Claudio Moyal	x	Yes	Literature
Australia	Queensland University of Technology	Daniel Owen	x	Yes	Literature
Australia	Resource Land Management Services	Grahame Baker	x	Yes	US EPA CMOP
Australia	RPS	Bob Pearson	x	x	Literature

Reference list for water-related coal seam gas and coal mining research (Report 4)

Country	Research institution	Contact name	Online survey completed	Active researcher	Information source
Australia	RPS	David Freebairn	x	Yes	Literature
Australia	RPS	Hugh Middlemis	x	Yes	Literature
Australia	RPS	Gordon Taylor	x	Yes	Literature
Australia	Schlumberger Water Services	Rolf Herrmann	x	Yes	Literature
Australia	Sinclair Knight Merz	R Evans	x	Yes	Literature
Australia	Sinclair Knight Merz	Louise Lennon	x	x	Literature
Australia	Standing Council on Energy and Resources	SCER	x	Yes	Literature
Australia	Stellar Corp	James Butterworth	x	Yes	Literature
Australia	Sydney Catchment Authority	Wendy McLean	x	Yes	Literature
Australia	Sydney Catchment Authority	Sydney Catchment Authority	x	Yes	Literature
Australia	University of Adelaide	David Ottaway	x	Yes	Literature
Australia	University of Adelaide	Seyed saeid Hashemi	x	Yes	Literature
Australia	University of Adelaide	Stephan Thiel	x	Yes	Literature
Australia	University of Melbourne	Mike Sandiford	x	Yes	Literature
Australia	University of New South Wales	Stuart Khan	x	Yes	Literature
Australia	University of New South Wales	Doug Anderson	x	Yes	Literature
Australia	University of New South Wales	Wendy Timms	x	Yes	Literature
Australia	University of New South Wales	Steven Pells	x	Yes	Literature
Australia	University of New South Wales	Bruce Hebblewhite	x	Yes	Literature
Australia	University of New South Wales	Richard Crane	x	Yes	Literature
Australia	University of New South Wales	Bryce Kelly	x	Yes	Literature
Australia	University of Newcastle	Stephen Fityus	x	Yes	Literature
Australia	University of Newcastle, Australia	Garry Willgoose	x	Yes	Literature

Reference list for water-related coal seam gas and coal mining research (Report 4)

Country	Research institution	Contact name	Online survey completed	Active researcher	Information source
Australia	University of Newcastle, Australia	Jubert Pineda	×	Yes	Literature
Australia	University of Queensland	Steven Pratt	×	Yes	Literature
Australia	University of Queensland	Joan Esterle	×	Yes	Literature
Australia	University of Queensland	Paul Lant	×	Yes	Literature
Australia	University of Queensland	Thomas Baumgartl	Yes	Yes	Literature
Australia	University of Queensland	Stephen Tyson	×	Yes	Literature
Australia	University of Queensland	Christine Adams-Hosking	Yes	Yes	Literature
Australia	University of Queensland	Peter Erskine	×	Yes	Literature
Australia	University of Queensland	Victor Rudolph	×	Yes	Literature
Australia	University of Queensland	Sue Vink	×	Yes	Literature
Australia	University of Queensland	Jim Cavaye	Yes	Yes	Literature
Australia	University of Queensland	Kim Baulbys	Yes	Yes	Literature
Australia	University of Queensland	Chris Moran	×	×	Literature
Australia	University of Queensland	Agi Burra	×	Yes	Literature
Australia	University of Queensland	Jo-Anne Everingham	×	Yes	Literature
Australia	University of Queensland	L. J Sonter	×	Yes	Literature
Australia	University of Queensland	Alan Woodley	×	×	Literature
Australia	University of Queensland	Helen Schultz	Yes	Yes	Literature
Australia	University of Queensland	Ling Li	×	Yes	Literature
Australia	University of Queensland	Simon Smart	×	Yes	Literature
Australia	University of	Alistair Innes-	×	Yes	Literature

Reference list for water-related coal seam gas and coal mining research (Report 4)

Country	Research institution	Contact name	Online survey completed	Active researcher	Information source
	Queensland	Walker			
Australia	University of Queensland	Xiaoyu Wang	x	Yes	Literature
Australia	University of Queensland	Max Shelton	x	Yes	Literature
Australia	University of Queensland	J H Park	x	x	Literature
Australia	University of Queensland	Will Rifkin	x	Yes	Literature
Australia	University of Queensland, Sustainable Minerals Institute	Daniel Franks	x	Yes	Literature
Australia	University of Southern Queensland	Steven Raine	x	Yes	Literature
Australia	University of Southern Queensland	Ihsan Hamawand	Yes	Yes	Literature
Australia	University of Southern Queensland	Vasanth Aravinthan	Yes	Yes	Literature
Australia	University of Sydney	Alan Randall	x	Yes	Literature
Australia	University of Technology Sydney	Ben Kefford	x	x	Literature
Australia	URS Australia	Stephen Hancock	x	Yes	Literature
Australia	Victoria University	Peter Sancio	x	Yes	Literature
Canada	Alberta Environment & Sustainable Resource Development	Curtis Brock	x	Yes	Literature
Canada	Alberta Environment & Sustainable Resource Development	Richard Casey	x	Yes	Literature
Canada	Alberta Geological Survey	Ryan Schultz	x	Yes	Literature
Canada	Alberta Innovates	Ernie Perkins	x	Yes	Literature
Canada	Alberta University	Tayfun Babadagli	x	Yes	Literature
Canada	CANMET Energy Technology Centre	Hristo Sapoundjiev	x	Yes	US EPA CMOP
Canada	Council of Canadian Academies	Elizabeth Dowdeswell	x	x	Literature
Canada	Environment Canada	James W Roy	x	x	Literature
Canada	Environment Canada	Dale Van	x	Yes	NGWA Workshop

Reference list for water-related coal seam gas and coal mining research (Report 4)

Country	Research institution	Contact name	Online survey completed	Active researcher	Information source
		Stempvoort			2014
Canada	Fourth Generation Corporation	Brian Watling	x	x	US EPA CMOP
Canada	Geofirma Engineering	R Jackson	x	Yes	Literature
Canada	Geofirma Engineering	Richard Jackson	x	Yes	Literature
Canada	Geofirma Engineering	A Gorody	x	Yes	Literature
Canada	Geological Survey of Canada	Christine Rivard	x	Yes	NGWA Workshop 2014
Canada	Integrated Sustainability Consultants Ltd., Calgary	Jon Fennell	x	Yes	NGWA Workshop 2014
Canada	Laval University	John W Molson	x	Yes	Literature
Canada	Royal Military College of Canada	K. J. Reimer	x	Yes	Literature
Canada	Simon Fraser University	Black Boutilier	x	Yes	Literature
Canada	University of British Columbia	Marc Bustin	x	Yes	Literature
Canada	University of British Columbia	Leslie Smith	x	Yes	Literature
Canada	University of British Columbia	William R. Cullen	x	x	Literature
Canada	University of Calgary	Cathryn Ryan	x	Yes	NGWA Workshop 2014
Canada	University of Calgary	Bernhard Mayer	Yes	Yes	Literature
Canada	University of Guelph	Beth Parker	x	Yes	Literature
Canada	University of Waterloo	David Rudolph	x	Yes	Literature
Canada	University of Waterloo	Ramon Aravena	x	Yes	Literature
Canada	University of Waterloo	Maurice B. Dusseault	x	Yes	Literature
China	Anhui University of Science and Technology	Ting-yu Fan	x	Yes	Literature
China	Anhui University of Science and Technology	Liang-Ji Xu	x	Yes	Literature
China	Anhui University of Science and	Qimeng Liu	x	Yes	Literature

Reference list for water-related coal seam gas and coal mining research (Report 4)

Country	Research institution	Contact name	Online survey completed	Active researcher	Information source
	Technology				
China	Anhui University of Science and Technology	HuiHu Liu	x	Yes	Literature
China	Anhui University of Science and Technology	Guo Hui	x	x	Literature
China	Changan University	Chao-ying Zhao	x	Yes	Literature
China	China Carbon Forum	Dr Anton G O Smitsendonk	x	Yes	US EPA CMOP
China	China Coal Information Institute (CCII)	Mr. Huang Shengchu	x	Yes	US EPA CMOP
China	China Coal Research Institute, Beijing, China	Weinan Deng	x	Yes	Literature
China	China Coal Research Institute, Beijing, China	Xingli Li	x	Yes	Literature
China	China Coal Technology and Engineering Group	Ru-Lu Zhou	x	Yes	Literature
China	China Coalbed Methane Clearinghouse	Han Jiaye	x	Yes	US EPA CMOP
China	China National Administration of Coal Geology (CNACG)	Peng Qin	x	Yes	Literature
China	China United Coalbed Methane Corporation Ltd	Sun Mao Yuen	x	x	US EPA CMOP
China	China United Coalbed Methane Corporation Ltd	Ben Guang Guo	x	x	Literature
China	China University of Geosciences, Beijing	Jun Gu	x	Yes	Literature
China	China University of Geosciences, Beijing	Guangcai Wang	x	Yes	Literature
China	China University of Geosciences, Beijing	Pinnaduwa Kulatilake	x	Yes	Literature
China	China University of Geosciences, Beijing	MeiChen Fu	x	x	Literature
China	China University of Geosciences, Beijing	Y. J. Meng	x	Yes	Literature
China	China University of Geosciences, Beijing	Xiong Wu	x	Yes	Literature

Reference list for water-related coal seam gas and coal mining research (Report 4)

Country	Research institution	Contact name	Online survey completed	Active researcher	Information source
China	China University of Geosciences, Beijing	BaoLin Liu	x	Yes	Literature
China	China University of Geosciences, Beijing	Shan-Bo Wang	x	Yes	Literature
China	China University of Mining and Technology	Zhenqi Hu	x	Yes	Literature
China	China University of Mining and Technology	Yan-Yan Ge	x	Yes	Literature
China	China University of Mining and Technology	Peng Qi	x	x	Literature
China	China University of Mining and Technology	Huang Hanfu	x	Yes	Literature
China	China University of Mining and Technology	Jian-Bing Wang	x	Yes	Literature
China	China University of Mining and Technology	Liqiang Ma	Yes	Yes	Literature
China	China University of Mining and Technology	Donglin Dong	x	Yes	Literature
China	China University of Mining and Technology	Xu-Wen He	x	Yes	Literature
China	China University of Mining and Technology	Han Chunjian	x	Yes	Literature
China	China University of Mining and Technology	Shu-Bi Zhang	x	Yes	Literature
China	China University of Mining and Technology	Bingxiang Huang	x	Yes	Literature
China	China University of Mining and Technology	Qiang Wu	x	Yes	Literature
China	China University of Mining and Technology	Sang Shuxun	x	Yes	Literature
China	China University of Mining and Technology	Ting-Jun Wang	x	Yes	Literature
China	China University of Mining and Technology	XiJun Ma	x	x	Literature
China	China University of Mining and Technology	Ying Zhang	x	Yes	Literature
China	China University of Mining and Technology	Zhao-Jun Tian	x	Yes	Literature
China	China University of Mining and Technology	Gangwei Fan	x	Yes	Literature
China	China University of	Y. Feng	x	Yes	Literature

Reference list for water-related coal seam gas and coal mining research (Report 4)

Country	Research institution	Contact name	Online survey completed	Active researcher	Information source
	Petroleum				
China	China University of Petroleum	Qiang Tan	x	Yes	Literature
China	China University of Petroleum	Y. H Lu	x	Yes	Literature
China	China University of Petroleum	Zhao-Min Li	x	Yes	Literature
China	China University of Petroleum	Haifeng Zhao	x	Yes	Literature
China	China University of Petroleum	Zhiyuan Liu	x	Yes	Literature
China	China University of Science and Technology	Haijiang Zhang	x	Yes	Literature
China	Chinese Academy of Geological Sciences	Chen Zongyu	x	Yes	Literature
China	Chinese Academy of Geological Sciences	Fawang Zhang	x	Yes	Literature
China	Chinese Academy of Sciences (CAS), Guiyang, China	W. X. Fang	x	x	Literature
China	Chongqing University of Science & Technology	Kanhua Su	x	Yes	Literature
China	Chongqing University of Science & Technology	Chunbi Xu	x	Yes	Literature
China	CNPC Drilling Research Institute	Heng-lin Yang	x	Yes	Literature
China	Department of Petroleum Engineering, TU Clausthal	Zhaoguang Yuan	x	Yes	Literature
China	Embassy of the Peoples Republic of China in Australia	Chinese Embassy	x	Yes	Literature
China	Energy Research Institute	Liu Hong	x	Yes	Literature
China	Foreign Economic Cooperation Office (FECO)	Yueyu Zou	x	x	Literature
China	Graduate University of Chinese Academy Sciences (GUCAS)	Ju Yi-wen	x	Yes	Literature

Reference list for water-related coal seam gas and coal mining research (Report 4)

Country	Research institution	Contact name	Online survey completed	Active researcher	Information source
China	Graduate University of Chinese Academy Sciences (GUCAS)	Zhisheng Yu	Yes	Yes	Literature
China	Guizhou International Cooperation Center for Environmental Protection	Mingjie Zheng	x	Yes	US EPA CMOP
China	Guizhou International Corporation Center for Environmental Protection	Katie Scott	x	Yes	US EPA CMOP
China	Guizhou University	Fen Liao	x	Yes	Literature
China	Guizhou University	Pan Wu	x	Yes	Literature
China	Hangzhou Research Institute	Jun Zhang	x	x	Literature
China	Harbin Institute of Technology, China	Hongjun Han	x	Yes	Literature
China	Hebei University of Engineering	Yu Sun	x	Yes	Literature
China	Hebei University of Engineering, China	Jinxi Wang	x	Yes	Literature
China	Henan Polytechnic University	Chai Huabin	x	Yes	Literature
China	Henan Polytechnic University	Pan Jienan	x	Yes	Literature
China	Henan Polytechnic University	Jienan Pan	x	Yes	Literature
China	Inner Mongolia Agricultural University	Ting Ting Yang	x	Yes	Literature
China	Liaoning Technical University	Guo-Liang Bai	x	Yes	Literature
China	Mandarin Resources	Frederick Lawrence	x	Yes	US EPA CMOP
China	Mining Technology Institute of TYUT	Zhao Jianzhong	x	Yes	US EPA CMOP
China	Ministry of Environmental Protection	Zhaojing Mu	x	Yes	Literature
China	Nanjing University	Wen-Tao Li	x	Yes	Literature
China	National Natural Science Foundation	Wei Quin	x	x	Literature

Reference list for water-related coal seam gas and coal mining research (Report 4)

Country	Research institution	Contact name	Online survey completed	Active researcher	Information source
China	North China Institute of Science and Technology	Shang-Xian Yin	x	Yes	Literature
China	North East Petroleum University	Y Li	x	Yes	Literature
China	North East Petroleum University, Daqing	Y. X. Sun	x	Yes	Literature
China	Northeast Forestry University	W. H Liu	x	Yes	Literature
China	Northeast Forestry University	Hong-Fu Bao	x	Yes	Literature
China	Northwest A and F University	Li Wang	x	Yes	Literature
China	Shandong University of Science and Technology	Chongge Wang	x	Yes	Literature
China	Shanxi Water Conservation Professional Technology Institute	Qi-Liang Wang	x	x	Literature
China	Shijiazhuang University of Economics, China	Aijun Shao	x	Yes	Literature
China	Sichuan University	Xie Heping	x	Yes	Literature
China	Simonin International Corp.	Kathy Wang	x	Yes	US EPA CMOP
China	South China University of Technology	Zhi Dang	x	Yes	Literature
China	Southeast University, Nanjing	Liyuan Tong	x	Yes	Literature
China	Taiyuan University of Technology	Jianzhong Zhao	x	Yes	US EPA CMOP
China	Taiyuan University of Technology	Yan Li	x	Yes	Literature
China	United Nations Centre for Regional Development (NCRD)	Bashiru Mohamed Koroma	x	x	Literature
China	University of Chinese Academy of Sciences	Mingyu Wang	x	Yes	Literature
China	Wuhan University of Technology	Guo Xing-qiang	x	Yes	Literature
China	Xi'an Research Institute of China Coal	Hao Wang	x	x	Literature

Reference list for water-related coal seam gas and coal mining research (Report 4)

Country	Research institution	Contact name	Online survey completed	Active researcher	Information source
	Technology and Engineering Group Corp				
India	Banaras Hindu University	Virendra Kumar Mishra	x	Yes	Literature
India	BIT Sindri	G Kumar	x	Yes	Literature
India	Central Institute of Mining and Fuel Research	N Tripathi	x	Yes	Literature
India	Central Mine Planning & Design Institute Ltd	B. C. Sarkar	x	Yes	Literature
India	Central Mine Planning and Design Institute Limited (CMPDI)	Subrata Chaudhuri	x	Yes	US EPA CMOP
India	Central Pollution Control Board	Sanjeev Aggarwal	x	Yes	Literature
India	Centre for Environmental Research and Engineering, Indian Institute of Technology, Bombay	Indian Institute of Technology	x	x	Literature
India	Department of Science and Technology	Sadhana Relia	x	Yes	Literature
India	Directorate General of Hydrocarbons	D. Dash	x	Yes	Literature
India	Hindusthan Infrastructure Projects & Engineering Pvt. Ltd.	Kiran Vivekananda	x	x	US EPA CMOP
India	Indian Institute of Mines,	Gurdeep Singh	x	Yes	Literature
India	Indian Institute of Technology Guwahati	Arup Kumar Sarma	x	Yes	Literature
India	Indian Institute of Technology Kanpur	Rajiv Sinha	x	Yes	Literature
India	Indian Institute of Technology Kanpur	Vinay K. Gupta	x	x	Literature
India	Indian Institute of Technology Kharagpur	Jayanta Bhattacharya	Yes	Yes	Literature
India	Indian School of Mines, Dhanbad	Keka Ojha	x	Yes	Literature
India	Maheshwari Mining	Vinay K. Sahay	x	Yes	US EPA CMOP

Reference list for water-related coal seam gas and coal mining research (Report 4)

Country	Research institution	Contact name	Online survey completed	Active researcher	Information source
India	National Geophysical Research Institute	Ratnakar Dhakate	x	Yes	Literature
India	National Institute of Technology	K Adhikari	Yes	Yes	Literature
India	National Institute of Technology Karnataka	Dr. Ch.S.N. Murthy	x	Yes	US EPA CMOP
India	North-Eastern Hill University	O. P. Singh	Yes	Yes	Literature
India	Oil and Natural Gas Corporation	S.K. Vij	x	Yes	US EPA CMOP
India	Patna University	A. K. Singh	x	Yes	Literature
India	Science and Engineering Research Board	Science and Engineering Research Board	x	Yes	Literature
India	University of Delhi	M.K. Pandit	x	Yes	Literature
India	University of Hyderabad	Manubhav Tyagi	x	Yes	US EPA CMOP
India	University of Pune	Nanasaheb Parulekar Paryavaran Bhavan	x	Yes	Literature
Russia	Embassy of the Russian Federation in Australia	Alexander Odoevskiy	x	x	Literature
Russia	Far East Federal University	O. D Arefieva	Yes	Yes	Literature
Russia	Institute of mining Siberian branch Russian Academy of Sciences	Anwar I. Chanyshv	x	Yes	Literature
Russia	Moscow State University	Viktor Antonovich Sadovnichy	x	Yes	Literature
Russia	Moscow State University of Environmental Engineering	Lagutin Natalia	x	x	Literature
Russia	Russian Academy of Sciences	Leyla Abukova	x	Yes	Literature
Russia	Russian Academy of Sciences	V Chudaeva	x	Yes	Literature
Russia	Russian Academy of Sciences	Sergey Kazantsev	x	Yes	Literature

Reference list for water-related coal seam gas and coal mining research (Report 4)

Country	Research institution	Contact name	Online survey completed	Active researcher	Information source
Russia	Russian Academy of Sciences, Russia	Alexander I Zakharov	x	Yes	Literature
Russia	SRK Consulting	Sylvie Ogier-Halimi	x	Yes	Literature
Russia	Tomsk Polytechnic University	Olga Mazurina	x	Yes	Literature
Russia	Uglemetan	Tamara Panchisheva	x	x	Russian
UK	Aberystwyth University	Jenny M Bearcock	x	Yes	Literature
UK	Alkane Energy	Dr. Cameron Davies	x	Yes	US EPA CMOP
UK	Durham University	Richard Davies	x	x	Literature
UK	ENER-G Natural Power Limited	Hugh Richmond	x	Yes	US EPA CMOP
UK	ENER-G Natural Power Limited	Ian Cooper	x	Yes	US EPA CMOP
UK	Environment Agency	Alwyn Hart	x	Yes	Literature
UK	Environment Agency, United Kingdom	Martin Shepley	x	x	Literature
UK	Environment Agency, United Kingdom	Hugh Potter	x	Yes	Literature
UK	Leeds University	Joseph Holden	x	Yes	Literature
UK	Leeds University	Simon Bottrell	Yes	Yes	Literature
UK	Leeds University	Nigel Mountney	x	Yes	Literature
UK	Natural Resources Wales	Dave Johnston	x	Yes	Literature
UK	Natural Resources Wales	Natural Resources Wales	x	Yes	Literature
UK	Northern Ireland Environment Agency	Northern Ireland Environment Agency	x	Yes	Literature
UK	Queen's University Belfast	Trevor Elliot	x	Yes	Literature
UK	Scottish Universities Environmental Research Centre	Fin Stuart	x	Yes	Literature
UK	The Coal Authority	Devin Sapsford	x	Yes	Literature
UK	The Coal Authority	Kevin M. Pickup	x	x	US EPA CMOP

Reference list for water-related coal seam gas and coal mining research (Report 4)

Country	Research institution	Contact name	Online survey completed	Active researcher	Information source
UK	The Coal Authority	Abby Moorhouse	x	Yes	Literature
UK	The Coal Authority, United Kingdom	Lee Wyatt	x	Yes	Literature
UK	University of Cardiff	Geroni Jennifer N.	x	Yes	Literature
UK	University of Edinburgh	Stuart Gilfillan	Yes	Yes	Literature
UK	University of Edinburgh	Simon Haunch	x	x	Literature
UK	University of Exeter	Daniel Cluff	Yes	Yes	US EPA CMOP
UK	University of Glasgow	Susan Waldron	x	Yes	Literature
UK	University of Leeds	Katarzyna Samborska	x	Yes	Literature
UK	University of Newcastle	F. M Kusin	x	Yes	Literature
UK	University of Newcastle	Faradiella M. Kusin	x	Yes	Literature
UK	University of Newcastle	P. R Helm	x	Yes	Literature
UK	University of Newcastle	Adam Jarvis	x	Yes	Literature
UK	University of Newcastle, United Kingdom	R Adams	x	x	Literature
UK	University of Newcastle, United Kingdom	Paul Younger	Yes	Yes	Literature
UK	University of Newcastle, United Kingdom	Natalie Kruse	x	Yes	Literature
UK	University of Salford	G. Swift	x	Yes	Literature
UK	University of Wales College of Cardiff	Bettina N. Bockelmann-Evans	x	Yes	Literature
USA	Accelerant Energy	Mark Wasilko	x	Yes	US EPA CMOP
USA	Access Energy	Bob McClenachan	x	Yes	US EPA CMOP
USA	Accession International	C. Derek Campbell	x	x	US EPA CMOP
USA	Advanced Center for Water Resources Development and Management	Himanshu Kulkarni	x	Yes	Literature

Reference list for water-related coal seam gas and coal mining research (Report 4)

Country	Research institution	Contact name	Online survey completed	Active researcher	Information source
USA	Advanced Resources International	Jonanthan Kelafant	x	Yes	US EPA CMOP
USA	AES Climate Solutions	Ian McInnes	x	x	US EPA CMOP
USA	Anadarko	Scott Millington	x	Yes	US EPA CMOP
USA	Apache Corporation	Julie Shemeta	x	Yes	Literature
USA	Appalachia-Pacific LNG	Charles Estes	x	Yes	US EPA CMOP
USA	Atlantic Hydrocarbon	Ramsay Barrett	x	Yes	US EPA CMOP
USA	Baker Energy	Dennis Higgins	x	x	US EPA CMOP
USA	BCS	Lee Schultz	x	x	US EPA CMOP
USA	BG Group	Patrick McKelvey	Yes	Yes	Literature
USA	BHP Billiton	Paul O'Grady	x	x	US EPA CMOP
USA	Bill Tonks Ventilation Services	Bill Tonks	x	Yes	US EPA CMOP
USA	Blue Tip Energy	Mark Wagner	x	x	US EPA CMOP
USA	Boston University	Alexis L Maule	x	Yes	Literature
USA	Bowles Rice	Joe Dawley	x	x	US EPA CMOP
USA	Brierley Associates	N Soule	x	Yes	Literature
USA	Burton Energy, LLC	William Root	x	Yes	US EPA CMOP
USA	Carnegie Mellon University	Greg Lowry	x	Yes	NGWA Workshop 2014
USA	Cipher Coal Consulting Limited	Romeo M. Flores	x	x	Literature
USA	Clemson University	Donald Beebe	x	Yes	Literature
USA	CNX Gas Company	Rick Toothman	x	Yes	US EPA CMOP
USA	Coal Gas Technology Co.	Gregory J Bell	x	Yes	US EPA CMOP
USA	Colorado School of Mines, Golden	Jörg E. Drewes	x	Yes	Literature

Reference list for water-related coal seam gas and coal mining research (Report 4)

Country	Research institution	Contact name	Online survey completed	Active researcher	Information source
USA	Colorado School of Mines, Golden	T. Y. Cath	x	x	Literature
USA	Colorado State University	S Mondal	x	Yes	Literature
USA	Columbia University	Won-Young Kim	x	Yes	Literature
USA	Consol Energy Inc.	Richard A.	x	Yes	US EPA CMOP
USA	Corporate Power	Dr. Gaurav K. Shukla	x	Yes	US EPA CMOP
USA	Deep Industries	Praful Tahala	x	x	US EPA CMOP
USA	Duke University	Emily Bernhardt	x	Yes	Literature
USA	Duke University	Joel N. Meyer	x	Yes	Literature
USA	Duke University	Avner Vengosh	x	Yes	Literature
USA	Durr Clean Technology	Karl Walby	x	Yes	US EPA CMOP
USA	East Resources	David T. Bajek	x	x	US EPA CMOP
USA	EDCPC	Edmond Chang	x	Yes	US EPA CMOP
USA	EHS Support LLC, Chicago	Greg White	x	Yes	NGWA Workshop 2014
USA	Electromec Corporation	Carlos Herrero	x	x	US EPA CMOP
USA	Element Markets	Devon Williams	x	x	US EPA CMOP
USA	Energy Saving	Justin Wang	x	Yes	US EPA CMOP
USA	Environmental Commodities Corporation	Ben Apple	x	Yes	US EPA CMOP
USA	EQS	Mark Malachowski	x	Yes	US EPA CMOP
USA	EUCI	Heath Clendenning	x	x	US EPA CMOP
USA	Eurofins Lancaster Laboratories Environmental	Charles Neslund	x	Yes	NGWA Workshop 2014
USA	European Gas LTD	Alan Flavelle	x	x	US EPA CMOP

Reference list for water-related coal seam gas and coal mining research (Report 4)

Country	Research institution	Contact name	Online survey completed	Active researcher	Information source
USA	Evolution Markets, Inc	Wes Miller	x	x	US EPA CMOP
USA	ExxonMobil Exploration Company	Christa L Ziegler	x	x	US EPA CMOP
USA	First Climate	Cizuka Seki	x	x	US EPA CMOP
USA	First Energy	Michael Horn	x	x	Literature
USA	Gannett Fleming	Monica L. McCullough	x	Yes	Literature
USA	Geological Survey of Alabama	Jack Pashin	x	Yes	Literature
USA	Gradient Corporation	Manu Sharma	x	Yes	Literature
USA	Green Gas Americas	Patrick Saint-Jean	x	x	US EPA CMOP
USA	Green Gas International Limited	Fawn Glen	x	Yes	US EPA CMOP
USA	Greenhouse Gas Services	Piers Lewis	x	x	US EPA CMOP
USA	Gremach Infrastructure Equipments & projects Ltd.	Kishor Mistry	x	Yes	US EPA CMOP
USA	Ground Water Protection Council, Oklahoma City	Mike Nickolaus	x	Yes	NGWA Workshop 2014
USA	Harworth Energy Ltd	Thomas Breheny	x	x	US EPA CMOP
USA	Hoosier Energy REC Inc	William Kaufman	x	Yes	US EPA CMOP
USA	HTC Energy	Graeme Lynch	x	Yes	US EPA CMOP
USA	Illinois Clean Coal Institute	Joseph Hirschi	x	Yes	US EPA CMOP
USA	John T Boyd Company	Joe Baran	x	Yes	US EPA CMOP
USA	Kennedy/Jenks Consultants	Megan Plumlee	x	Yes	Literature
USA	Kinetic Star	Scott Gannon	x	Yes	US EPA CMOP
USA	Kinley Exploration	Colin B. Kinley	x	Yes	US EPA CMOP
USA	Koveva Ltd.	Taku Ide	x	Yes	US EPA

Reference list for water-related coal seam gas and coal mining research (Report 4)

Country	Research institution	Contact name	Online survey completed	Active researcher	Information source
					CMOP
USA	Lamont-Doherty Earth Observatory of Columbia University	Nicholas J van der Elst	x	Yes	Literature
USA	Marathon Oil Company	Sharma Dronamraju	x	Yes	US EPA CMOP
USA	Maryland Geological Survey	David Bolton	x	Yes	NGWA Workshop 2014
USA	McCartney Engineering, LLC	Jack McCartney	x	Yes	US EPA CMOP
USA	Montana State University	Timothy Fitzgerald	x	Yes	Literature
USA	Mott MacDonald	Charles Lesz	x	Yes	US EPA CMOP
USA	National Energy Technology Laboratory	Bill O'Dowd	x	Yes	US EPA CMOP
USA	National Energy Technology Laboratory	Kathy Bruner	x	Yes	US EPA CMOP
USA	National Institute for Occupational Safety and Health (NIOSH)	C. Özgen Karacan	x	Yes	US EPA CMOP
USA	National Institute of Occupational Safety and Health (NIOSH)	C. O. Karacan	x	Yes	Literature
USA	National Mining Association	Craig Montesanu	x	x	US EPA CMOP
USA	National Park Service	Pete Penoyer	x	Yes	NGWA Workshop 2014
USA	National Renewable Energy Laboratory	Chad Augustine	x	Yes	Literature
USA	New Mexico Institute of Mining and Technology	Jana Pursley	x	Yes	Literature
USA	NewLife Resources of America	Jacques Anderson	x	Yes	US EPA CMOP
USA	North American World Trade	George Popa	x	Yes	US EPA CMOP
USA	Ohio Coal Development Office	Gregory Walter Payne	x	Yes	US EPA CMOP
USA	Ohio Division of Geological Survey	Ernie R Slucher	x	x	US EPA CMOP

Reference list for water-related coal seam gas and coal mining research (Report 4)

Country	Research institution	Contact name	Online survey completed	Active researcher	Information source
USA	Penn State Extension	Dana Rizzo	x	x	NGWA Workshop 2014
USA	Penn State Extension	James Clark	x	Yes	NGWA Workshop 2014
USA	Pennsylvania State University	Jan M. Mutmanský	x	Yes	US EPA CMOP
USA	Pennsylvania State University	Elizabeth Boyer	x	Yes	NGWA Workshop 2014
USA	Pennsylvania State University	Benjamin Turner	x	Yes	Literature
USA	Pennsylvania State University	John Wang	x	Yes	Literature
USA	Perkins Trotter	John Peiserich	x	Yes	Literature
USA	Raven Ridge Resources, Inc.	Sherry Buckley	x	Yes	US EPA CMOP
USA	Research Center for Eco-environmental Sciences in Shanxi	Zheng Yanqiang	Yes	Yes	US EPA CMOP
USA	Ruby Canyon Engineering	Michael M. Coté	x	Yes	US EPA CMOP
USA	S.S. Papadopoulos & Associates Inc., Bethesda	Kathleen A. Mihm	x	Yes	NGWA Workshop 2014
USA	SH Consulting Services	Shane Harrison	x	Yes	Literature
USA	Shell	Ron Cramer	x	Yes	Literature
USA	Sindicatum Carbon Capital, SCC Americas	Clark Talkington	x	x	US EPA CMOP
USA	Solvay Chemicals	Bryan Mortimer	x	Yes	US EPA CMOP
USA	Southern Illinois University	Evan R Walters	x	Yes	Literature
USA	Southern Illinois University	K S Bender	x	Yes	Literature
USA	Southern Methodist University	Ashley Howe Justinic	x	Yes	Literature
USA	Stanbridge Capital	David Willson	x	Yes	US EPA CMOP

Reference list for water-related coal seam gas and coal mining research (Report 4)

Country	Research institution	Contact name	Online survey completed	Active researcher	Information source
USA	State University of New York	X. C. Wei	x	Yes	Literature
USA	Syracuse University	Donald Siegel	x	Yes	NGWA Workshop 2014
USA	Systech Environmental	Greg Hendrick	x	Yes	US EPA CMOP
USA	Texas A&M University	Walter B. Ayers	x	Yes	US EPA CMOP
USA	U.S. EPA	Dayna Gibbons	x	Yes	Literature
USA	U.S. Geological Survey	William L. Ellsworth	x	Yes	Literature
USA	U.S. Geological Survey	William Orem	x	Yes	Literature
USA	U.S. Geological Survey	Peter B. McMahon	x	Yes	NGWA Workshop 2014
USA	U.S. Geological Survey	Victor M Heilweil	Yes	Yes	Literature
USA	U.S. Geological Survey	James L Kunz	x	Yes	Literature
USA	U.S. Geological Survey	Andrea L Llenos	x	Yes	Literature
USA	U.S. Geological Survey	Zack Bowen	x	Yes	Literature
USA	U.S. Geological Survey	Mark Engle	Yes	Yes	Literature
USA	U.S. Geological Survey	A McGarr	x	Yes	Literature
USA	U.S. Geological Survey	Richard Healy	x	Yes	Literature
USA	U.S. Geological Survey	Carleton R. Bern	x	Yes	Literature
USA	U.S. Geological Survey	Dennis Risser	x	Yes	NGWA Workshop 2014
USA	U.S. Geological Survey	Charles A. Cravotta	x	Yes	Literature
USA	U.S. Geological Survey	John H. Williams	x	Yes	NGWA Workshop 2014
USA	U.S. Geological Survey	Aida M. Farag	x	Yes	Literature
USA	University of Cornell	K. Keranen	x	Yes	Literature
USA	University of Memphis	S Horton	x	Yes	Literature
USA	University of Oklahoma	Elizabeth S. Cochran	x	Yes	Literature
USA	University of Potsdam	Francesco Grigoli	x	x	Literature

Reference list for water-related coal seam gas and coal mining research (Report 4)

Country	Research institution	Contact name	Online survey completed	Active researcher	Information source
USA	University of Rio Grande	Robert Hopkins	x	Yes	Literature
USA	University of Tennessee	Grant Mincy	x	Yes	Literature
USA	University of Texas	Cliff Frohlich	x	Yes	Literature
USA	University of Texas	Ernest C. Crosby	x	x	Literature
USA	University of Texas	Mark McClure	x	Yes	Literature
USA	University of Texas at Austin	Ian Duncan	x	Yes	Literature
USA	University of Utah	Fitra Ismaya	x	Yes	Literature
USA	University of Utah	John McLennan	x	Yes	US EPA CMOP
USA	University of Wyoming	K.J. Reddy	x	Yes	Literature
USA	University of Wyoming	Scott Quillinan	x	Yes	Literature
USA	University of Wyoming	Valtcho D Zheljazkov	x	Yes	Literature
USA	University of Wyoming	Carol D. Frost	Yes	Yes	Literature
USA	US Bureau of Reclamation	Lisa Block	x	Yes	Literature
USA	Verdeo Group	Jeffrey Liebert	x	x	US EPA CMOP
USA	Vessels Coal Gas, Inc.	Tom Vessels	x	Yes	US EPA CMOP
USA	Virginia Tech	Carl Zipper	x	Yes	Literature
USA	Wabashco	Nathan Clark	x	Yes	US EPA CMOP
USA	West Virginia University	Yi Luo	x	Yes	Literature
USA	West Virginia University	Andrew Miller	x	Yes	Literature
USA	West Virginia University	Jalal Jalali	x	x	US EPA CMOP
USA	West Virginia University	Biao Qiu	x	Yes	Literature
USA	Western Michigan University	David Piacenti	x	x	US EPA CMOP
USA	World Coal Institute	Richard Nevinson	x	x	US EPA CMOP
USA	World Resources	Paul Reig	x	x	Literature

Reference list for water-related coal seam gas and coal mining research (Report 4)

Country	Research institution	Contact name	Online survey completed	Active researcher	Information source
	Institute				
USA	Wyoming State Geological Survey	Jim Rodgers	x	x	Literature
USA	Yonder Environmental Engineering	Xiang Yu	x	x	US EPA CMOP

Appendix C – Literature search methodology

Search methodology

The emphasis of the searching was on a high degree of sensitivity (recall) rather than specificity. To ensure the widest 'capture' the search employed keyword searching. This involved identifying in each question relevant keywords and synonyms and word variations. Search strategies were developed for each question employing standard techniques: Boolean logic operators and truncation. Multiple keyword searches were carried out across multiple databases indexing literature from: Engineering, Geosciences, Mining, Environmental and Agricultural Sciences, Health Sciences, and Science.

The specific database search systems employed were Proquest, Web of Science, Scopus, Engineering Village (Compendex, GeoRef, Geobase), OnePetro and Informit Australian databases.

The database included references from a wide variety of information resources: journal articles, conference papers, book chapters, books, reports, etc. (see full description of database below for resource coverage). Across the different database search systems, search functionality, search syntax, indexing, field structures, sort and display options, and download options varied greatly. Limited time availability and competing work demands meant library catalogues have not been included in this search. Limiting keyword searching of the Internet to supplement database searching was also carried out by consultant engineers.

The keyword searches were performed as an 'all fields' search on the databases. This approach allowed for different field structures on different search systems. A standard strategy was employed, creating groups or 'sets' of the different keyword concepts, then combining these sets which were then further limited (by countries and publication year). This strategy generally worked well in reducing the volume of search results. However, in cases where excessive numbers of records retrieved were deemed to have a high degree of irrelevance, further refinements were applied. This included:

- adding extra keywords
- excluding irrelevant topics (e.g. power stations)
- limiting keyword searching to title, abstract fields.

The ability to refine the search was based largely on the degree of functionality provided by the specific search interface.

To ensure specificity, search results were further refined by WRL consultant engineers viewing and deleting records deemed irrelevant.

Databases

The following information regarding the databases searched within this report is provided below.

Web of Science

Type: Citations/Abstracts.

Description: The Web of Science delivers web-based access to the citation indexes. Complete coverage is now provided. The citation indexes include:

- Science Citation Index 1899+
- Social Sciences Citation Index 1898+
- Arts & Humanities Citation Index 1975+
- Conference Proceedings Citation Index: Science 1990+
- Conference Proceedings Citation Index: social Sciences & Humanities 1990+

The database covers over 8000 journals across all disciplines worldwide, with about 22 000 articles being added weekly. The journals are selected as the most influential and relevant peer-reviewed titles across all disciplines.

Keywords: Anthropology; Architecture; Art; Art Education; Arts; Astronomy; Aviation; Biochemistry; Biology; Biomedicine; Biotechnology; Chemical Engineering; Chemistry; Computer; Computer Science; Criminology; Dance; Demography; Design; Digital Media; Economics; Education; Engineering; Folklore; Geography; Geomatic Engineering; History; Humanities; Industrial Chemistry; Industrial Relations; Information Science; International Relations; Language; Law; Librarianship; Life Sciences; Linguistics; Literature; Management; Marketing; Materials Science; Mathematics; Media and Mass Communication; Medicine; Mining Engineering; Multidisciplinary; Music; Optometry; Pharmacology; Philosophy; Photovoltaics; Physics; Plant Sciences; Poetry; Political Science; Psychiatry; Psychology; Public Administration; Public Health; Religion; Safety Science; Science Technology; Social Issues; Social Work; Sociology; Statistical Sciences; Substance Abuse; Surgery; Surveying; Technology Management; Theatre; Town Planning; Transportation; Urban Studies; Veterinary Sciences; Women's Studies; Zoology.

Coverage: International.

Search hints: Year can only be searched as part of a Boolean search and may provide results from different years.

ISSN/ISBN search is not supported.

Publisher: Thomson Scientific.

Additional publisher name: formerly Institute for Scientific Information (ISI).

Scopus

Type: Database.

Description: Scopus is an abstract and citation database of research literature including peer-reviewed titles, Open Access journals, conference proceedings, trade publications, patent records, scientific web pages, and seamless links to full text articles and other library resources. It is updated daily.

Search hints: External links lead to a login page that requires a Username/Password.

Author searches are done on the last name only.

Subject searches are performed in All Fields.

Publisher: Elsevier.

Science Direct

Type: Fulltext.

Description: Fulltext journal titles published by Elsevier.

Keywords: Anthropology; Architecture; Astronomy; Aviation; Biochemistry; Biology; Biomedicine; Biomedical Engineering; Biotechnology; Building; Chemical Engineering; Chemistry; Civil Engineering; Computer Science; Criminology; Design; Design Environments; Digital Media; Economics; Education; Educational Technology; Energy; Engineering; Environmental Engineering; Geography; Geomatic Engineering; Graphic Design; Humanities; Industrial Chemistry; Industrial Design; Industrial Relations; Information Science; International Relations; Landscape Architecture; Law; Librarianship; Life Sciences; Management; Marketing; Materials Science; Mathematics; Manufacturing Engineering; Marketing; Mechanical Engineering; Media and Mass Communication; Medicine; Mining Engineering; Multidisciplinary; Object Design; Optometry; Petroleum Engineering; Pharmacology; Philosophy; Photovoltaics; Physics; Plant Sciences; Political Science; Psychiatry; Public Administration; Public Health; Real Estate; Safety Science; Science Direct; Science Technology; Social Issues; Social Work; Sociology; Substance Abuse; Surgery; Surveying; Technology Management Psychology; Textile Technology; Theatre; Town Planning; Urban Studies; Veterinary Sciences; Waste Management; Zoology.

Coverage: International.

Search hints: Author searches are done on the last name only.

Subject searches are supported, but subjects are not presented within the records.

Truncation is not supported in phrases.

Publisher: Elsevier.

Additional publisher name: Elsevier Science B.V.

Publisher URL: <http://www.elsevier.com/>

Engineering Village (Compendex, GeoRef, Geobase)

Type: Database.

Keywords: Astronomy; Biomedical Engineering; Chemistry; Computer Engineering; Computer Technology; Computers; Computing; Computing Sciences; Communications Technology; Digital Media; Electrical Engineering; Electronics; Energy; Information Systems; Information Technology; Manufacturing; Manufacturing Engineering; Materials; Materials Science; Mechanical Engineering; Optometry; Photovoltaics; Physics; Statistical Sciences; Telecommunications.

Publisher: Elsevier Engineering Information.

Publisher URL: <http://www.ei.org/eicorp/>

OnePetro

Type: Database.

Description: OnePetro.org is a multi-society library that provides a simple way to search for and access a broad range of technical literature related to the oil and gas exploration and production industry. The database includes full-text from numerous organisations, including the Society of Petroleum Engineers (SPE).

Keywords: Petroleum; Resources Engineering; SPE.

Publisher: The Society of Petroleum Engineers (SPE).

Link to Database Guide: http://www.onepetro.org/search_help.htm

Australian databases (Informit)

Type: Fulltext.

Publisher: Informit.

Additional publisher name: RMIT Publishing.

Publisher URL: <http://www.informit.com.au/>

Databases searched:

- Australia's National Geosciences, Minerals and Petroleum Reference Database (AESIS)
- Australasian Medical Index (AMI)
- Agriculture and Natural Resources Index [formerly ABOA and STREAMLINE] (ANR-Index)
- Agriculture and Natural Resources Index Archive (ANR-Index Archive)
- Agriculture and Natural Resources Research (ANR-Research)
- Agriculture and Natural Resources Research Archive (ANR-Research Archive)
- Australian Public Affairs Information Service (APAIS)
- Aboriginal and Torres Strait Islander Health Bibliography (ATSIhealth)
- Australian Engineering Database (ENGINE)
- Engineering Collection (Engineering Collection)
- Environmental Abstracts (EVA)
- Health Collection (Health Collection)
- Australia's Natural Resources Database (STREAMLINE)

Proquest Databases

Type: Fulltext.

Description: ProQuest Central is the largest multidisciplinary database with over 11 000 titles, with over 8000 titles in full-text.

It serves as the central resource for researchers at all levels in all markets.

Over 160 subjects areas are covered extensively in this product including business and economics, health and medical, news and world affairs, technology, social sciences and more.

Publisher: ProQuest Information and Learning Company.

Publisher URL: <http://www.il.proquest.com/>

Databases searched:

- AGRICOLA (1970 – current)
- Aqualine (1960 – current)
- ASFA: Aquatic Sciences and Fisheries Abstracts (1971 – current)
- Biological Sciences (1946 – current)
- Dissertations & Theses @ University of New South Wales
- ebrary® e-books
- Environmental Impact Statements: Full Text (1985 – current)
- Environmental Sciences and Pollution Management (1967 – current)
- Meteorological & Geostrophysical Abstracts (1974 – current)
- ProQuest Biology Journals (1998 – current)
- ProQuest Health & Medical Complete
- ProQuest Research Library
- ProQuest Science Journals
- ProQuest Dissertations & Theses: UK & Ireland
- ProQuest Dissertations & Theses Full Text
- ProQuest Illustrata: Technology
- ProQuest Natural Science Collection (1693 – current)
- Technology Research Database (1962 – current)
- Water Resources Abstracts (1967 – current)

Search methodology

A brief summary of the search methodology and keywords used within each database is shown in Table C1.

Table C1 Search methodology

Search method	Main research theme	Search terms – level 1		Search terms – level 2		Search terms – level 3		Search terms – level 4
A	Aquifer interconnectivity (R1)	csg OR cbm OR “coal seam gas” OR “coal bed methane” OR “coalbed methane”	AND	water OR aquifer OR aquiclude OR “groundwater basin*” OR “groundwater reservoir” OR “ground water basin” OR “ground water reservoir” OR “underground basin” OR multiaquifer OR “water bearing formation*”	AND	connect* OR connexion* OR interconnect* OR interconnexion OR link*	LIMITED TO	Australia OR Australian OR England OR UK OR “United Kingdom” OR Canada OR Canadian OR USA OR “United States” OR US OR “United States Of America” OR China OR Chinese OR India OR Indian OR Russia OR Russian
B	Aquifer interconnectivity (R1)	csg OR cbm OR “coal seam gas” OR “coal bed methane” OR “coalbed methane”	AND	“Water Quality” OR Contaminant* OR pollut* OR “Water Purity” OR “Freshwater quality” OR “Ground water quality” OR “quality of water” OR impurit* OR “Water Quantity” OR volume OR yield OR amount OR Model* OR “Field based” OR “Groundwater flow” OR “Ground water flow” OR “Ground water movement” OR “subsurface flow” OR “flow of groundwater” OR Solute* OR chemicals OR matter OR materials OR substances OR inorganic OR organic OR “Transport dynamic*” OR dispers* OR flow OR movement OR pathway*	AND	connect* OR connexion* OR interconnect* OR interconnexion OR link*	LIMITED TO	Australia OR Australian OR England OR UK OR “United Kingdom” OR Canada OR Canadian OR USA OR “United States” OR US OR “United States Of America” OR China OR Chinese OR India OR Indian OR Russia OR Russian

Reference list for water-related coal seam gas and coal mining research (Report 4)

Search method	Main research theme	Search terms – level 1		Search terms – level 2		Search terms – level 3		Search terms – level 4
C	Surface water (R2)	csg OR cbm OR “coal seam gas” OR “coal bed methane” OR “coalbed methane”	AND	“surface water” OR stream OR river OR lake OR wetland OR ocean OR creek OR estuary OR dam OR reservoir OR watercourse AND (Flow OR pathway OR path OR movement)	AND	Disrup* OR diversion OR divert* OR impact* OR assess* OR evaluat* OR chang* subsid* OR sink* “mine cone of depression” OR “cone of depression”	LIMITED TO	Australia OR Australian OR England OR UK OR “United Kingdom” OR Canada OR Canadian OR USA OR “United States” OR US OR “United States Of America” OR China OR Chinese OR India OR Indian OR Russia OR Russian
D	Co-produced/ mine water (R3)	csg OR cbm OR “coal seam gas” OR “coal bed methane” OR “coalbed methane”	AND	“produced water” OR “co-produced water” OR “mine water” OR salt OR “salt management” OR saline	AND	aquifer inject* OR “water treatment” OR “water technolog*” OR “advanced Water Treatment Technolog*” OR AWTT OR Effect*OR impact* OR outcome*	LIMITED TO	Australia OR Australian OR England OR UK OR “United Kingdom” OR Canada OR Canadian OR USA OR “United States” OR US OR “United States Of America” OR China OR Chinese OR India OR Indian OR Russia OR Russian
E	Seismicity (R4)	csg OR cbm OR “coal seam gas” OR “coal bed methane” OR “coalbed methane”	AND	seismicity OR seismic OR seismology OR earthquake*	AND	nil	LIMITED TO	Australia OR Australian OR England OR UK OR “United Kingdom” OR Canada OR Canadian OR USA OR “United States” OR US OR “United States Of America” OR China OR Chinese OR India OR Indian OR Russia OR Russian
F	Well integrity	csg OR cbm	AND	“well integrity” OR “integrity of	AND	nil	LIMITED	Australia OR Australian OR

Reference list for water-related coal seam gas and coal mining research (Report 4)

Search method	Main research theme	Search terms – level 1		Search terms – level 2		Search terms – level 3		Search terms – level 4
	(R5)	OR “coal seam gas” OR “coal bed methane” OR “coalbed methane”		well*” OR installation OR drill* OR “wellbore” OR bore*			TO	England OR UK OR “United Kingdom” OR Canada OR Canadian OR USA OR “United States” OR US OR “United States Of America” OR China OR Chinese OR India OR Indian OR Russia OR Russian
G	Hydraulic fracturing (R6)	csg OR cbm OR “coal seam gas” OR “coal bed methane” OR “coalbed methane”	AND	surface OR water OR “Water Supply” OR River* OR lake OR stream OR ocean OR creek* OR dam OR floodplain OR wetland* OR Estuar* OR Reservoir OR Groundwater OR Aquifer OR Aquitard OR “water table”	AND	quality OR chemical* OR contaminat* OR toxic* OR chemical* OR metal* OR solute* OR “heavy metals” OR salt OR saline OR pollut* OR spill* OR “backflow” OR “back flow” OR “flow back”	LIMITED TO	Australia OR Australian OR England OR UK OR “United Kingdom” OR Canada OR Canadian OR USA OR “United States” OR US OR “United States Of America” OR China OR Chinese OR India OR Indian OR Russia OR Russian
H	Water supplies (R7)	csg OR cbm OR “coal seam gas” OR “coal bed methane” OR “coalbed methane”	AND	Quantity OR “water level” OR reliability OR depletion OR sustainability OR “aquifer stress”	AND	Remediat* OR Regenerat* OR Rehabilitat* OR “well decommissioning” OR “post mining voids” OR “Pre development” OR “Post development” OR “Pre mining” OR “Post mining” OR “Water level” OR “Water quality”	LIMITED TO	Australia OR Australian OR England OR UK OR “United Kingdom” OR Canada OR Canadian OR USA OR “United States” OR US OR “United States Of America” OR China OR Chinese OR India OR Indian OR Russia OR Russian

Reference list for water-related coal seam gas and coal mining research (Report 4)

Search method	Main research theme	Search terms – level 1		Search terms – level 2		Search terms – level 3		Search terms – level 4
I	Water-dependent ecosystems (R8)	csg OR cbm OR “coal seam gas” OR “coal bed methane” OR “coalbed methane”	AND	Predict* OR Estim* OR Forecast* OR Respon* OR Quality OR Projection OR Impact OR Influence OR Effect OR Affect	AND	Ecosystem_OR Environment OR “surface water” OR River* OR lake OR stream OR ocean OR creek* OR dam OR floodplain OR wetland* OR GDEs OR “Peat swamp*” OR Estuar* OR Reservoir OR “Water course” OR Water	LIMITED TO	Australia OR Australian OR England OR UK OR “United Kingdom” OR Canada OR Canadian OR USA OR “United States” OR US OR “United States Of America” OR China OR Chinese OR India OR Indian OR Russia OR Russian
J	Cumulative impact assessment (R9)	csg OR cbm OR “coal seam gas” OR “coal bed methane” OR “coalbed methane”	AND	"Cumulative impact" OR "impact assessment"	AND	nil	LIMITED TO	Australia OR Australian OR England OR UK OR “United Kingdom” OR Canada OR Canadian OR USA OR “United States” OR US OR “United States Of America” OR China OR Chinese OR India OR Indian OR Russia OR Russian

Appendix D – Project index

Table D1 Research projects titles and themes

Project no.	Project title	Aquifer connectivity	Disruption of surface water	Co-produced/ mine water & salt management	Seismicity	Integrity of wells	Hydraulic fracturing	Water supplies	Water-dependent ecosystems	Cumulative impact assessments
1	Fuzzy reliability index used for quantification of uncertainties in the groundwater impact assessment in a coal seam gas field	✓	.	.	.	.	.	.	.	.
2	Aquitard hydraulic properties estimation from wireline logs analysis: an application to the Surat Basin, Queensland	✓	.	.	.	.	.	.	.	.
3	Background review: Aquifer connectivity within the Great Artesian Basin, and the Surat, Bowen and Galilee Basins	✓	.	.	.	.	.	.	.	.
4	Review of QGC groundwater modelling - upscaling Eclipse insight into Modflow for the Surat Basin	✓	.	.	.	.	.	.	✓	.
5	Upscaling of two-phase, near-source groundwater flow in CSG regional modelling	✓	.	.	.	.	.	.	✓	.
6	Groundwater hydrochemical characterisation of the Surat region and Laura Basin – Queensland. Final technical report for the National Collaboration Framework Hydrochemical Characterisation Project	.	.	.	.	.	.	✓	.	.
7	Technical reports for the National Collaboration Framework Regional Hydrogeology Project – four reports on regional hydrogeological characterisations of the Laura Basin, the Maryborough Basin, the St Vincent Basin and the Otway Basin	.	.	.	.	.	.	✓	✓	.
8	Monitoring with Intent: a proposal for measuring and responding to groundwater impacts from coal seam gas activities	✓	.	.	.	.	.	.	.	.
9	Application of hydrochemistry for the detection of inter-aquifer connectivity at coal seam gas fields	✓	.	.	.	.	.	.	.	.

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project no.	Project title	Aquifer connectivity	Disruption of surface water	Co-produced/ mine water & salt management	Seismicity	Integrity of wells	Hydraulic fracturing	Water supplies	Water-dependent ecosystems	Cumulative impact assessments
10	Review of dissolved hydrocarbons in groundwater in the Surat and Bowen Basins	✓	.	.	.	.	.	✓	.	.
11	Innovative characterisation of aquifers and aquitards–NCGRT Program 1	✓	.	.	.	.	.	✓	.	.
12	Influence of geological structures on groundwater flow project	✓	.	.	.	.	.	.	.	✓
13	Geological modelling project	✓	.	.	.	.	.	.	.	✓
14	Condamine connectivity project	✓	.	.	.	.	.	.	✓	✓
15	Spring knowledge projects	✓	.	.	.	.	.	.	.	✓
16	Modelling methodology project	✓	.	.	.	.	.	✓	.	✓
17	Temporal groundwater level responses in groundwater monitoring bores and their significance, Surat Basin, Queensland	✓	.	.	.	.	.	.	.	.
18	Implementation of a regional groundwater monitoring programme in the developing coal seam gas (CSG) fields, Surat and Southern Bowen Basins, Queensland, Australia	✓	.	.	.	.	.	.	.	.
19	AGL Gloucester water studies	✓	✓	.	.	.	.	✓	.	.
20	Introducing dual phase to integrated regional groundwater numerical modelling of large scale coal seam gas development	✓	.	.	.	.	.	.	✓	.
21	GEN3 Surat Basin dual phase regional groundwater flow model	✓	.	.	.	.	.	.	.	.
22	Surat Basin aquifer connectivity study	✓	.	.	.	✓	.	.	✓	✓
23	Development of 3D geological model of the Clarence-Moreton Basin and the eastern part of the Surat Basin	✓	.	.	.	.	.	.	.	.

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project no.	Project title	Aquifer connectivity	Disruption of surface water	Co-produced/ mine water & salt management	Seismicity	Integrity of wells	Hydraulic fracturing	Water supplies	Water-dependent ecosystems	Cumulative impact assessments
24	Groundwater chemistry baseline of the Walloon Coal Measures in the Clarence-Moreton and Surat Basins, Queensland, Australia	✓	.	.	.	.	.	.	.	.
25	Aquifer interconnectivity in the Galilee and Eromanga basins	✓	.	.	.	.	.	.	.	.
26	Geological framework model for the Surat Cumulative Management Area (Surat and southern Bowen Basin)	✓	.	.	.	.	.	.	.	.
27	Estimation and measurement of vertical connectivity in the Surat Basin, Australia	✓	.	.	.	.	.	.	✓	.
28	A baseline groundwater methane survey in the Richmond River catchment; a potential coal seam gas exploration area	✓	.	.	.	.	.	.	.	.
29	The role of mining driven de-pressurisation in deep coal seams at the AGL Broke/Bulga exploration sites	✓	✓	.	.	✓	.	✓	.	✓
30	Screening model of the groundwater regime in the Murrumbidgee Trough, Upper Hunter	✓	✓	✓	.	✓	.	.	.	✓
31	A water chemistry atlas for CSG fields	✓	.	.	.	.	.	.	.	✓
32	Gas distribution is fundamental to estimation and management of fugitive emissions C21061	✓	.	.	.	.	.	.	.	.
33	Hydraulic connectivity between mines and adjacent river and groundwater systems in the Hunter River Valley- C20022	✓	.	.	.	.	.	.	✓	.
34	Controls on the isotope and molecular composition of coal seam gases and production waters of the Walloon Subgroup, Surat Basin, Queensland, Australia.	✓	.	✓	.	.	.	.	.	.

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project no.	Project title	Aquifer connectivity	Disruption of surface water	Co-produced/ mine water & salt management	Seismicity	Integrity of wells	Hydraulic fracturing	Water supplies	Water-dependent ecosystems	Cumulative impact assessments
35	Implication of the permafrost on hydrogeological conditions and on mine environment controls: case of the Amaan Coking Coal Project in north-eastern Russia	✓	.	.	.	.	.	.	.	.
36	Stream methane sampling for evaluating groundwater impacts associated with unconventional gas development	✓	.	.	.	.	.	.	.	.
37	Monitoring of ground movements at Sandy Creek Waterfall and Implications for understanding the mechanics of valley closure movements	.	✓	.	.	✓	.	.	✓	.
38	Valley closure impact model for rock bar controlled streams in the Southern Coalfield	.	✓	.	.	.	✓	✓	.	✓
39	Investigation into the height of discontinuous fracturing above longwall panels at Springvale Mine	✓	✓	.	.	.	.	.	✓	.
40	Case studies of groundwater response to mine subsidence in the Western Coalfields of NSW	.	✓	.	.	.	.	.	.	.
41	Analytical modelling of subsidence due to coal seam gas extraction	✓	✓	.	.	.	.	.	.	.
42	Coal seam gas extraction: modelling groundwater impacts	.	✓	.	.	.	.	.	.	.
43	Monitoring and management of subsidence induced by coal seam gas extraction	.	✓	.	.	.	.	.	.	.
44	Assessing predictive error when up-scaling CSG reservoir models for regional GW model impact assessment	.	✓	.	.	.	.	.	.	.
45	Applications of signal decomposition and surrogate modelling to assist the identification of aquifer stressors and sentinel well selection	.	✓	.	.	.	.	.	.	.

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project no.	Project title	Aquifer connectivity	Disruption of surface water	Co-produced/ mine water & salt management	Seismicity	Integrity of wells	Hydraulic fracturing	Water supplies	Water-dependent ecosystems	Cumulative impact assessments
46	A new subsurface fracture height prediction model for longwall mines in the NSW coalfields	✓	✓	.	.	.	.	.	.	.
47	Management of mine subsidence impacts beneath the township of Tahmoor	.	✓	.	.	.	.	.	.	✓
48	Walloon connectivity project	✓	.	.	.	.	.	.	.	✓
49	Assessment of potential for formation compaction and surface subsidence associated with CSG production in the Surat Basin, Queensland	.	.	.	.	.	.	.	.	.
50	Numerical modelling of mining subsidence in the Southern Coalfield of New South Wales, Australia	.	✓	.	.	.	.	.	.	.
51	Background review: Subsidence from coal seam gas extraction in Australia	.	✓	.	.	.	.	.	.	.
52	Background review: Subsidence from coal mining activities	.	✓	.	.	.	.	.	.	.
53	Radon-222 studies in a longwall mining impacted water supply catchment	.	✓	.	.	.	.	.	.	.
54	Improved methods for predicting mining induced horizontal movements and ground strains caused by longwall mining	.	✓	.	.	.	.	.	.	.
55	Subsidence monitoring – technical background paper for NSW Chief Scientist and Engineer	.	✓	.	.	.	.	.	.	.
56	Treatment methods of coal mining subsidence area at South Lake in Tangshan city, Hebei province	.	✓	.	.	.	.	.	.	.

Project no.	Project title	Aquifer connectivity	Disruption of surface water	Co-produced/ mine water & salt management	Seismicity	Integrity of wells	Hydraulic fracturing	Water supplies	Water-dependent ecosystems	Cumulative impact assessments
57	Effect of mining subsidence on soil erosion in mountainous area of the Loess Plateau	.	✓	.	.	.	.	.	.	.
58	Surface water and groundwater interactions in an extensively mined watershed, upper Schuylkill River, Pennsylvania, USA	.	✓	.	.	.	.	✓	.	.
59	Understanding the salinity issue of coal mine spoils in the context of salt cycle	.	.	✓	.	.	.	.	.	.
60	Assessing environmental safety of in-pit disposal of tailings in coal mines C20027	.	.	✓	.	.	.	.	.	.
61	Managed aquifer recharge and re-injection of aquifers	.	.	✓	.	.	.	.	.	.
62	Pilot scale integrated forward and reverse osmosis system for mine water reuse C23031	.	.	✓	.	.	.	.	.	.
63	Enhancing ecological values of coal pit lakes with simple nutrient additions and bankside vegetation C21038	.	.	✓	.	.	.	.	.	.
64	Understanding and quantifying clogging and its management during re-injection of CSG water permeates, brines and blends	.	.	✓	.	.	.	.	.	.
65	Understanding and quantifying the geochemical response to re-injection of CSG water permeates, brines and blends	.	.	✓	.	.	.	.	✓	.
66	High performance groundwater modelling for risk assessment and management option analysis of large scale injection schemes	.	.	✓	.	.	.	.	✓	.
67	Background paper on produced water and solids in relation to coal seam gas production	.	.	✓	.	.	✓	✓	.	.

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project no.	Project title	Aquifer connectivity	Disruption of surface water	Co-produced/ mine water & salt management	Seismicity	Integrity of wells	Hydraulic fracturing	Water supplies	Water-dependent ecosystems	Cumulative impact assessments
68	Development of a management tool to support the beneficial use of treated coal seam gas water for irrigation in eastern Australia	✓	.	✓	.	.	.	✓	.	.
69	Growing algae using water from coal seam gas industry and harvesting using an innovative technique: A review and a potential	.	.	✓	.	.	.	.	.	.
70	Gloucester NSW Camden NSW Narrabri NSW	✓	✓	✓	.	.	.	.	.	.
71	Mount Hope Station pilot project	.	.	✓	.	.	.	.	.	.
72	Investigation of the plant production and water use of forages irrigated with CSG water	.	.	✓	.	.	.	.	.	.
73	Biological silica removal to aid coal seam gas (CSG) water management	.	.	✓	.	.	.	.	.	.
74	Adsorption on activated alumina: mitigating fouling of water treatment processes caused by deposition of silica, organics and hardness ions	.	.	✓	.	.	.	.	.	.
73	Treatment of coal seam gas (CSG) co-produced water using natural and modified zeolite	.	.	✓	.	.	.	.	.	.
74	Smart Futures Fellowship (Early): Inorganic membranes of CSG water and brine treatment	.	.	✓	.	.	.	✓	✓	.
77	Produced water and solids – technical background paper for NSW Chief Scientist and Engineer	.	.	✓	.	.	.	.	.	.
78	Engineering design of low permeability barriers between open pit mine sites and surface waters	.	.	✓	.	.	.	✓	✓	.
79	Interactions between agriculture and coal seam gas development	.	.	✓	.	.	.	.	.	.

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project no.	Project title	Aquifer connectivity	Disruption of surface water	Co-produced/ mine water & salt management	Seismicity	Integrity of wells	Hydraulic fracturing	Water supplies	Water-dependent ecosystems	Cumulative impact assessments
80	Salinity tolerance of freshwater organisms from the Southern and Western Coalfields C23010	.	.	✓	.	.	.	.	✓	.
81	Stabilisation of algal biomass harvested from coal seam gas associated water to generate a renewable, high nutrient resource	.	.	✓	.	.	.	.	.	.
82	Coal seam gas water as a medium to grow <i>Dunalliella tertiolecta</i> for lipid extraction	.	.	✓	.	.	.	✓	.	.
83	Salty gas: the ecological risk of saline effluents from coal seam gas and other hydrocarbon resources	.	.	✓	.	.	.	✓	.	.
84	Silica scale mitigation for high recovery reverse osmosis of groundwater for a mining process	.	.	✓	.	.	.	.	✓	.
85	Speciation and toxicity of arsenic in mining-affected lake sediments in the Quinsam watershed, British Columbia	.	.	✓	.	.	.	.	.	.
86	Influences of coal mining water irrigation on the maize losses in the Xingdong Mine area, China	.	.	✓	.	.	.	.	.	.
87	Treatment of the produced water of coalbed methane using artificial wetland in Qinshui Basin, China	.	.	✓	.	.	.	.	.	.
88	Using modified perlites to treat mine water of abandoned coal mines in Partizansk city, Primorskiy Krai	.	.	✓	.	.	.	.	.	.
89	Hydraulic performance and iron removal in wetlands and lagoons treating ferruginous coal mine waters	.	.	✓	.	.	.	.	.	.
90	Investigating the unpublished EPA results for Pavilion, Wyoming	.	.	✓	.	.	✓	.	✓	.
91	Coal and coalbed gas	.	.	✓	.	.	.	.	.	.

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project no.	Project title	Aquifer connectivity	Disruption of surface water	Co-produced/ mine water & salt management	Seismicity	Integrity of wells	Hydraulic fracturing	Water supplies	Water-dependent ecosystems	Cumulative impact assessments
92	Coalbed methane produced water screening tool for treatment technology and beneficial use	.	.	✓	.	.	.	.	.	.
93	Energy resources: environmental geochemistry and health	.	.	✓	.	.	.	✓	.	.
94	Impacts from beneficial use of produced waters	.	.	✓	.	.	✓	.	.	.
95	Carbon isotope characterization of Powder River Basin Coal Bed Waters: Key to minimizing unnecessary water production and implications for exploration and timing of biogenic gas.	.	.	✓	.	.	.	.	.	.
96	Mountaintop Removal Mining and Catchment Hydrology	.	✓	✓	.	.	.	.	.	.
97	Reference list for water-related coal seam gas and coal mining research – Australia, Canada, China, India, Russia, United Kingdom and United States of America (January 2000 to September 2014)	✓	✓	✓	✓	✓	✓	✓	✓	✓
98	An investigation of seismicity clustered near the Cordell Field, west central Alberta, and its relation to a nearby disposal well	.	.	✓	✓	.	.	.	.	.
99	Induced seismicity associated with fluid injection into a deep well in Youngstown, Ohio	.	.	✓	✓	.	.	.	.	.
100	Analysis of the Cleburne, Texas, Earthquake Sequence from June 2009 to June 2010	.	.	✓	✓	.	.	.	.	.
101	Modelling earthquake rate changes in Oklahoma and Arkansas: Possible signatures of induced seismicity	.	.	✓	✓	.	.	.	.	.
102	Maximum magnitude earthquakes induced by fluid injection	.	.	✓	✓	.	.	.	.	.
103	Sharp increase in central Oklahoma seismicity since 2008 induced by massive wastewater injection	.	.	✓	✓	.	.	.	.	.

Project no.	Project title	Aquifer connectivity	Disruption of surface water	Co-produced/ mine water & salt management	Seismicity	Integrity of wells	Hydraulic fracturing	Water supplies	Water-dependent ecosystems	Cumulative impact assessments
104	The 17 May 2012 M4.8 earthquake near Timpson, East Texas: An event possibly triggered by fluid injection	.	.	✓	✓	.	.	.	.	.
105	Correlations between formation properties and induced seismicity during high pressure injection into granitic rock	.	.	✓	✓	.	.	.	.	.
106	The 24 January 2013 ML 4.4 Earthquake near Paradox, Colorado, and Its Relation to Deep Well Injection	.	.	✓	✓	.	.	.	.	.
107	Investigation of borehole stability in poorly cemented granular formations by discrete element method	.	.	.	.	✓	.	.	.	.
108	Coal-seam-gas reservoir surveillance - Extracting value from suspended coreholes, Surat Basin, Queensland, Australia	.	.	.	.	✓	.	.	.	.
109	Background review: bore integrity	.	.	.	.	✓	.	.	.	.
110	Environmental impacts of coal seam gas activities on water resources	✓	✓	✓	.	✓	✓	✓	.	✓
111	Seepage pathway assessment for natural gas to shallow groundwater during well stimulation, in production, and after abandonment	.	.	.	.	✓	.	.	.	.
112	Towards a road map for mitigating the rates and occurrences of long-term wellbore leakage	.	.	✓	.	✓	.	.	.	.
113	Integrity analysis of gas field water re-injection well wellbore	.	.	.	.	✓	.	.	.	.
114	Calculation model for borehole collapse volume in horizontal openhole in formation with multiple weak planes	.	.	.	.	✓	.	.	.	.
115	Oil and gas wells and their integrity: Implications for shale and unconventional resource exploitation	.	.	.	.	✓	.	.	.	.
116	Fault seal characterisation for CSG–aquifer interaction	✓	.	.	.	.	✓	.	.	.

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project no.	Project title	Aquifer connectivity	Disruption of surface water	Co-produced/ mine water & salt management	Seismicity	Integrity of wells	Hydraulic fracturing	Water supplies	Water-dependent ecosystems	Cumulative impact assessments
117	Independent review of tight gas stimulation 2014 Environmental Plan (TGS 14 EP) for Nyanba Buru Yawuru Ltd	.	.	✓	✓	✓	✓	.	.	.
118	National assessment of chemicals associated with coal seam gas extraction in Australia	.	.	.	.	.	✓	.	.	.
119	Hydraulic fracturing risk assessment – review and experience with the Queensland regulatory framework	.	.	.	.	.	✓	✓	.	.
120	Qualitative and quantitative modelling of hydraulic fracturing of brittle materials	.	.	.	.	.	✓	.	.	.
121	Background review: Hydraulic fracturing ('fracking') techniques, including reporting requirements and governance arrangements	.	.	.	.	.	✓	.	.	.
122	Chemical and isotopic characterization of shallow groundwater in the vicinity of coal bed methane operations in Alberta	.	.	.	.	.	✓	✓	.	.
123	The environmental impacts of coalbed methane industry on groundwater	.	.	✓	.	.	✓	✓	.	.
124	Regional environmental carrying capacity of coalbed methane hotspot and ecosystem restoration study	.	.	.	.	.	.	.	✓	✓
125	Research on treatment and resource recovery of produced water from coal methane production wells	.	.	✓	.	.	.	.	.	.
126	Recharge estimation in the Surat Basin	.	.	.	.	.	.	✓	.	✓
127	Environmental stewardship: lessons for European unconventional gas from the United States and Australia	.	.	.	.	.	.	✓	.	.

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project no.	Project title	Aquifer connectivity	Disruption of surface water	Co-produced/ mine water & salt management	Seismicity	Integrity of wells	Hydraulic fracturing	Water supplies	Water-dependent ecosystems	Cumulative impact assessments
128	Unconventional gas: coal seam gas, shale gas, tight gas. An introduction and overview of issues relevant to the development of unconventional gas in Victoria	.	.	✓	.	.	.	✓	.	.
129	Background paper on groundwater resources in relation to coal seam gas production	.	✓	✓	.	.	✓	✓	✓	.
130	Characteristics of ion concentration in groundwater drainage from coalbed methane wells in Panzhuang of China	.	.	.	.	.	.	✓	.	.
131	Evaluation of water environmental quality in Feng Zi Jian mining area based on analytic hierarchy process	.	.	✓	.	.	.	.	✓	.
132	Coalbed methane produced water in China: status and environmental issues	.	.	✓	.	.	.	✓	✓	.
133	Diagnostics of soils in the areas of abandoned coal mines of Primorskiy Krai	.	.	✓	.	.	.	✓	.	✓
134	Detection of mixing dynamics during pumping of a flooded coal mine	.	.	✓	.	.	.	✓	✓	.
135	Scottish Government: Expert Scientific Panel on Unconventional Oil and Gas	✓	✓	✓	✓	✓	✓	✓	✓	✓
136	Acute toxicity of sodium bicarbonate, a major component of coal bed natural gas produced waters, to 13 aquatic species as defined in the laboratory	.	.	✓	.	.	.	✓	✓	.
137	Geochemical processes controlling trace elemental mobility in coalbed natural gas (CBNG) disposal ponds in the Powder River Basin, WY	.	.	✓	.	.	.	✓	.	.
138	Bioregional Assessment Programme	✓	✓	✓	.	.	.	.	✓	✓

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project no.	Project title	Aquifer connectivity	Disruption of surface water	Co-produced/ mine water & salt management	Seismicity	Integrity of wells	Hydraulic fracturing	Water supplies	Water-dependent ecosystems	Cumulative impact assessments
139	Hydrogeological characterisation of Temperate Highland Peat Swamps on Sandstone on the Newnes Plateau	.	.	.	.	.	.	.	✓	.
140	The geology of the shrub swamps within Angus Place, Springvale and the Springvale Mine Extension project areas	.	.	.	.	.	.	.	✓	.
141	Tool to assess mining impacts on river condition C21031	.	.	.	.	.	.	.	✓	.
142	Temperate Highland Peat Swamps on Sandstone: ecological characteristics, sensitivities to change, and monitoring and reporting techniques	.	.	.	.	.	.	.	✓	.
143	Temperate Highland Peat Swamps on Sandstone: longwall mining engineering design – subsidence prediction, buffer distances and mine design options	.	.	.	.	.	.	.	✓	.
144	Temperate Highland Peat Swamps on Sandstone: mitigation and remediation techniques	.	.	.	.	.	.	.	✓	.
145	The spatial distribution, geomorphic evolution and genetic biodiversity of upland swamps in Eastern Australia: Implications for protecting these endangered ecosystems	.	.	.	.	.	.	.	✓	.
146	A multi-criteria evaluation of water management for sustainable development in mining	.	.	.	.	.	.	.	✓	.
147	Secure mine water use with compliant discharge	.	.	.	.	.	.	.	✓	.
148	Enhanced groundwater modelling – Coal seam gas and large coal mines	.	.	✓	.	.	.	.	.	.

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project no.	Project title	Aquifer connectivity	Disruption of surface water	Co-produced/ mine water & salt management	Seismicity	Integrity of wells	Hydraulic fracturing	Water supplies	Water-dependent ecosystems	Cumulative impact assessments
149	Ecological and hydrological survey of the Great Artesian Basin springs – Springsure, Eulo, Bourke and Bogan River supergroups – Volume 1 History, ecology and hydrogeology; Volume 2 Hydrogeological profiles	.	.	.	.	.	.	.	✓	.
150	Modelling water-related ecological responses to coal seam gas extraction and coal mining	.	.	.	.	.	.	.	✓	.
151	Impact of mine subsidence on threatened ecological communities C22019	.	.	.	.	.	.	.	✓	.
152	Monitoring of geochemical and isotopic characteristics of CSG formation waters, adjacent aquifers and springs	.	.	.	.	.	.	.	✓	.
153	Towards an integrated study of the Gladstone Marine System	.	.	.	.	.	.	.	✓	.
154	Priority threat identification, management and appraisal	.	.	.	.	.	.	.	✓	.
155	Assessing the cumulative risks of mining and extractive industries to the Namoi Catchment's Natural Resource Assets	.	.	.	.	.	.	✓	✓	.
156	On the establishment of acceptability criteria for subsidence impacts on the natural environment	.	✓	.	.	.	.	.	✓	.
157	Preferential flow paths in a complex coal seam system	.	.	.	.	.	.	.	✓	.
158	Remote sensing of peatland swamps	.	.	.	.	.	.	.	✓	.
159	Background review: Co-produced water – risks to aquatic ecosystems	.	.	✓	.	.	.	.	✓	.
160	Peer review of exploration impact on groundwater in the AGL Hunter Gas Exploration Project	✓	✓	✓	.	✓	.	.	.	✓
161	Flora monitoring methods for Newnes Plateau Shrub Swamps and Hanging Swamps	.	.	.	.	.	.	.	✓	.

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project no.	Project title	Aquifer connectivity	Disruption of surface water	Co-produced/ mine water & salt management	Seismicity	Integrity of wells	Hydraulic fracturing	Water supplies	Water-dependent ecosystems	Cumulative impact assessments
162	THPSS identification and classification in the Blue Mountains and Lithgow Region of NSW	.	.	.	.	.	.	.	✓	.
163	Monitoring surface condition of upland swamps subject to mining subsidence with very high-resolution imagery C20046	.	✓	.	.	.	.	.	✓	.
164	Guidelines for establishing ecologically sustainable discharge criteria in seasonally flowing streams C19024	.	.	✓	.	.	.	.	✓	.
165	A field study of irrigated soil properties comparing land conditioning of applied coal seam gas (CSG) water, application of chemically amended CSG water and good quality groundwater	.	.	.	.	.	.	.	✓	.
166	Ground control and water resources protection	✓	✓	✓	.	.	✓	✓	✓	✓
167	The application of chemical tracer experiments on exploring the mine water filling conditions	.	.	✓	.	.	.	✓	✓	.
168	Impacts of coal mining on groundwater environment in northwestern coal mine area	.	✓	✓	.	.	.	.	✓	.
169	Pilot project on remediation of AMD in catchment of Kopili River at the upstream of Kopili Hydro Electric Plant, Umrongso, Assam, India	.	.	.	.	.	.	✓	✓	.
170	Applying natural tracer technologies in the environmental monitoring of unconventional gas extraction	.	✓	.	.	.	✓	✓	.	.
171	Fugitive emissions associated with existing coal mining	.	.	✓	.	.	.	.	✓	.
172	Organic substances in produced and formation water from unconventional natural gas extraction in coal and shale	.	.	✓	.	.	✓	✓	✓	.

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project no.	Project title	Aquifer connectivity	Disruption of surface water	Co-produced/ mine water & salt management	Seismicity	Integrity of wells	Hydraulic fracturing	Water supplies	Water-dependent ecosystems	Cumulative impact assessments
173	A review of environmental impacts of salts from produced waters on aquatic resources	.	.	✓	.	.	.	✓	.	.
174	Stream methane monitoring for evaluating impacts of coal seam and shale gas development on water resources	✓	.	✓	.	.	✓	✓	✓	.
175	Use of reconstituted waters to evaluate effects of elevated major ions associated with mountaintop coal mining on freshwater invertebrates	.	.	.	.	.	.	.	✓	.
176	Application of a Bayesian model to infer the contribution of coalbed natural gas produced water to the Powder River, Wyoming and Montana	.	.	✓	.	.	.	✓	✓	.
177	The potential impacts of coal seam gas on biodiversity in Australia: Identification of knowledge gaps and research priorities	.	.	.	.	.	.	.	.	✓
178	Cumulative socioeconomic impacts: Phase 1	.	.	.	.	.	.	.	.	✓
179	Impacts of CSG production on regional groundwater systems	✓	.	.	.	.	.	.	✓	.
180	A collaborative approach to address the cumulative impacts of mine-water discharge: Negotiating a cross-sectoral waterway partnership in the Bowen Basin, Australia	.	.	.	.	.	.	.	✓	✓
181	Water sharing and coal mining in the Gunnedah Basin – an overallocated catchment	.	.	.	.	.	.	✓	.	.
182	Towards best practice in sustainability reporting on water for the mining industry in Australia	.	.	.	.	.	.	✓	✓	.
183	Leading practice framework for coal seam gas development in Australia	.	.	.	.	.	.	.	.	✓

Reference list for water-related coal seam gas and coal mining research (Report 4)

Project no.	Project title	Aquifer connectivity	Disruption of surface water	Co-produced/ mine water & salt management	Seismicity	Integrity of wells	Hydraulic fracturing	Water supplies	Water-dependent ecosystems	Cumulative impact assessments
184	Quantifying the uncertainty associated with predicting CSG production impacts	✓	✓	.	.	.	.	✓	✓	✓
185	Characterisation of current groundwater uses in the Surat and Bowen Basins	.	.	.	.	.	.	.	✓	✓
186	The coal and water consumption forecast analysis of China's coal chemical industry	.	.	.	.	.	.	.	.	✓
187	An Environmental Risk Assessment for coal bed methane, coal mine methane and abandoned mine methane operations in England	.	.	.	.	.	.	.	.	✓